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Inefficient centralization of imperfect complements

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Inefficient centralization of imperfect complements

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Abstract:
If local public goods exhibit spillovers and regions are sufficiently symmetric, decentralization implies underprovision, whereas cooperative centralization is associated with strict Pareto-improvement. This classic inference rests on two assumptions: local politicians are delegated sincerely and never provide voluntary transfers to the other regions. We abandon these assumptions in a setup of two symmetric regions with imperfect complementarity between local public goods. For this particular aggregation, non-cooperative decentralization can achieve the social optimum, whereas cooperative centralization cannot.

Keywords: centralization, public goods, strategic delegation, weakest-link, voluntary transfers

JEL: C72, D72, H40, H70, H73

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1. Introduction

Recent explosion of political economy sheds new light on the classic tradeoffs in public economics, such as the one between benefits and costs of decentralization. In the first generation of fiscal federalism, decentralization was perceived only as a safeguard against uniform (one-size-fits-all) policies for asymmetric regions. In the second generation of fiscal federalism (Oates, 2005), decentralization wins endorsement especially by political economists. Among others, Persson and Tabellini (2000, p. 325-39) argue that cooperative centralization may exacerbate the effects of domestic incentive constraints, for example in the case of dynamic inconsistency in capital taxation. Wilson and Janeba (2003) show that decentralization allows for a more optimal mix of vertical and horizontal externalities under tax competition; Hindriks and Lockwood (2005) point to the higher accountability of the governments. Particularly in the European Union, trade-offs associated with centralization are increasingly more studied since the current assignment of tasks in multilevel EU-governance is contested both in theory and policy (see, e.g., Alesina *et al.*, 2005).

We aim to contribute to this literature by a theoretical analysis of the case of *imperfect complementarity*. This particular aggregation occurs when one local good is complementary with another local good, but only imperfectly. For illustration of this aggregation, consider a stylized example of two terrorist groups, e.g. ETA and IRA. Suppose IRA is interested only in attacks in the U.K., and ETA in attacks in Spain; we call IRA 'domestic terrorists' in the U.K. and 'foreign terrorists' in Spain, and vice versa. Let both terrorist groups be perfectly mobile across the two countries, and assume that they can organize their activities from any country, if necessary. The countries spend g_1, respectively g_2, on non-rival domestic antiterrorist measures. Non-rival antiterrorist spending covers, for example, monitoring of suspicious financial flows. Because of local knowledge, the spending has efficiency one if applied towards domestic terrorists and $\kappa < 1$ if applied towards foreign terrorists. Rational terrorists select the country with the lowest effective amount of antiterrorist spending and the effective levels of protection are $G_1 = \min(g_1, \kappa g_2)$ and $G_2 = \min(g_2, \kappa g_1)$.

Although complementary or Leontief-type aggregation may be regarded as too extreme

(Cornes, 1993), it has rationale for situations when regions eliminate adversaries, or if the output depends on the least amount of inputs due to certain physical characteristics. In the former case, for example, rational terrorists tend to attack the least protected airline (Heal and Kuhnreuther, 2005); in the latter case, the level of protection against flood hinges on the level of the lowest dike (Hirshleifer, 1983). Extensive discussion on applicability of imperfect complementarity (specifically on the source of the imperfection) follows in Section 5.

We apply imperfect complementarity on the strategic situation of two regions, each producing one local input. The local inputs are complements into the production of local outputs; the domestic input enters perfectly and the foreign input enters imperfectly. We adjust the seminal setup by Besley and Coate (2003), by two modifications, complementary aggregation (instead of substitutes) and voluntary transfers. This allows comparison with their main result: in Besley and Coate (2003), cooperative centralization produces a higher level of public good surplus if spillovers exceed a critical level. For our particular aggregation, this tradeoff is different; cooperative centralization never attains the social optimum, whereas non-cooperative decentralization does, in some specifications even for all levels of spillovers.

We assume a two-stage game of voters grouped in two regions and two delegates, one per region. In Stage 1, voters in each region simultaneously elect their policy-seeking delegate. In Stage 2, the delegates simultaneously decide on the production of local inputs. We will specifically focus on the willingness to cover costs of the production of the local input in the other region (voluntary transfers). In the electoral game of voters, we will further examine incentives to strategic elect or delegate; we will concentrate on whether voting for a less interested representative will extract voluntary transfers from a relatively more interested representative from the other region. For this purpose we disregard any exogenously given heterogeneity by considering fully symmetric regions.

Strategic delegation is a phenomenon with long history in economics (Crawford and Varian, 1979), having been applied in monetary economics (Rogoff, 1995; Chari *et al.*, 2004), industrial organization (Aghion and Tirole, 1997), tax competition (Brueckner, 2004) or environmental economics (Buchholz *et al.*, 2005). Incentives for strategic delegation emerge especially when delegates are expected to bargain. Conservative delegation is used to strategically decrease the breakdown allocation, and induce relatively larger compensations (Segendorff, 1998). In contrast, progressive delegation gives advantage in the case of fixed cost-sharing rules (Besley and Coate, 2003). Dur and Roelfsema (2005) point that the cost-sharing rule is the key: the larger non-shareable costs, the larger incentive to delegate conservatively and vice versa, both in decentralization and centralization. In our setup with the fixed cost-sharing rule, we will observe that other aspects (possibility of transfers or specification of marginal rate of substitution) play also a key role.

The remainder of the paper is organized as follows. Section 2 outlines the model, and solves for the social optimum serving as the benchmark for normative analysis. Section 3 solves for equilibria in decentralization with and without transfers. It derives the sufficient condition for decentralization with transfers to deliver the social optimum. Section 4 examines cooperative centralization, and proves that cooperative centralization never attains the social optimum. Combined together, we derive the sufficient condition for cooperative centralization to be Pareto-inferior to non-cooperative decentralization. Section 5 motivates imperfect complementarity and discusses applications. Section 6 concludes.

2. Model

2.1 Assumptions

Our model closely follows the framework by Besley and Coate (2003). The main difference is that a local public good and a 'spillover' from the other local public good are not substitutes, but complements. Motivation for this extension has been provided already by Besley and Coate, who anticipated that their main result may not be robust to different aggregation (Besley and Coate, 2003, fn. 15). The extension is interesting since complementarity requires the setup to be substantially reinterpreted: instead of local public goods, we speak of local inputs, and instead of imperfect spillovers, we assume imperfect access to the other local input (more on interpretation follows in Section 5).

Assume two regions of equal size, $i = 1,2$. In each region, there is a continuum of voters j differing only in preferences for public goods, $\lambda_i^j \in [0, \overline{\lambda}]$, distributed by $F_1(\lambda_1)$ and $F_2(\lambda_2)$. Like Besley and Coate (2003), suppose that mean and median values are identical, and the same in the two regions: $F_1(\lambda^m) = F_2(\lambda^m) = \frac{1}{2}$ and $E(\lambda_1) = E(\lambda_2) = \lambda^m$.[1]

Each region produces a local input. The local input is also available in the other region, but only in share κ, where $0 < \kappa < 1$. The local input in region $i \in \{1,2\}$ is financed either by the region itself (at amount g_i), or subsidized by the other region, at amount s_{-i}. Total amount of the local input is $x_i = g_i + s_{-i}$. Imperfectly complementary aggregation implies that the amount of the local output in region i is $G_i \equiv \min(x_i, \kappa x_{-i}) = \min\{g_i + s_{-i}, \kappa(g_{-i} + s_i)\}$. If voluntary transfers are not feasible, then $s_1 = s_2 = 0$.

