Political Institutions and Investment in Public Infrastructure[1]

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Abstract

We present a theoretical model of the provision of a durable public good over an infinite horizion. In each period, there is a societal endowment of which each of n districts owns a share. This endowment can either be invested in the public good or consumed. We characterize the planner's optimal solution and time path of investment and consumption. We then consider alternative political mechanisms for deciding on the time path, and analyze the Markov perfect equilibrium of these mechanisms. One class of these mechanisms involves a legislature where representatives of each district bargain with each other to decide how to divide the distribute current period's societal endowment between investment in the public good and transfers to each district. The second class of mechanisms involves the districts making independent decisions for how to divide their own share of the endowment between consumption and investment. We conduct an experiment to assess the performance these mechanisms, and compare the observed allocations to the Markov perfect equilibrium.
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1 Introduction

Most public goods provided by governments are durable, and hence dynamic in nature. It takes time to accumulate them; and they depreciate slowly, projecting their benefits for many years. Prominent examples are national defense, environmental protection and public infrastructure. Considering the dynamic nature of public goods is particularly important when public policies are not taken by a benevolent planner, but are the result of political struggle, and therefore depend on the details of the institutional setting. The institutional environment does not only determine the extent to which the policy will reflect the welfare of the citizens when the policy is chosen: but it also determines the extent to which political actors will internalize the benefits that will accrue in future periods; in a word, how "shortsighted" the policy is. The dynamic nature of public goods and the institutional setting, therefore cannot be studied separately: on the one hand, the institutional setting will determine the shortsightedness of the policy and the nature of the free rider problem; on the other hand, the dynamic free rider problem should be an important factor in evaluating the institutional setting.

In this paper we present a comparative study of two alternative institutional frameworks in the provision of dynamic public goods: a legislative model in which agents choose a collective policy by non cooperative bargaining; and an autarchy model in which there is no central authority. We first propose a theoretical model and then use it to design a laboratory experiment as a first step to assessing the empirical viability of the theory, and to collect empirical data on how the *dynamic* free rider problem impacts public good provision. Experimental analysis is particularly important when studying a highly structured dynamic environment that cannot be easily replaced by field data; this is because strategic behavior can be observed only if there is a precise measurement of the "state variable" and the actions space available to the players. To our knowledge, this is the first experimental study of the dynamic accumulation process of a durable public good.

The economy we study has a continuum of infinitely lived citizens who live in n districts. A durable public good can be accumulated and depreciates a rate $d < 1$. We consider two institutional mechanisms in which public good investment decisions can be taken. The first is a purely decentralized mechanism, which we call *Autarky*, whereby each district retains full property rights over its share of the societal endowment and in each period chooses on its own how to allocate it between investment in the public good (which is shared by all districts) and private consumption, taking as given the current and future strategies of the other districts. The total economy-wide investment in the public good in each period is then given by the sum of the district investments. In the second mechanism, the policy is taken by a centralized body, *the Legislature*, composed of a single representative from each district. The legislature is endowed with the power to tax and allocate revenues between a general public good and targeted transfers. Representatives bargain in the legislature over the allocation of resources. For both these mechanisms, we characterize the public policies that will result from a symmetric Markov perfect equilibrium, and we compare them with the optimal policy of a benevolent social planner.

The equilibrium generates predictions about how the dynamics of investment are affected by the political mechanism used to make these decisions. The equilibrium solution to the model implies that the legislative mechanism should generate a higher level of investment and a higher steady state of the public good than the autarky model. For both mechanisms, investment should start high and gradually decline until the steady state is reached. For both mechanisms, both the investment level along the transition path and the steady state are predicted to be substantially lower than in the benevolent planner's solution. These key predictions of the theory are confirmed by the experimental data. We do, however, observe some differerncces between the finer details of the theoretical predictions and the data. The clearest such deviation is a statistically significant overinvestment that characterizes the legislative model and, to a lesser extent, the autarchy model. This phenomenon is familiar from experiments on static public good provision, but is more subtle and complex in our dynamic setting.[1] The observed transition paths provide additional insights about strategic behavior under these mechanisms. For example, we observe a large initial overinvestment in the early rounds, followed by a significant disinvestment approaching the equilibrium steady state.