Production of inputs is financed through non-distortionary lump-sum taxes, t_i. A unit of any

[1] Besley and Coate (2003) impose that distributions must be symmetric and identical. This is unnecessarily restrictive since the purpose of these restrictions is only to get that a median (median-type) politician maximizes welfare of her region. In other words, the aim is to assume away any difference between median interests and (regional) social optimum, which is typically caused by skewed distribution of income (cf. Meltzer-Richard's classic model of redistribution). In our setup, to eliminate the difference, it is sufficient to impose that the mean type is identical to the median type, because social optimum can be written as optimum of a hypothetical individual with the mean of preference for public good. Whenever the median is equal to the mean, then this hypothetical individual in fact represents the median voter.

input requires collecting revenue p from each individual in either of the regions. (Throughout the text, all cost variables are normalized *per capita*.) In decentralization without transfers, each region can only pay expenditures for its own input, and the tax *per capita* is $t_i = pg_i$. In decentralization with transfers, the tax *per capita* writes $t_i = p(g_i + s_i)$. In centralization, we assume equal-cost sharing rule for any given x_1 and x_2, $t_1 = t_2 = (x_1 + x_2)p/2$. If only this rule holds, and nothing else, then the level of transfers in centralization (i.e. the distribution of costs across transfers and payments for own inputs) is arbitrary and irrelevant for utility of any citizen. To illustrate the point: Cost sharing, $t_1 = t_2$, implies $2(s_{-i} - s_i) = x_i - x_{-i}$. There is an infinite amount of possibilities how to determine the pair of subsidies, (s_i, s_{-i}) and keep (x_i, x_{-i}) intact, as long as non-negativity constraints are satisfied. Bound by cost sharing, any pair (s_i, s_{-i}) satisfies:

$$s_i(s_{-i}) = s_{-i} - \tfrac{1}{2}\left(x_i - x_{-i}\right), \quad g_i(s_{-i}) = x_i - s_{-i}\,. \tag{1}$$

Then, as calculated below in (2), the tax $t_i(s_{-i})$ is independent on s_{-i}. Therefore, we need not to specify how transfers are determined in centralization.

$$t_i(s_{-i}) = p(s_i(s_{-i}) + g_i(s_{-i})) = p\left(s_{-i} - \frac{x_i - x_{-i}}{2} + x_i - s_{-i}\right) = \frac{p}{2}\left(x_i + x_{-i}\right) \tag{2}$$

Any individual of type λ^j from region i has a quasi-linear utility function with the complementary aggregation of local public goods,

$$U_i^j = \lambda_i^j b\left(\min\left\{x_i, \kappa x_{-i}\right\}\right) - t_i, \tag{3}$$

where $b(G)$ is an increasing and concave C^2-function, and $b(0) = 0$. Assume that all citizens are able to meet any tax obligation.

The timing is as follows. In Stage 1, both regions independently and simultaneously delegate two purely policy-seeking citizen-candidates, one each. The delegates are the majority-preferred types $\lambda_1^d, \lambda_2^d \in \left[0, \bar{\lambda}\right] \times \left[0, \bar{\lambda}\right]$. Like in Besley and Coate (2003), the pair of delegates $\left(\lambda_1^d, \lambda_2^d\right)$ is majority preferred if, in each region a majority of citizens prefer the type of their representative to any other type, given the other region's representative type. Later in the text, in order to derive the majority-preferred types, we use that the equilibrium pair is identical as if the Stage 1 reduced to a non-cooperative game of two individuals, median voters from the two regions (defined by $\lambda_i^j = \lambda_{-i}^j = \lambda^m$); this claim will be separately proved for decentralization and centralization. Three types of best responses of the median voters may arise, sincere delegation ($\lambda_i^d = \lambda_i^m$; the median voter in region i supports a candidate of identical type), conservative delegation $(\lambda_i^d < \lambda_i^m)$, or progressive delegation $(\lambda_i^d > \lambda_i^m)$.

In Stage 2, we distinguish between decentralization and centralization. For decentralization, each delegate chooses the contribution to the domestic input, g_i, and voluntary transfer to the other region, s_i, if allowed. In centralization, the elected policy-makers bargain over the amounts of public goods, maximizing the sum of their utilities, $U_1^d + U_2^d$. This also implies that Oates' decentralization theorem does not apply here; in centralization, we are not bound by the requirement to provide the identical amounts of local outputs.

2.2 Social optimum

In this section, we will determine the socially optimal amounts of the inputs. We apply the utilitarian measure of welfare, namely the sum of utilities of all individuals in both regions. Let $V_i = \int_0^{\bar{\lambda}} U_i^j d\lambda_i^j$ be the sum of utilities of all individuals in region i. Social optimum is then defined as $\left(g_1^*, g_2^*, s_1^*, s_2^*\right) = \arg\max\left(V_1 + V_2\right)$. We can immediately infer that with transfers, social optimum is not unique in distribution of costs. The first reason is that–like for transfers under centralization discussed in (1) and (2)–the distribution of tax costs into subsidies and payments for own input is irrelevant for utility of any individual. The second reason is that the distribution of total costs $p(x_1 + x_2)$ across individuals is irrelevant for total welfare (because of constant marginal utility of private consumption).

Hence, only production matters, so we can re-write the maximization program into $(x_1^*, x_2^*) = \arg\max(V_i + V_{-i})$ and let $g_i = x_i$. To identify the social optimum, we use that $\arg\max\left(V_1 + V_2\right) = \arg\max\left(U_1^m + U_2^m\right)$. This is because the sum of utilities in either of regions writes as

$$V_i = \int_0^{\bar{\lambda}} \left[F_i' \lambda_i^j b(x_i, x_{-i}, \kappa) - px_i \right] d\lambda_i^j = b(\cdot) \int_0^{\bar{\lambda}} F_i' \lambda_i^j d\lambda_i^j - px_i = E(\lambda_i) b(\cdot) - px_i . \tag{4}$$

By definition, for the median voter, $U_i^m = \lambda^m b(\cdot) - pg_i$. This together with the assumption $E(\lambda_i) = \lambda^m$ and $g_i = x_i$ implies $V_i = U_i^m$. In other words, the social optimum is an argument maximizing the following function,

$$U_1^m + U_2^m = \lambda^m b(\min\{x_1, \kappa x_2\}) + \lambda^m b(\min\{x_2, \kappa x_1\}) - p(x_1 + x_2)\,. \qquad (5)$$

We maximize (5) by optimizing under the fixed total costs, $x = x_i + x_{-i}$. Under this restriction, $\partial x_{-i}/\partial x_i = -1$. Thereby, we can focus only on the marginal benefits associated with increase in x_i and respective decrease in x_{-i}:

$$\frac{d(U_i^m + U_{-i}^m)}{dx_i} = \frac{\partial U_i^m}{\partial x_i} + \frac{\partial U_i^m}{\partial x_{-i}}\frac{\partial x_{-i}}{\partial x_i} + \frac{\partial U_{-i}^m}{\partial x_i} + \frac{\partial U_{-i}^m}{\partial x_{-i}}\frac{\partial x_{-i}}{\partial x_i} = \frac{\partial U_i^m}{\partial x_i} - \frac{\partial U_i^m}{\partial x_{-i}} + \frac{\partial U_{-i}^m}{\partial x_i} - \frac{\partial U_{-i}^m}{\partial x_{-i}} \qquad (6)$$

We have three cases, $x_i \le \kappa x_{-i}$, $x_i \in [\kappa x_{-i}, x_{-i}/\kappa]$, and $x_i \ge x_{-i}/\kappa$. Marginal benefits for each case are listed in Table 1.

Table 1 Marginal benefits in the social optimum under fixed x

	$x_i \le \kappa x_{-i}$	$x_i \in [\kappa x_{-i}, x_{-i}/\kappa]$	$x_i \ge x_{-i}/\kappa$
$\partial U_i^m/\partial x_i$	$\lambda^m b'(x_i)$	0	0
$\partial U_i^m/\partial x_{-i}$	0	$\lambda^m \kappa b'(\kappa x_{-i})$	$\lambda^m \kappa b'(\kappa x_{-i})$
$\partial U_{-i}^m/\partial x_i$	$\lambda^m \kappa b'(\kappa x_i)$	$\lambda^m \kappa b'(\kappa x_i)$	0
$\partial U_{-i}^m/\partial x_{-i}$	0	0	$\lambda^m b'(x_{-i})$
$\partial(U_i^m + U_{-i}^m)/\partial x_i$	$\lambda^m[b'(x_i) + \kappa b'(\kappa x_i)]$	$\lambda^m \kappa[b'(\kappa x_i) - b'(\kappa x_{-i})]$	$-\lambda^m[b'(x_{-i}) + \kappa b'(\kappa x_{-i})]$

The last row in Table 1 indicates that (i) if x_i is relatively low, the utilitarian criterion yields maximum feasible x_i, and (ii) if x_i is relatively high, it yields minimum feasible x_i. The optimum therefore lies in the intermediate part (involving corners from previous types), where the interior first order condition applies, $\lambda^m \kappa[b'(\kappa x_1) - b'(\kappa x_2)] = 0$. Due to monotonicity of $b'(\cdot)$, this implies symmetry, $x_1 = x_2$. Imposing symmetry into (3), we derive the condition for the social optimum as a maximand of (5),

$$\lambda^m \kappa b'(\kappa x^*) = p\,. \qquad (7)$$

3. Decentralization

3.1 No voluntary transfers

Besley and Coate (2003) found that if regions provide local public goods with spillovers, and the goods are pure substitutes, decentralization without transfers leads to sincere delegation, but also to underprovision. Dur and Roelfsema (2005) distinguish between pure substitution, defined as $U_i = b(g_i) + b(g_{-i}) + c_i$, and strategic substitution, defined as $U_i = b(g_i + g_{-i}) + c_i$, where c_i denotes private good (the difference is whether an increase in one public good affects marginal rate of substitution of the other public good with the private good). They highlight that if the local public goods are strategic substitutes, decentralization in addition leads to conservative delegation. Incentives for underprovision are thus even stronger.

In this section, we show that for our aggregation, these effects are extremely sensitive to the assumption of zero voluntary transfers. The complementary technology is extremely helpful to capture this point: without transfers, decentralization yields extreme underprovision; with transfers, it may even secure the social optimum. It is exactly complementary aggregation that reveals that the realistic possibility of voluntary transfers strikingly modifies results in non-cooperative models of public good provision.

Proposition 1 In decentralization without transfers, for any two delegates $\lambda_1^d, \lambda_2^d \in \left[0, \bar{\lambda}\right] \times \left[0, \bar{\lambda}\right]$, zero provision $g_1 = g_2 = 0$ is a unique Nash equilibrium.

Proof If $g_i > \kappa g_{-i}$, a policy maker $i \in 1,2$ can reduce g_i (less costs) and at the same time keep $G_i = \min(g_i, \kappa g_{-i}) = \kappa g_{-i}$ unchanged (constant benefits). This strictly increases utility U_i^d, so $g_i(g_{-i}) > \kappa g_{-i}$ cannot be the best response, and the best response has to satisfy $g_i(g_{-i}) \leq \kappa g_{-i}$. For $\kappa < 1$, this condition applied simultaneously to delegate 1 and delegate 2 ($g_1 \leq \kappa g_2$ and $g_2 \leq \kappa g_1$) is satisfied only as long as $g_1 = g_2 = 0$. □

The proposition is driven by the fact that for $\kappa < 1$, the best responses of delegates intersect in zero, regardless of the delegates' preferences for the public good. As a result, voters have no incentive to behave strategically, and the possibility to vote strategically in Stage 1 brings no change to this extreme outcome.

3.2 Voluntary transfers

The opportunity to compensate another, less interested region has been highlighted by Vicary (1990) and for complementary aggregation studied by Sandler and Vicary (2001), Vicary and Sandler (2002), and experimentally by Lei *et al.* (2007). We will see that the extension of a strategy set by voluntary transfers may restore the social optimum, and this efficient equilibrium will moreover be immune to the strategic delegation.

First of all, we will examine incentives in the subgame of delegates (Stage 2). In the very beginning, consider that the necessary condition for the best response (and henceforth for a

Nash equilibrium) to exist is that each delegate minimizes costs for the fixed amount of the local output (no-waste property). We use this rather trivial property of the equilibrium in the proof of the following lemma.

Lemma 1 In decentralization with transfers, in Nash equilibrium of the subgame of delegates, at least one of the regions contributes nothing to its own input, $\exists i \in 1,2 : g_i = 0$.

Proof We partition the set of strategy profiles in the following subsets: (a) $s_1 = s_2 = 0$, (b) $s_1 > 0, s_2 = 0$, (c) $s_1 = 0, s_2 > 0$, and (d) $s_1 > 0, s_2 > 0$. Incentives for deviation in subset (a) have been examined in Proposition 1, although on a restricted strategy set. From there, the only candidate for equilibrium in subset (a) is $g_1 = g_2 = 0$.

In subset (b), the delegate 1 contributes to both inputs, and cannot tolerate waste in either of them. The reason is that a strictly positive subsidy $s_1 > 0$ implies a strictly positive $g_1 > 0$, and no-waste property gives $G_1 = g_1 = \kappa(g_2 + s_1)$. Output in region 2 is $G_2 = \min(g_2 + s_1, \kappa g_1)$. If region 2 provides $g_2 > 0$, then $g_2 + s_1 \leq \kappa g_1$ (otherwise no-waste property is violated). However, we know $G_1 / \kappa = g_2 + s_1 = g_1 / \kappa > g_1$. Thus, $g_2 = 0$. In subset (c), an equilibrium is symmetric to the equilibrium in subset (b), $g_1 = 0$.

In subset (d), suppose first $g_1 > 0$ and $g_2 > 0$. Then, no-waste properties for both delegates dictate $G_1 = g_1 + s_2 = \kappa(g_2 + s_1)$ and symmetrically $G_2 = g_2 + s_1 = \kappa(g_1 + s_2)$. This implies $1 = \kappa^2$, which is false. Therefore, any equilibrium profile must be either in subset (a), (b) or (c). And in these subsets, there exists i, such that $g_i = 0$. □

Lemma 1 suggests that in the equilibrium, at least one of the delegates reneges on providing domestic input, and rather cross-subsidizes the foreign input. The point is hidden is in the combination of complementarity and imperfect access to the foreign input: any delegate who contributes to own input in fact needs *strictly more (at least* $1/\kappa$*-times) inputs to be located in the other region*. This obviously cannot hold for both regions at the same time.

To simplify search for equilibrium, we introduce two extra terms: for any delegate i, let *S-strategy* be any strategy for which $g_i = 0$, and *T-strategy* be any strategy for which $g_i > 0$. Strategy profiles can be, using this notation and ordering (g_1, g_2), classified into SS, ST, TS, or TT. By Lemma 1, TT is never in equilibrium. Next, notice that ST implies $s_2 > 0$ (and TS implies $s_1 > 0$). The proof is simple: If not and $s_2 = 0$, then $G_1 = \min\{0, \kappa(g_2 + s_1)\} = G_2 = \min\{g_2 + s_1, \kappa 0\} = 0$, which violates the no-waste property at least for the delegate 2 (a decrease in g_2 will not affect G_2 and at the same time will decrease costs).

To summarize: T-strategy in equilibrium is always characterized by $g_i > 0$ and $s_i > 0$, while for S-strategy, we have $g_i = 0$ and $s_i \geq 0$. T-strategy thus can be re-interpreted as a strict *two-input strategy* (paying both own and foreign input), whereas S-strategy is a weak *single-input strategy* (paying only the foreign input, if anything).

The useful properties of quasi-linear preferences are that without additional restrictions, the marginal utility of public consumption is independent on the amount of private consumption, and the marginal utility of private consumption is constant. Therefore, we can define an interior optimal amount of output for each strategy type (S or T), denoted as $G^S(\lambda)$ and $G^T(\lambda)$. The former is the optimal amount of the local output if any additional output requires paying *only* extra foreign input, and the latter is the optimal amount of the local output if any additional output requires paying both inputs. (Interior optimum means that if a delegate i uses S-strategy, she is not bound by the insufficient amount of s_{-i}; we can write $G_i = \min(s_{-i}, \kappa(s_i + g_{-i})) = \kappa(s_i + g_{-i})$.)