Overall, the findings are supportive of the equilibrium predictions, but with a few interesting exceptions. Consistent with the equilibrium of the

[1] In many static public goods experiments, overprovision relative to the equilibrium is observed. This is particularly the case where the equilibrium level of investment is 0. See the Ledyard (1996) survey. However, in experiments where the equilibrium level of investment is positive, the results are mixed, and sometimes very close to equilibrium or even underprovision. See, for example, Palfrey and Prisbrey (1996,1997), Palfrey and Rosenthal (1991), Holt and Laury (2008)

mechanisms, players are clearly forward looking, and the expected continuation value function are significant variables explaining voting behavior. However, we detect some evidence of non stationary behavior in proposals. For example, voters tend to punish past proposers who made proposals in a non-egalitarian way or "greedily" (by proposing policies that favor themselves). There is however little evidence that players have a memory for punishments longer than one period. The observed punishments apparently are not sufficiently powerful to enforce an efficient outcome; indeed more than being part of a "trigger strategy" equilibrium, they seem to follow from a myopic behavioral response, perhaps motivated by an aversion to non-egalitarian proposals. We conclude that observed behavior lies somewhat in between the prediction of a purely forward looking Markov equilibrium, and an equilibrium in which agents look back in a limited way at the past to punish "unfair" proposals, resulting in only slight increases in investment above equilibrium levels.

This work contributes primarily to a growing literature on dynamic political economy. Two papers are related to the institutional settings that we study. The first is Battaglini and Coate [2006], who have studied public good accumulation in a legislative model. As in Battaglini and Coate, in our model legislative bargaining is dynamic in the sense that the policy choice at t will affect utilities and choices in the following periods through a change of the state variable, the level of cumulated public good. Although the solution of our model maintains some features of the solution in Battaglini and Coate, the equilibrium is different because the bargaining protocol is different. We choose a different bargaining protocol to facilitate the experimental analysis. The second paper is Fershtman and Nitzan [1991] which studies a model similar to our autarky mechanism, except in the assumptions of continuous time and quadratic payoffs, and identifies the dynamic free riding effect. Neither of these two papers, however, provide a comparative study of different institutional settings; and, given the differences in the models, do not present results that can be directly compared, even from a qualitative point of view. These two papers, moreover, do not provide any empirical evidence about behavior, under the mechanisms.

The findings of this paper, however, contribute to the literature on dynamic political economy at a more general level. As mentioned, previous work in the dynamic political economy literature typically explores a single specific political mechanism in a dynamic environment,[2] rather than conducting a comparative analysis of alternative institutions as in this paper. More importantly, this paper takes a first step in providing experimental evidence about the empirical validity of the equilibrium predictions.[3] This evidence is particularly useful for assessing the comparative static predictions of the model, as well as various assumptions common in the literature, e.g., the assumptions of symmetry and stationarity of the equilibrium. Much of the literature has focused attention on Markov equilibria in which strategies depend only on a restricted number of state variables;[4] some previous work has also focused on Pareto efficient equilibria sustained by punishment strategies.[5] Our evidence allows us to provide an assessment of these model restrictions.

Finally, our work contributes to the experimental literature on public good provision. This literature has traditionally focused on static environments and identified a number of behavioral biases in public good contributions. In our work we contribute to documenting and qualifying the extent to which these biases extend to dynamic settings, and to the provision of *durable* public goods, where current investment decisions have long term effects on welfare.