Specifically, let $G_i^S(\lambda_i^d)$ be the optimal amount of the local output that the delegate i prefers to be provided if any additional output requires from her paying *only* extra foreign input, and let $S(\lambda_i^d)$ be the total amount of the foreign inputs corresponding to $G_i^S(\lambda_i^d)$, hence $G_i^S(\lambda_i^d) = \kappa S(\lambda_i^d)$. Then, for any λ_i^d we have

$$G_i^S(\lambda_i^d) = \arg\max \lambda_i^d b(G_i) - ps_i = \arg\max \lambda_i^d b(G_i) - \frac{pG_i}{\kappa} + pg_{-i}, \tag{8}$$

$$\lambda_i^d \kappa b'(G_i^S(\lambda_i^d)) = p. \tag{9}$$

Let $G_i^T(\lambda_i^d)$ be the optimal amount of the local output preferred by delegate i if any additional output requires from her paying *both* domestic and foreign input, and let $T(\lambda_i^d)$ be the total amount of the foreign inputs corresponding to $G_i^T(\lambda_i^d)$, hence $G_i^T(\lambda_i^d) = \kappa T(\lambda_i^d)$. We use that for interior optimum in T-strategy, $G_i = \kappa s_i = g_i + s_{-i}$:

$$G_i^T(\lambda_i^d) = \arg\max \lambda_i^d b(G_i) - p(g_i + s_i) = \arg\max \lambda_i^d b(G_i) - \frac{(1+\kappa)pG_i}{\kappa} + ps_{-i}, \tag{10}$$

$$\lambda_i^d \kappa b'(G_i^T(\lambda_i^d)) = p(1+\kappa). \tag{11}$$

Notice that the marginal price per extra output is $1+\kappa$-times higher, hence $T(\lambda_i^d) < S(\lambda_i^d)$. Also, because of symmetry of the optimization problem, $\lambda_1^d = \lambda_2^d$ implies $S(\lambda_1^d) = S(\lambda_2^d)$ and

$T(\lambda_1^d) = T(\lambda_2^d)$. What is particularly important is that the values of these interior optimal outputs are *not* affected by the strategy of the other delegate, (g_{-i}, s_{-i}); later we will see that the other delegate only affects whether the optimum is available or not.

Finally, by comparing (7), (9) and (11), notice that $S(\lambda^m)$ is also the socially-optimal amount of inputs, $x^* = S(\lambda^m)$. This means that if both median-type candidates $(\lambda_1^d = \lambda_2^d = \lambda^m)$ expect SS-profile, each of them selects $s_1 = s_2 = S(\lambda^m)$, which yields the socially optimal allocation. Here, complementarity is never binding, since $\kappa s_i \le s_{-i}$, and $G_i = \min(s_{-i}, \kappa s_i) = \kappa s_i$. Proposition 2 formally proves that such candidates indeed expect SS-profile, not ST or TS, and therefore coordinate on the social optimum.

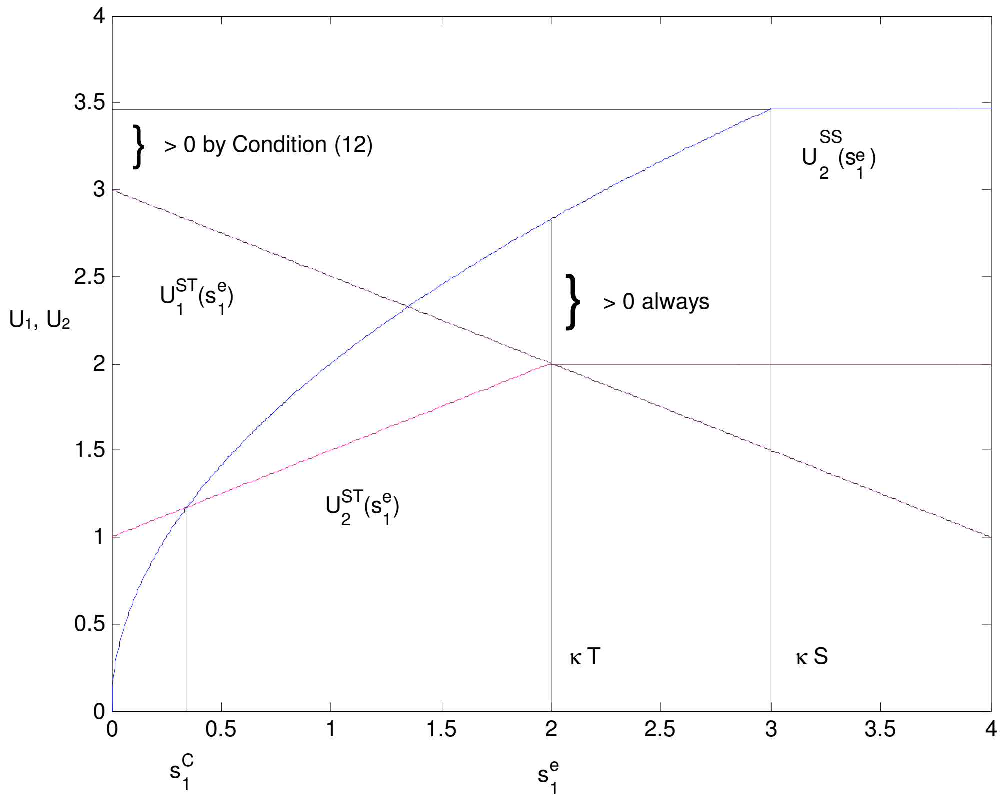
Proposition 2 In decentralization with transfers, in the subgame of delegates, where $\lambda_1^d = \lambda_2^d = \lambda^m$, a unique subgame-perfect Nash equilibrium is $s_1 = s_2 = S(\lambda^m)$ and $g_1 = g_2 = 0$.

Proof Using Lemma 1, impose without loss of generality $g_1 = 0$. First, examine the best response of delegate 2 (g_2, s_2) as a function of the expected s_1^e. To get this best response, we use that only two strategy profiles, ST and SS, can be in equilibrium (TT is impossible by Lemma 1, and TS violates $g_1 = 0$). Therefore, we can find an optimal response of delegate 2 limited to the set of ST profiles and an optimal response limited to the set of SS profiles; by comparing utility for each of the optimal responses, we get the genuine best response.

If s_1^e is large enough, $s_1^e \ge \kappa S(\lambda_2^d)$, an optimal S-strategy of delegate 2 involves $G_2 = G_2^S$, $s_2 = S(\lambda_2^d)$ and $g_2 = 0$; if $s_1^e < \kappa S(\lambda_2^d)$, an optimal S-strategy of delegate 2 involves $G_2 = s_1^e$, $s_2 = s_1^e / \kappa$ and $g_2 = 0$. Similarly, an optimal T-strategy of delegate 2 must give $G_2 = G_2^T(\lambda^m)$, $s_2 = T(\lambda_2^d)$ and $g_2 = \max\left\{0, \kappa T(\lambda_2^d) - s_1^e\right\}$. Figure 1 depicts utilities of delegate 2 corresponding to each of these optimal responses (S-strategy giving SS-profile and T-strategy giving ST-profile), $U_2^{SS}(s_1^e)$ and $U_2^{ST}(s_1^e)$.

Due to concavity of $b(\cdot)$, there is a critical level of the expected s_1^e, denoted as s_1^C: if $s_1^e < s_1^C$, then the delegate 2 chooses the expensive, two-input T-strategy (and profile ST); otherwise she chooses the cheaper, single-input S-strategy (and profile SS). (For the sake of completeness, the tie-breaking rule is in favor of SS; its precise specification does not affect the results.) Evidently from Fig. 1, $0 < s_1^C < \kappa T(\lambda^m)$.

Fig. 1. Utility of the median-type delegate 2 under optimal SS- and ST-responses to s_1^e, $U_2^{SS}(s_1^e)$ and $U_2^{ST}(s_1^e)$



The next condition necessary to hold in equilibrium is $s_1 = s_1^e$, i.e. the equilibrium beliefs are correct. In other words, the best response of the delegate 1 to $g_2(s_1^e)$ and $s_2(s_1^e)$ must be $s_1 = s_1^e$ and $g_1 = 0$. Thereby we check for the mutual best responses of the delegate 1 and the delegate 2.