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[2] Recent contributions in dynamic bargaining are Baron [2006], Battaglini and Coate [2006, 2008, 2009], Baron, Diermeier and Fong [2009], Diermeier and Fong [2009], Duggan and Kalandrakis [2008], Kalandrakis [2004, 2005], Penn [2009]. Dynamic models in which policies are determined by a median voter have recently been studied by Hassler, Rodriguez-Mora, Storesletten and Zilibotti [2003], Sleet and Yeltekin [2007]. Political agency models have been presented by Acemoglu, Golosov and Tsyvinsky [2006] and Yared [2007].

[3] Diermeier and Gailmard [2006], Diermeier and Morton [2006], Frechette, Kagel, Lehrer [2003], Frechette, Kagel, Morelli [2005], McKelvey [1991] provide important experimental analyses of legislative bargaining à la Baron and Ferejohn [1989], but in a *static* setting with purely distributive policies. Frechette, Kagel, Morelli [2009] extend the experimental analysis to policy spaces with public goods using a model by Volden and Wiseman [2006]. All of this works, however, limit the analysis to static environments in which only a single policy outcome is decided. Battaglini and Palfrey [2008] a simple *dynamic* model of legislative bargaining, but limit the analysis to purely distributive policies in which public goods cannot be accumulated.

[4] Among these there is Battaglini and Coate [2008, 2009], Baron, Diermeier and Pohan [2009], Duggan and Kalandrakis [2008], Hassler, Rodriguez-Mora, Storesletten and Zilibotti [2003].

[5] Among these: Acemoglu, Golosov and Tsyvinsky [2006], Yared [2007], Sleet and Yeltekin [2007].

2 The model

Consider an economy in which a continuum of infinitely lived citizens live in n districts and each district contains a mass one of citizens. There are two goods: private good x and a public good g. An allocation is an infinite nonnegative sequence of public policies, $z = (x_\infty, g_\infty)$ where $x_\infty = (x_1^1, ..., x_1^n, ..., x_t^1, ..., x_t^n, ...)$ and $g_\infty = (g_1, ..., g_t, ...)$. We refer to $z_t = (x_t, g_t)$ as the *public policy* in period t. The utility U^i of a representative citizen in district j is a function of $z^j = (x_\infty^j, g_\infty)$, where $x_\infty^j = (x_1^j, ..., x_t^j, ...)$ We assume that U^j can be written as:

$$U^j(z^j) = \sum_{t=1}^{\infty} \delta^{t-1} \left[x_t^j + u(g_t) \right],$$

where $u(\cdot)$ is continuously twice differentiable, strictly increasing, and strictly concave on $[0, \infty)$, with $\lim_{g \to 0^+} u'(g) = \infty$ and $\lim_{g \to \infty^+} u'(g) = 0$. The future is discounted at a rate δ.

There is a linear technology by which the private good can be used to produce public good, with a marginal rate of transformation p. The private consumption good is nondurable, the public good is durable, and the stock of the public good depreciates at a rate $d \in [0, 1]$ between periods. Thus, if the level of public good at time $t-1$ is g_{t-1} and the total investment in the public good is I_t, then the level of public good at time t will be

$$g_t = (1-d)g_{t-1} + I_t.$$

Because all citizens in district j are identical, we refer collectively to the "behavior of a district" as described by the behavior of a representative citizen j. Henceforth we will simply refer to district j. In period t, each district j is endowed with w_t^j units of private good, and we denote $W_t = \sum_{i=1}^{n} w_t^j$. Except where noted, we will restrict attention in this paper to *symmetric* economies, where $w_t^j = \frac{W_t}{n}$ $\forall j$, and $W_t = \mathrm{W} \forall t$. The initial stock of public good is $g_0 \geq 0$, an exogenous constant.

The *public policy* in period t is required to satisfy three feasibility conditions:

$$\begin{aligned} x_t^j &\geq 0 \ \forall j \\ I_t &\geq -g_{t-1} \ \forall t \\ I_t + \sum_{j=1}^{n} x_t^j &\leq W_t \ \forall t \end{aligned}$$

The first two conditions guarantee that allocations are nonnegative. The third condition requires that the current economy-wide budget is balanced. These conditions can be rewritten slightly. If we denote $y \equiv g_t = (1-d)g_{t-1} + I_t$ as the new level of public good after an investment I_t when the last period's level of the public good is g_{t-1}, then the public policy in period t can be represented by a vector $(y, x_t^1, ..., x_t^n)$. Dropping the t subscripts and substituting y, the budget balance constraint $I_t + \sum_{j=1}^{n} x_t^j \leq W_t$ can be rewritten as:

$$\sum_{j=1}^{n} x^j + p\left[y - (1-d)g\right] \leq W,$$

recalling that we use y to denote the post-investment level of public good attained in period t, and $(1-d)g$ for the pre-investment level of public good inherited from period $t-1$. The one-shot utility to district j from this public policy, $(y, x^1, ..., x^n)$, is $U^j = x^j + u(y)$.

Our interest in this paper is to compare the performance of different mechanisms for building public infrastructure, i.e., generating a feasible sequence of public policies, z. While more general formulations are possible, we will consider mechanisms that are time independent and have no commitment. That is, the mechanism is played in every period, the rules of the mechanism are the same in every period, and the outcome of the mechanism is a public policy for only the current period. In such mechanisms we will characterize the outcomes associated with symmetric Markov perfect equilibria.

3 The planner's problem

As a benchmark with which to compare the equilibria in mechanisms, we first analyze the sequence of public policies that would be chosen by a benevolent planner who maximizes the sum of utilities of the districts. This is the welfare optimum in this case because the private good enters linearly in each district's utility function. The planner's problem has a recursive representation in which g is the state variable, and $v_P(g)$, the planner's value function can be represented as:

$$v_P(g) = \max_{y,x} \left\{ \begin{array}{c} X + nu(y) + \delta v_p(y) \\ s.t \quad X + y - (1-d)g \leq W, \ X \geq 0 \ , y \geq 0 \end{array} \right\} \qquad (1)$$

where $X = \sum_{j=1}^{n} x^i$. is the sum of private transfers to the districts, and $v_P(g)$ is the planner's value function. By standard methods (see Stokey and Lucas [1989]) we can show that a continuous, concave and differentiable $v_P(g)$ that satisfies (1) exists and is unique.

Since we can assume without loss of generality that the budget constraint, $X + y - (1-d)g \leq W$, is binding and $y \geq 0$ is never binding,[6] we can rewrite the planner's problem as:

$$\max_y \left\{ \begin{array}{c} W + (1-d)g - y + nu(y) + \delta v_P(y) \\ X = W + (1-d)g - y \geq 0. \end{array} \right\} \tag{2}$$

The optimal policy $y_P(g)$ can be characterized by studying (2). Depending on whether the constraint is binding, there are two possible cases. In the first case, where it is binding, the planner would like to invest an amount I (which equals $y-$ $(1-d)g$, by definition) greater than W but cannot because of the constraint. Thus, the solution is this case is $y_P(g) = W + (1-d)g$, and $X_P(g) = 0$. In the second case, the constraint is not binding and the unconstrained optimization yields $y_P(g) \leq W + (1-d)g$ and $X_P(g) > 0$. In this case a necessary condition for $y_P(g)$ is characterized by the first order equation:

$$nu'(y_P(g)) + \delta v_P'(y_P(g)) = 1$$

By the concavity of u and v_P, the second order condition is satisfied, and furthermore the first order condition has a unique solution for $y_P(g)$, independent of g, which we denote y_P^*.