ST profile. If the delegate 2 uses T-strategy, then $G_2 = G_2^T(\lambda^m)$ always holds. Notice from Fig. 1 that $s_1^C < \kappa T(\lambda^m)$, hence in ST-profile, we have $s_1^e \le s_1^C < \kappa T(\lambda^m)$. This gives us a full specification of the best response of the delegate 2 for any $s_1^e \le s_1^C$, namely $s_2 = T(\lambda^m)$ and $g_2 = \kappa T(\lambda^m) - s_1^e \ge 0$.

On this interval, $G_1 = \min\{s_2, \kappa(g_2 + s_1)\} = \min\{T(\lambda^m), \kappa(\kappa T(\lambda^m) - s_1^e + s_1)\}$. This allows to derive the best response of the delegate 1, namely the optimal $s_1 = s_1(s_2, g_2)$. We have to realize that the delegate 1 considers both S-strategy and T-strategy.

i. For T-strategy, the interior optimum $G_1 = G_1^T(\lambda^m) = \kappa T(\lambda^m)$ gives $g_1 = 0$, since the other input is provided in a sufficient amount, $s_2 = T(\lambda^m) > \kappa T(\lambda^m)$, exceeding the optimum $x_1 = \kappa T(\lambda^m)$ under T-strategy. This implies that the delegate 1 responds only by S-strategy.

ii. For S-strategy, we have to distinguish between two cases:

a) $T(\lambda^m) < \kappa S(\lambda^m)$: The delegate 1 gets $G_1 < G_1^S(\lambda^m) = \kappa S(\lambda^m)$, because complementarity is binding in the amount of input 1, $x_1 = s_2 = T(\lambda^m) < \kappa S(\lambda^m)$. Her best response is therefore to match the amount of input 1, $\kappa(g_2 + s_1) = \kappa x_2 = G_1 = x_1 = T(\lambda^m)$, from which we derive $s_1 = T(\lambda^m)/\kappa - g_2 = T(\lambda^m)(1-\kappa^2)/\kappa + s_1^e$. Since $(1-\kappa^2)/\kappa > 0$, the delegate 1 sets $s_1 > s_1^e$ (deviates from expectations of the delegate 2), so for this case, the equilibrium cannot be in ST-profile.

b) $\kappa S(\lambda^m) \le T(\lambda^m)$: Complementarity is not binding, and $G_1 = G_1^S(\lambda^m) = \kappa S(\lambda^m)$. The best response of the delegate 1 satisfies $s_1 = S(\lambda^m) - g_2 = S(\lambda^m) - \kappa T(\lambda^m) + s_1^e$. Since $S(\lambda^m) > T(\lambda^m) > \kappa T(\lambda^m)$, we have $s_1 > s_1^e$. This again implies that the delegate 1 deviates from expectations of the delegate 2, and the condition $s_1 = s_1^e$ cannot be satisfied. Also for this case, no ST-profile is a Nash equilibrium.

iii. In total, Nash equilibrium cannot occur for any ST-profile under any condition.

SS profile. The delegate 2 uses S-strategy, where $G_2 = \min(s_1^e, \kappa s_2)$. She aims at the interior equilibrium $G_2 = G_2^S(\lambda^m)$, but can be constrained by unavailability of the other input (too low s_1^e, namely $x_2 = s_1^e < \kappa S(\lambda^m)$. Therefore, for $s_1^e \ge \kappa S(\lambda^m)$, we have the interior optimum $s_2 = S(\lambda^m)$; otherwise $s_2 = s_1^e/\kappa$.

What is the best response s_1, considering $s_2 = s_2(s_1^e)$? We have $G_1 = \min(s_2, \kappa s_1)$. Like the delegate 2, also the delegate 1 wants in the interior optimum $G_1 = G_1(\lambda^m)$ and $s_1 = S(\lambda^m)$; this is limited by complementarity in the production of G_1 as long as $s_2 < \kappa S(\lambda^m)$. However, can this complementarity be binding in equilibrium, where $s_1 = s_1^e$? No. First, suppose that both complementarities bind, i.e. $s_2 = s_1/\kappa$ and $s_1 = s_2/\kappa$. This obviously implies a false statement, $1 = \kappa^2$. Second, if only the latter complementarity binds, we have $s_2 < \kappa S(\lambda^m)$ (the delegate 1 is bound) and $s_2 = S(\lambda^m)$ (the delegate 2 is not bound), which is obviously inconsistent with each other. Therefore, the delegate 1 is never bound and $s_1 = S(\lambda^m)$. The delegate 2 responds to $s_1 = S(\lambda^m) > \kappa S(\lambda^m) > \kappa T(\lambda^m)$ by selecting S-strategy, and since $s_1 = S(\lambda^m) > \kappa S(\lambda^m)$, the delegate 2 is not bound, and sets $s_2 = S(\lambda^m)$. □

The mechanics of the proof has illustrated crucial properties of the equilibrium in the subgame of delegates. We found that the possibility of compensations makes median-type delegates install the social optimum, even in the purely non-cooperative mode. Nevertheless, we still do not know if the socially optimal allocation is immune to the possibility of strategic delegation. This is addressed by Proposition 3, whereby we deliver the core result of this section.

Proposition 3 In decentralization with voluntary transfers, delegation of median-type representatives, $\lambda_1^d = \lambda_2^d = \lambda^m$, who employ inputs at socially optimal levels, $x_1 = x_2 = x^*$, is a subgame-perfect Nash equilibrium if

$$\lambda^m b\left(\kappa^2 T(\lambda^m)\right) < \lambda^m b\left(\kappa S(\lambda^m)\right) - pS(\lambda^m). \tag{12}$$

Proof As in decentralization, we solve the Stage 1 as if the median voters were regional dictators. Then we will prove that the resulting delegates are Condorcet winners in elections in each region. We analyse stability of the symmetric median-type delegation. When considering deviation, the median voter in region 1 expects that only SS, ST, or TS profiles can emerge in the subgame of delegates. If SS-profile occurs, any strategic delegation that would involve $s_1 \neq S(\lambda^m)$ would be obviously dominated by $s_1 = S(\lambda^m)$ (recall definition of $G^S(\lambda^m)$). Also if TS-profile occurs, the median voter would lose comparing to social optimum, because her delegate would have to employ a more expensive technology (for any level of output). Thus, the only incentive for strategic delegation is to induce an ST-profile, and free ride on the region 2 whose median-type delegate resorts to an expensive two-input strategy.

To keep ST profile in an equilibrium of the subgame of delegates, where $s_1 = s_1^e$, the delegate 1 must prefer a credibly low $s_1 = s_1^e = S(\lambda_1^d) < s_1^C$, hence must be sufficiently *uninterested* in public goods. The existence of ST-profile is thus conditional on median voter 1 nominating a sufficiently conservative (low λ-type) delegate. In ST-profile, we know that the best response of delegate 2 is $s_2 = T(\lambda^m)$ and $g_2 = \kappa T(\lambda^m) - s_1^e$. This implies that for the best response of the delegate 2 to be in ST-profile (where $g_2 > 0$), we have to have $s_1^e < \kappa T(\lambda^m)$. Now, for what kind of delegate 1 is a strictly positive $0 < s_1 = s_1^e < \kappa T(\lambda^m)$ her best response? First, recall that we always have $G_1 = \min\left\{T(\lambda^m), \kappa(\kappa T(\lambda^m) - s_1^e + s_1)\right\} = \kappa^2 T(\lambda^m)$. Any delegate who has no incentive to decrease the strictly positive $s_1 > 0$ below expectations and thereby decrease G_1 below $G_1 = \kappa^2 T(\lambda^m)$ must satisfy $S(\lambda_1^d) \geq \kappa T(\lambda^m)$. Any delegate who has no incentive to increase s_1 and thereby increase G_1 (under non-binding complementarity

$\kappa^2 T(\lambda^m) < T(\lambda^m)$) must satisfy $S(\lambda_1^d) \le \kappa T(\lambda^m)$. This gives that only one specific type of the delegate, for whom $S(\lambda_1^d) = \kappa T(\lambda^m)$, produces in equilibrium $0 < s_1 = s_1^e < \kappa T(\lambda^m)$.

For any λ_1^d such that $S(\lambda_1^d) < \kappa T(\lambda^m)$, the best response of the delegate 1 satisfies $\kappa(g_2 + s_1) = \kappa S(\lambda_1^d)$, hence $s_1 = S(\lambda_1^d) - g_2 = S(\lambda_1^d) - \kappa T(\lambda^m) + s_1^e < s_1^e$. Only corner solution applies, $s_1 = s_1^e = 0$. Recall also that any conservative delegate for whom $S(\lambda_1^d) \le \kappa T(\lambda^m)$ induces identical $G_1 = \kappa^2 T(\lambda^m)$ in the subgame of delegates. Clearly, since this amount of output G_1 is independent on s_1, the median voter 1 chooses some of the more conservative delegates, defined by $S(\lambda_1^d) < \kappa T(\lambda^m)$ who sets $s_1 = 0$; although delegating a candidate defined by $S(\lambda_1^d) = \kappa T(\lambda^m)$ would bring identical output, there would be an infinite number of multiple equilibria in the subgame of delegates (Stage 2), characterized by $s_1 \in [0, \kappa T(\lambda^m)]$ and $g_2 = \kappa T(\lambda^m) - s_1$; with exception of $s_1 = 0$, all are from the perspective of the median voter 1 inferior to delegating $S(\lambda_1^d) < \kappa T(\lambda^m)$, and obtaining $s_1 = 0$ with certainty. To conclude this part, the median voter 1–if invokes an ST-profile–delegates in such a way that the local output is $G_1 = \kappa^2 T(\lambda^m)$ and her costs are zero $(s_1 = 0)$. Her utility from the profile is $U_1^m = \lambda^m b(\kappa^2 T(\lambda^m))$.

Condition (12) then imposes that if the median voter 1 nominates in this conservative way and free rides on the other region, her utility from invoking the best of ST-profiles is still less than the utility from the social optimum, involving the symmetric SS-profile. Since no other profile can give any better outcome, this condition is sufficiently strong to deter the median voter 1 from anything but sincere delegation.

Finally, we prove that $\lambda_1^d = \lambda^m$ is a Condorcet winner in electoral Stage 1. Let $\lambda_1^d(\lambda_1^j)$ be the optimal delegate for voter j of type λ_1^j; this is the delegate who induces $x_2 = s_1 = S(\lambda_1^j)$ in SS-profile. First, $S(\lambda_1^j)$ as the optimal s_1 (and optimal x_2) is increasing in λ_1^j. Second, the preferences of any voter over s_1 (or x_2) under SS-profile are single-peaked. Third, by (9) and $S(\lambda) = G^S(\lambda)/\kappa$, in order to increase $S(\lambda)$, a more progressive delegate has to be elected (monotonic transformation). Together, $\lambda_1^d(\lambda_1^j)$ is increasing in λ_1^j and preferences of voters over types λ_1^d are single-peaked, which is a sufficient condition for the median voter theorem to hold. □

Put in brief, condition (12) is for *unwillingness of the median voter 1 to impose even the most favorable ST profile*. If it holds, ST profile cannot be in equilibrium, and SS profile is the only equilibrium profile. With this, it is easy to conclude that none of median voters deviates from $\lambda_i^d = \lambda^m$, since none of them wants her delegate to deviate from $s_1 = s_2 = S(\lambda^m)$.

3.3 Example

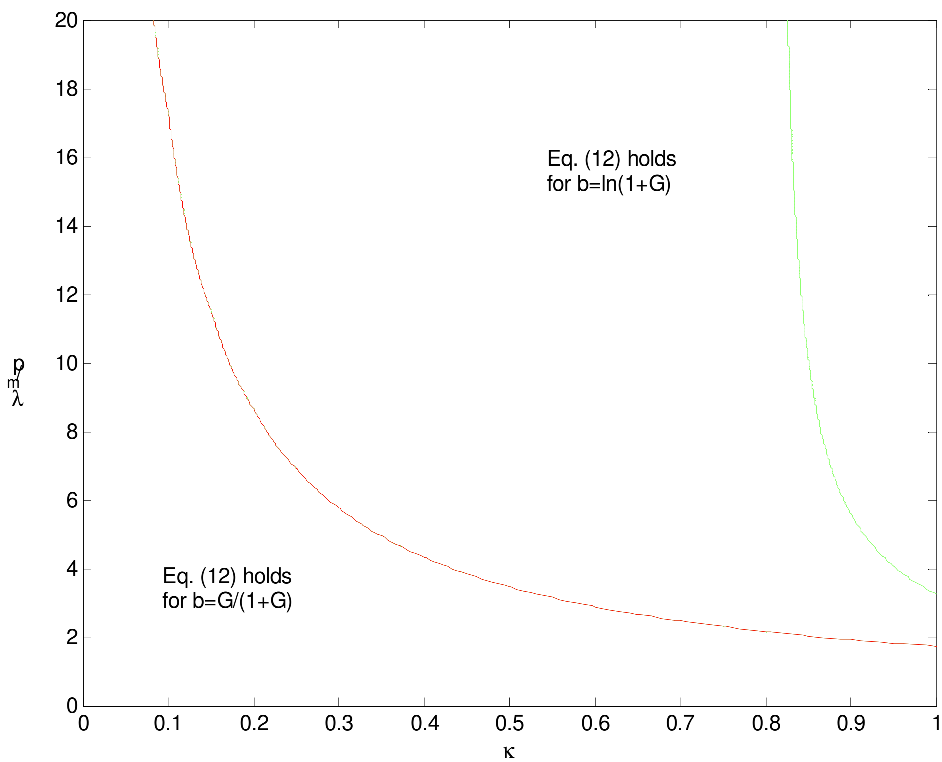
The condition (12) may hold in entire parameter space $\kappa \times \lambda^m \times p \in (0,1)\times(0,\infty)\times(0,\infty)$. This is the case of $b(G)=2\sqrt{G}$, where the condition (12) reduces to $(\kappa-1)^2>0$, which is true. For other functions, validity of the condition may be restricted to a parameter subspace. This is illustrated on Fig. 2 with the functions $b(G)=\ln(G+1)$ and $b(G)=G/(G+1)$, both satisfying requirements of monotonicity, concavity, and $b(0)=0$. In space of $\kappa \times \lambda^m / p$, the figure captures when (12) is satisfied for each of the two functions. It can be shown that all values to the left from the respective curves satisfy the condition. From the location of parameters $(\kappa, \lambda^m/p)$ which violate (12), we can conjecture–at least for this two particular functions–that the efficient equilibrium is more likely with

(i) the worse access to the foreign complement (lower κ),

(ii) the lower median interest in public goods (lower λ^m), and

(iii) the higher price p.

Fig. 2. Condition (12) for $b(G)=\ln(G+1)$ and $b(G)=G/(G+1)$



4. Cooperative centralization

If decentralization can deliver the social optimum, why not cooperative centralization, where cost shares are equalized and delegates have access to perfect commitment/cooperation devices? With sincere delegation, joint bargaining of the two median-type politicians would indeed deliver the social optimum. Rational voters nevertheless tend to elect different delegates. This stems from dichotomy in devices available in each stage: in electoral stage, voters in one region play non-cooperatively with voters from the other region; in policy-making stage, the delegates play cooperatively among each other (bargain). Non-cooperative voters may welcome surplus from bargaining, but also try to improve their odds by effectively delegating a delegate with specific preferences. We find that the strategic delegation in centralization implies an unambiguous welfare loss in comparison with the social optimum.