This implies the following simple rule-of-thumb optimal policy for investing in the public good as a function of its current level g. For any values of g such that $y_P^* - (1-d)g \leq W$, invest $I_P(g) = y_P^* - (1-d)g$ and total private good consumption is $X_P(g) = W + (1-d)g - y_P^*$. For any values of g such that $y_P^* - (1-d)g > W$, invest $I_P(g) = W$ and private good consumption is $X_P(g) = 0$. This second case is possible only if $y_P^* - (1-d)g \geq W$, i.e., if g is lower or equal to a threshold g_P:

$$g_P = \max \left\{ \frac{y_P^* - W}{1-d}, 0 \right\}$$

We summarize the above argument as Proposition 1, below:

[6] The constraint $y \geq 0$ is never binding because $\lim_{g \to 0^+} u'(g) = \infty$.

Proposition 1. *The optimal solution to the planner's problem is uniquely characterized by a* y_P^* *solving* $nu'(y_P^*)+\delta v'_P(y_P^*)=1$ *and an investment policy function* $I_P(g)=\min\{W, y_P^*-(1-d)g\}$*.*

This implies that the optimal public policy is time independent and given by $((X_P(g), y_P(g))$,where:

$$y_P(g) = \min\{W+(1-d)g, y_P^*\} \quad \text{and} \tag{3}$$
$$X_P(g) = W - \min\{W, y_P^*-(1-d)g\} \tag{4}$$

Clearly in a symmetric solution each district would receive $x_P^j(g)=\frac{X_P(g)}{n}$, but any other division is equally efficient for an utilitarian planner. Formulas (3) and (4) have a clear intuition. When the state g is sufficiently low, the planner invests all currently available resources (W) in the public good: this is because the marginal value of an additional unit of the public good is so high that each dollar invested in the public good yields more than a dollar in value. For $g>\frac{y_P^*-W}{1-d}$, however, the marginal value of the public good investment is lower than 1, so it is more valuable to leave some resources to the districts for private consumption. In this region of g, the planner expends resources just enough to cover depreciation and maintain the level of the public good at y_P^*, where the marginal value of investment is exactly 1. Note that if for some reason the stock of public good at period $t-1$ is equal to $g>\frac{y_P^*}{1-d}$,[7] then optimal investment is negative in period t. For future reference, when we will compare this solution with the equilibria in the political systems, it is interesting to note that this investment function $I_P(g)$ is (weakly) monotone decreasing in g.

[Figure 1 here]

From Proposition 1, one can see that there can actually be two types of equilibria, depending on how high the optimal steady state, y_P^*, is relative to the parameters of the model $\{n, W, d, \alpha, \delta\}$. The steady state is at the intersection point between the 45^o line and the investment curve (3). This is illustrated in Figure 1. The first case, shown in the left panel of the figure is when the steady state is $g_P=y_P^*=y(g_P)$ and, therefore, $X(g_P)>0$. The second case is when the steady state g_P satisfies $g_P=y(g_P)<y_P^*$. In this

[7] For example, it could be that $g_0>\frac{y_p^*-W}{1-d}$.

case $W + (1-d)g = g$, so $g_P = W/d$ and $X(g_P) = 0$. If $g_P \leq y_P^*$, then $y_P(g)$ crosses the 45^o degree line on the right of g_P. In this case the steady state is y_P^*. If $g_P > y_P^*$, then the steady state is on the left of g_P and lower than y_P^*.

To illustrate the planner's solution, we derive the analytical solution for the case when the utility function is given by $u(y) = B\frac{1}{\alpha}y^\alpha$. In the Appendix we show that:

Proposition 2. Let $u(y) = B\frac{1}{\alpha}y^\alpha$. *If* $1 - \delta(1-d) > Bn\left(\frac{d}{W}\right)^{1-\alpha}$, *the long run steady state in the planner's solution is* $g_P = \left(\frac{Bn}{1-\delta(1-d)}\right)^{\frac{1}{1-\alpha}} = y_P^*$. *If* $1 - \delta(1-d) \leq Bn\left(\frac{d}{W}\right)^{1-\alpha}$ *the steady state is* $g_P = \frac{W}{d} < y_P^*$.

This result gives us a complete characterization of the equilibrium dynamics and long term behavior. When the economy has relatively large resources as measured by W (i.e. $1 - \delta(1-d) > Bn\left(\frac{d}{W}\right)^{1-\alpha}$) eventually the level of the public good will reach a saturation point at which its marginal value is equal to the marginal utility of consumption (*one*), and the steady state is y_P^*. When $1 - \delta(1-d) \leq Bn\left(\frac{d}{W}\right)^{1-\alpha}$ this optimal saturation point, y_P^*, will never be reached if one starts at $g_0 = 0$. Depreciation is too high compared to W for the saturation point to ever be reached ($\frac{W}{d} < y_P^*$). The actual time path depends on initial conditions. In both cases investment in public goods is a non decreasing function of g: It is constant ($= W$) for low values of $g \leq g_P = \max\left\{\frac{y_P^* - W}{1-d}, 0\right\}$, and strictly decreasing above g_P.

An immediate corollary of Proposition 2 that will be useful in the experimental application is that if $d = 0$, then we are always in the first case, and the steady state is $\left(\frac{Bn}{1-\delta}\right)^{\frac{1}{1-\alpha}}$.

4 Political Mechanisms for Building Public Infrastructure

The set of possible mechanisms to implement sequences of public policies is obviously huge. We limit ourselves to two different types of mechanisms.

The first is a purely decentralized mechanism, which we call *Autarky*, whereby each district retains full property rights over a share of the endowment ($\frac{W}{n}$) and in each period chooses on its own how to allocate its endowment between investment in the public good (which is shared by all districts) and private consumption, taking as given the strategies of the other districts.

The total economy-wide investment in the public good in any period is then given by the sum of the district investments.

The second type of mechanism we consider is a bargaining mechanism for a centralized economy-wide representative legislature, which we call the *Legislative* mechanism. In this mechanism, each district cedes its property right over its share of the economy wide endowment in exchange for $1/n$ representation in the legislature. In each period, the legislature decides on a uniform lump sum tax on all districts, which cannot exceed a district's endowment, W/n, and a level of investment in the public good. The legislative policy also includes an allocation of the budgetary surplus (tax revenue minus investment) to the districts, which is non-negative for all districts, but not necessarily uniform. Investment can be negative, but the amount of negative investment cannot exceed the current stock of public good. Thus, as before, we can represent a policy by the legislature at time t, by an public policy $(x_t^1, ..., x_t^n, y_t)$ that satisfies the same feasibility constraints as in the planner's problem. The bargaining protocol with which a public policy is chosen in a legislature is as follows. At the beginning of each period an agent is chosen by nature to propose a policy $(x^1, ..., x^n, y)$. Each legislator has the same probability to be recognized as proposer. If at least q legislators vote in favor of the proposal, it passes and it is implemented. The legislature then adjourns and meets in the following period with a new level of public good y. If instead the policy does not receive a qualified majority, then the status quo policy is implemented. We assume that the status quo is zero taxation, which implies zero investment in public goods and so $x^j = W/n$ for all j. The legislature, moreover, adjourns and meets in the following period with a new level of public good $(1-d)g$.[8].

We study the equilibria of these two equilibria in the next two subsections.

4.1 *Decentralized Provision*: The Autarky Mechanism

To study the properties of the Autarky mechanism we focus on symmetric Markov-perfect equilibria, where all districts use the same strategy, and these strategies are time-independent functions of the state, g. A strategy is a pair

[8]This bargaining protocol differs from the protocol adopted in Battaglini and Coate [2008]. There if no agreement is reached in the previous attempts, a new legislator is randomly selected to make a proposal for at least T times. In the last stage of the bargaining game, a legislator is chosen to make a default proposal that must treat all the legislators identically.