First, consider that the objective function of the two policy-makers who bargain over the provision of local inputs is

$$U_1^d + U_2^d = \lambda_1^d b(\min(x_1, \kappa x_2)) + \lambda_2^d b(\min(x_2, \kappa x_1)) - p(x_1 + x_2)\,. \tag{13}$$

In analysing the optimum, we are firstly interested in the relative size of x_1 to x_2. Therefore, suppose for the moment fixed total revenues (hence also fixed total spending), and derive the optimal $x_1(x)$ under $x_1 + x_2 = x$. We have three intervals, $x_1 \le \kappa x_2$, $x_1 \in [\kappa x_2, x_2/\kappa]$, and $x_1 \ge x_2/\kappa$, alternatively written as $x_1 \le x\kappa/(1+\kappa)$, $x_1 \in [x\kappa/(1+\kappa), x/(1+\kappa)]$, and $x_1 \ge x/(1+\kappa)$. Marginal benefits associated with an increase in x_1 and a respective decrease in x_2 are shown in Table 2, created analogically to Table 1, where for all intervals

$$\frac{d(U_1^d + U_2^d)}{dx_1} = \frac{\partial U_1^d}{\partial x_1} - \frac{\partial U_1^d}{\partial x_2} + \frac{\partial U_2^d}{\partial x_1} - \frac{\partial U_2^d}{\partial x_2}\,. \tag{14}$$

Table 2 Marginal benefits in the bargaining outcome under fixed x

	$x_1 \le \kappa x_2$	$x_1 \in [\kappa x_2, x_2/\kappa]$	$x_1 \ge x_2/\kappa$
$\partial U_1^d/\partial x_1$	$\lambda_1^d b'(x_1)$	0	0
$\partial U_1^d/\partial x_2$	0	$\lambda_1^d \kappa b'(\kappa x_2)$	$\lambda_1^d \kappa b'(\kappa x_2)$
$\partial U_2^d/\partial x_1$	$\lambda_2^d \kappa b'(x_1)$	$\lambda_2^d \kappa b'(x_1)$	0
$\partial U_2^d/\partial x_2$	0	0	$\lambda_2^d b'(x_2)$
$\partial(U_1^d + U_2^d)/\partial x_1$	$\lambda_1^d b'(x_1) + \lambda_2^d \kappa b'(\kappa x_1)$	$\lambda_2^d \kappa b'(\kappa x_1) - \lambda_1^d \kappa b'(\kappa x_2)$	$-\lambda_2^d b'(x_2) - \lambda_1^d \kappa b'(\kappa x_2)$

From Table 2 we deduce (like when identifying the social optimum) that the bargaining outcome must be in the middle interval for any λ_1^d and λ_2^d. We can write explicitly

$$\begin{aligned}
x_1 &= \frac{\kappa x}{1+\kappa} \quad \text{if} \quad \frac{dU_1^d + U_2^d}{dx_1}\left(x_1 = \frac{\kappa}{1+\kappa} \right) \le 0, \\
x_1 &= \frac{x}{1+\kappa} \quad \text{if} \quad \frac{dU_1^d + U_2^d}{dx_1}\left(x_1 = \frac{1}{1+\kappa} \right) \ge 0, \\
\frac{\kappa x}{1+\kappa} < x_1 &< \frac{x}{1+\kappa}, \frac{\lambda_1^d}{\lambda_2^d} = \frac{b'(\kappa x_1^*)}{b'\left(\kappa(x-x_1^*)\right)} \quad \text{otherwise.}
\end{aligned} \tag{15}$$

Notice that the bargaining result is unique, since $U_1^d + U_2^d$, subject to constant x, is strictly concave in x_1 on the middle interval,

$$\frac{d(U_1^d + U_2^d)^2}{d^2 x_1} = \lambda_2^d \kappa b''(x_1) + \lambda_1^d \kappa b''(x - x_1) < 0. \tag{16}$$

Importantly, notice that if the solution is interior (of the third type), we can derive any x_i in the following implicit form as a function $x_i = x_i(\lambda_{-i}^d)$:

$$\lambda_{-i}^d \kappa b'(\kappa x_i) = p \tag{17}$$

After this introductory part, we can proceed to the main result. We again use that median voters are decisive in their regions. We will focus on their best responses in the non-cooperative game in Stage 1 where the strategy is a type of the delegate. Finally we check that the delegates are Condorcet winners in regional elections.

Since we are only interested in stability of the socially optimal allocation, and this allocation can be achieved only via median-type delegates (obviously from (7) and (17)), this task reduces to discerning whether median-type delegates occur in equilibrium. Proposition 3 rejects this possibility; if a median voter expects a median-type delegate from the other region, she has an incentive to vote for a progressive delegate.

Proposition 4 In cooperative centralization, median-type delegates $\lambda_1^d = \lambda_2^d = \lambda^m$ cannot be simultaneously present in the Nash equilibrium.

Proof If median-type delegates are in place, then the median voter 1 considers delegating other than the median-type delegate. The bargaining result for sufficiently close delegates gives $G_1 = \kappa x_2$, so on the neighborhood of $\lambda_1^d \in (\lambda^m - \varepsilon, \lambda^m + \varepsilon)$, the median voter 1 maximizes $U_1^m = \lambda_1^m b(\kappa x_2) - (x_1 + x_2)p/2$, and the FOC writes

$$\frac{dU_1^m}{d\lambda_1^d} = \left(\lambda_1^m \kappa b'(\kappa x_2) - \frac{p}{2}\right)\frac{dx_2}{d\lambda_1^d} = 0. \tag{18}$$

We apply the implicit function theorem on (17) and derive that

$$\frac{dx_2}{d\lambda_1^d} = -\frac{p}{\kappa^2(\lambda_1^d)^2 b''(\kappa x_1)} > 0. \tag{19}$$

Plugging (19) into (18), we recognize that for λ_1^d in order to be in interior optimum, we need that x_2 satisfies $\lambda_1^m \kappa b'(\kappa x_2) = p/2$. By inspection of (15), this holds exactly when $\lambda_1^d = 2\lambda^m > \lambda^m$. From the perspective of the median voter 1, delegating a progressive candidate dominates delegating a median-type candidate, hence median-type delegates are not the mutual best responses and cannot both occur in equilibrium if the median voters are decisive.

Finally, we prove that $\lambda_1^d = 2\lambda^m > \lambda^m$ is a Condorcet winner in electoral Stage 1. Let $\lambda_1^d(\lambda_1^j)$ be the optimal delegate for voter j of type λ_1^j; this is the delegate who satisfies $\lambda_1^j \kappa b'(\kappa x_2) = p/2$. First, the optimal x_2 is increasing in λ_1^j. Second, the preferences of any voter j over x_2 are single-peaked. Third, by (17), in order to increase x_2, a more progressive delegate has to be elected. Together, $\lambda_1^d(\lambda_1^j)$ is increasing in λ_1^j and preferences of voters over types λ_1^d are single-peaked, which is a sufficient condition for the median voter theorem to hold. □

The concluding proposition combines results from Proposition 3 and 4.

Proposition 5 If (12) holds, then cooperative centralization is Pareto-inferior to non-cooperative decentralization with transfers.

Proof First, we prove that the social optimum in cooperative centralization needs median-type delegates: social optimum is symmetric, $x_1 = x_2 = x^*$, so it must be the third type of solution in (15). This type of solution must satisfy (17). Comparing (17) and (7), and considering monotonicity of $b(\cdot)$, this means that $\lambda_i^d = \lambda^m$ in order to $x_i = x^*$.

Second, by Proposition 4, median-type delegates are not in equilibrium of cooperative centralization, hence cooperative centralization yields allocation that doesn't maximize welfare. Third, by Proposition 3, under condition (12) decentralization with transfers achieves the social optimum, hence welfare is greater than in cooperative centralization. □

5. Imperfect complementarity

In the introduction, we have considered a case where complementarity is due to strategic choice of an adversary. We can think of at least three other possibilities.