$(x_A(\cdot), i_A(\cdot))$: where $x_A(g)$ is the level of consumption in the district and $i_A(g)$ is a district's level of investment in the public good in state g. Given these strategies, by symmetry the public good in state g is $y_A(g) = (1-d)g + ni_A(g)$. Associated with any equilibrium is a value function $v_A(g)$ which specifies the expected discounted future payoff to a legislator when the state is g. In the remainder we focus on an equilibrium in which v_A is concave. Proposition 3 shows that such an equilibrium exists for the range of parameters of interest for the experiment.

The optimization problem for district j if the current level of public good is g, and the district's value function is $v_A(y)$ is:

$$\max_{y,x} \left\{ \begin{array}{c} x + u(y) + \delta v_A(y) \\ s.t \;\; x + y - (1-d)g = W - (n-1)x_A(g) \\ W - (n-1)x_A(g) + (1-d)g - y \geq 0 \\ x \leq (1-d)g/n + W/n \end{array} \right\} \tag{5}$$

where y is the new level of public good and x is private consumption: district j realizes that given the other districts' contributions, his/her investment ultimately determines y. The first constraint is a rewritten form of $I_A(g)+x = W$, substituting out for $I_A(g)$ (where $I_A(g)$ is the total investment $ni_A(g)$) The second constraint is derived from $x_A(g) \geq 0$. The third constraint is derived from $I_A(g) \geq -\frac{(1-d)g}{n}$; it requires that no legislator can reduce $y_A(g)$ by more than his share $(1-d)g/n$.[9] Note that since $x_A(g)$ is an endogenous variable that depends on v_A, (5) is not necessarily a contraction. The proposer, however, takes $x_A(g)$ as given.

Depending on the state g the solution of (5) falls in one of two cases: we may have $W+(1-d)g = y_A(g)+(n-1)x_A(g)$, so $x_A(g) = 0$; or $W+(1-d)g > y_A(g) + (n-1)x_A(g)$, so $x_A(g) > 0$.

If v_A is concave, then in the latter case the solution is characterized by a unique public good level y_A^* satisfying the first order equation:

$$u'(y_A^*) + \delta v_A'(y_A^*) = 1 \tag{6}$$

The investment by each district is equal to $i_A(g) = \frac{1}{n}\left[y_A^* - (1-d)g\right]$ and per capita private consumption is $x_A(g) = \frac{W+(1-d)g-y_A^*}{n}$.

[9] Legislators choose $y_A(g) \geq g$ for any g that is reached on the equilibrium path when the initial level g_0 is below the steady state. As in the legislative model, however, legislators can reduce it if they want. In a decentralized system as the VC game, $y \geq \frac{n-1}{n}g$ guarantees that (out of equilibrium) the sum of reductions in g can not be larger than the stock of g.

In the other possible case, if $x_A(g) = 0$, then $y_A(g) = W + (1-d)g$ and investment by each district is $i_A(g) = \frac{W}{n}$. This second condition is possible only if and only if $W \leq y_A^* - (1-d)g_A$, that is if g is below some threshold g_A defined by:

$$g_A = \max\left\{\frac{y_A^* - W}{1-d}, 0\right\}$$

We summarize this in the following proposition, which also provides sufficient conditions for v_A to be concave:

Proposition 3. *A concave equilibrium exists. In a concave equilibrium of the Autarky game, public investment is:* $y_A(g) = \min\{W + (1-d)g, y_A^*\}$.