Consumption complementarity. Extremely high (ideally infinitely large) marginal rate of substitution may be realistic for extreme scarcity of subsistence goods, e.g. sleep, water, or security. (Lei et al. (2007) discuss poverty to be a weakest-link public good.) Drawing partial inspiration from William Styron's *Sophie's choice*, consider a drastic but instructive case of a family with a large number of children subject to famine and genocide. Then, a child survives only if supplied with the subsistence amount of food as well as the subsistence amount of security, and the number of children survived is given by a complementary function.

An example of imperfect consumption complementarity follows: Suppose two extremely poor, neighboring regions. Region W has access to river and thereby disposes with water reservoirs in volume w; Region R has a road network to the port, with density r. Region R can use only water from wells, where the level is determined by the level in the water reservoirs in region W; water consumption is κw, where realistically $\kappa < 1$. Water decays if transported across borders. Region W earns foreign exchange only by using roads in region R; sales write κr. It may be that water consumption and foreign exchange are complementary, especially if the money is used mainly to purchase medicine against epidemics or necessities for living. Then, utilities write $U^W = \min(w, \kappa r)$ and $U^R = \min(r, \kappa w)$.

Piece-to-piece complementarity. Instead of local goods, we can think of inputs that are technologically predetermined to be pieces into a compound good. Imperfection may reflect that a norm prescribes access to certain amount of one of the inputs. Non-rivalry can be explained by time structure of the provision of inputs; the rival inputs are used in different, mutually exclusive time spans.

As an example of imperfect piece-to-piece complementarity, consider an organization with a technical unit and personal unit, T and P. The technical unit has t supercomputers, and personal unit has p experts. The management prescribes that each unit devotes ρ of working hours to the needs of the other unit ($1-\rho$ remains). To process certain tasks, the personal unit needs supercomputers, whereas the technical unit needs to sit the experts to the computers. One task is done if exactly one expert works for one working hour on a supercomputer (notice that we do not need that working time of each expert is identical or that working time of each computer is the same). Then, if we let $\kappa = \rho/(1-\rho)$, the outputs write $Y^P = (1-\rho)\min(p, \kappa t)$, and $Y^P = (1-\rho)\min(t, \kappa p)$.

Norm-imposed complementarity. Even when inputs are effective substitutes, regulation can impose a fixed ratio, hence establishes artificial complementarity. Consider an example of a university consisting of two parts, a research center C and a teaching department D. The center hires r experienced researchers with the status of professors, and the department hires l lecturers. The research center pays researchers and department pays lecturers, but the university has a (more or less formal) rule that any employee must be available for the other part of the organization, at working capacity $\kappa < 1$.

If either C or D wants to establish a program, they need both professors' working time and lecturers' working time. The required capacities are given by the government administration (at least in the Czech Republic). If normalized to one, the number of programs is $Y^C = \min(r, \kappa l)$ and $Y^D = \min(l, \kappa r)$.

To summarize: Imperfect complementarity can be traced in the production of governments, organizations and perhaps also in teams. Any interpretation of this very special aggregation has to address four issues:

i. Complementarity. What makes production or consumption complementary? We recognized either strategic choice of an adversary (terrorists), an extreme marginal rate of substitution for subsistence (water and medicine), combination of physical and human capital (supercomputer and expert), or regulation (minimal number of professors and lecturers).
ii. Imperfection. Why does an input/good from the other region enter imperfectly? We have suggested the importance of local knowledge (antiterrorist measures), spatial characteristics (spillovers), or regulation (organizational directives).
iii. Immobility. What makes production locally specific? There can be spatial characteristic (borders, or rivers), or an exogenously predetermined allocation of competencies (organizational rules).
iv. Non-rivalry and non-exclusion. Why is an input or good of one region or one organization unit available to the others, and for free? This was by mobility of an adversary (antiterrorist measures), uncontrolled spillovers (water), or regulation (organizational directives).

6. Conclusion

In this paper, we have examined decentralization and centralization of the provision of imperfect complements, in the case of two fully symmetric regions. We have extended Besley and Coate (2003) in two respects: (i) complements, not substitutes were investigated; (ii) voluntary transfers from one region to another were permitted. Like the previous literature (cf. Dur and Roelfsema, 2005), we find that cooperative centralization with uniform taxation induces progressive delegation; voters tend to delegate politicians who are very much in favor of public-good provision.

We stress two novel findings: the possibility of transfers allows non-cooperative decentralization to reach even the first-best allocation (social optimum), immune to strategic delegation, whereas cooperative centralization always implies deviation from the first best. Hence, cooperative centralization of imperfect complements is never the first best, and may not even be the second best. Also, the tradeoffs associated with centralization need not to exist at all.

Albeit the scope of complementary aggregation is limited, it is useful to find out this straightforward result in a strategically rich and realistic setting where both voluntary transfers and strategic delegation are taken into account.

References

Aghion, P., Tirole, J. (1997) Formal and Real Authority in Organizations, *Journal of Political Economy*, **105**, 1-29.

Alesina, A., Angeloni, I., Schuknecht, L. (2005) What Does the European Union Do? *Public Choice*, **123**, 275-319.

Besley, T., Coate, S. (2003) Centralized versus Decentralized Provision of Local Public Goods: A Political Economy Analysis, *Journal of Public Economics*, **87**, 2611-37.

Brueckner, J. K. (2004) Fiscal decentralization with distortionary taxation: Tiebout vs tax competition, *International Tax and Public Finance*, **11**, 133–53.

Buchholz, W., Haupt, P., Peters, W. (2005) International environmental agreements and strategic voting, *Scandinavian Journal of Economics*, **107**, 175-95.

Chari, V. V., Jones, L., Marimon, R. (2004) Strategic Delegation in Monetary Unions, *The Manchester School*, **72**, 19-35.

Crawford, V. P., Varian, H. R. (1979) Distortion of preferences and the Nash theory of bargaining, *Economics Letters*, **3**, 203-6.

Croson, R., Fatas, E., Neugebauer, T. (2005) Reciprocity, matching and conditional cooperation in two public goods games, *Economics Letters*, **87**, 95-101.

Dur, R., Roelfsema, H. (2005) Why Does Centralization Fail to Internalize Policy Externalities? *Public Choice*, **122**, 395-416.

Heal, G., Kunreuther, H. (2005) IDS Models of Airline Security, *Journal of Conflict Resolution*, **49**, 201-17.

Hirshleifer, J. (1983) From weakest link to best shot: The voluntary provision of public goods, *Public Choice*, **41**, 371-86.

Hindriks, J., Lockwood, B. (2005) Decentralization and Electoral Accountability: Incentives, Separation and Voter Welfare, Working paper No. 1509, Centre for Economic Studies and Ifo Institute for Economic Research, Munich.

Lei, V., Tucker, S., Vesely, F. (2007) Foreign aid and weakest-link international public goods: An experimental study, *European Economic Review*, **51**, 599-624.

Oates, W. E. (2005) Toward a Second Generation Theory of Fiscal Federalism, *International Tax and Public Finance*, **12**, 349-73.

Persson, T., Tabellini, G. (2000) *Political Economics: Explaining Economic Policy*, MIT Press, Cambridge, MA.

Redoano, M., Scharf, K. A. (2004) The Political Economy of Policy Centralization: Direct versus Representative Democracy, *Journal of Public Economics*, **88**, 799-817.

Rogoff, K. (1985) The Optimal Degree of Commitment to an Intermediate Monetary Target, *Quarterly Journal of Economics*, **100**, 1169-89.

Sandler, T., Vicary, S. (2001) Weakest-link public goods: giving in-kind or transferring money in a sequential game, *Economics Letters*, **74**, 71-5.

Segendorff, B. (1998) Delegation and Threat in Bargaining, *Games and Economic Behavior*, **23**, 266-83.
Vicary, S. (1990) Transfers and the weakest-link: An extension of Hirshleifer's analysis, *Journal of Public Economics*, **43**, 375-94.
Vicary, S., Sandler, T. (2002) Weakest-link public goods: giving in-kind or transferring money, *European Economic Review*, **41**, 1506-20.
Wilson, J. D., Janeba, E. (2003) Decentralization and international tax competition, Working paper No. 854, Centre for Economic Studies and Ifo Institute for Economic Research, Munich.

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