The public good function $y_A(g)$ is qualitatively similar to the corresponding planner's function $y_P(g)$. The main difference is that $y_A^* < y_P^*$ and $g_A < g_P$, so public good provision is typically smaller (and always smaller in the steady state). This is a dynamic version of the usual free rider problem associated with public good provision: each agent invests less than is socially optimal because he/she fails to fully internalize all legislators' utilities. Part of the free rider problem can be seen from (6): in choosing investment, legislators count only the marginal benefit to their district, $u'(y) + \delta v_A'(y)$, rather than $nu'(y) + \delta n v_A'(y))$, but all the marginal costs (-1). In this dynamic model, however, there is an additional effect that reduces incentives to invest, called *dynamic free riding.*[10] To see this, consider the value function for $g > g_A$ (where we have an interior solution):

$$\begin{aligned} v(g) &= W - (n-1)x_A(g) - (y_A^* - (1-d)g) + u(y_A^*) + \delta v_A(y_A^*) \\ &= \frac{W - (y_A^* - (1-d)g)}{n} + u(y_A^*) + \delta v_A(y_A^*) \end{aligned}$$

where the last equation follows by the fact that in a symmetric equilibrium: $x_A(g) = W - (n-1)x_A(g) - (y_A^* - (1-d)g)$. A marginal increase in g has two effects. An immediate effect, corresponding to the increase in resources available in the following period: $(1-d)g$. But there is also a delayed effect on next period's investment: the increase in g triggers a reduction in the future investment of all the other districts through an increase in $x_A(g)$: for any level of $g > g_A$, $y_A(g)$ will be kept at y_A^*. In a symmetric equilibrium, if district j increases the investment by 1 dollar, he will trigger a reduction in

[10] The same dynamic free riding effect arises in the Fershtman and Nitzan (1991) model.

future investment by all future districts by $1/n$ dollars; the net value of the increase in g for j will be only δ/n.

Proposition 4. Let $u(y) = B\frac{1}{\alpha}y^{\alpha}$. *If* $n - \delta(1-d) > Bn\left(\frac{d}{W}\right)^{1-\alpha}$, *there is an equilibrium in which the long run steady state in the Autarky mechanism is* $y_A^* = \left(\frac{Bn}{n-\delta(1-d)}\right)^{\frac{1}{1-\alpha}}$. *If* $n - \delta(1-d) \leq Bn\left(\frac{d}{W}\right)^{1-\alpha}$ *the steady state is* $g_A = \frac{W}{d} < y_A^*$.

In the experiment we assume $u(y) = B\frac{1}{\alpha}y^{\alpha}$ and (as in the legislative game) $\alpha = 0.5$, $d = 0$, $\delta = .75$, $B = 1$. Two treatments are considered, corresponding to the similar treatments in the legislative game: $n = 3$, $W = 15$; and $n = 5$, $W = 20$. For both these parameterization, we obtain that $g_A = 0$; moreover y_A^* is equal to $\left(\frac{4}{3}\right)^2$ in the $n = 3$ case, and to $\left(\frac{20}{17}\right)^2$ in the $n = 5$ case.

4.2 *Centralized Provision*: The Legislative (L) Mechanism

As in the previous section, to characterize behavior when policies are chosen by a legislature we look for a symmetric Markov perfect equilibrium. In this type of equilibrium any representative selected to propose at some time t uses the same strategy, and this depends only on the current stock of public good (g). Similarly, the probability a legislator votes for a proposal depends only on the proposal itself and the state g. As is standard in the theory of legislative voting, we focus on weakly stage-undominated strategies, which implies that legislators vote for a proposal if they prefer it (weakly) to the status quo. Without loss of generality, we focus on an equilibrium in which proposals are accepted with probability one.

As it is easy to verify, in a symmetric Markov equilibrium, a proposer would either make no monetary transfer to the other districts, or would make a transfer only to $q-1$ legislators, selected randomly each with the same probability of being selected. An equilibrium can therefore be described by a collection of functions $\{y_L(g), s_L(g)\}$ that specifies the choice made by the proposer in a period in which the state is g. Here $y_L(g)$ is the proposed new level of public good and $s_L(g)$ is a transfer offered to the districts of the $q-1$ randomly selected representatives. The proposer's district receives the surplus revenues $x_L(g) = W - y_L(g) + (1-d)g - (q-1)s_L(g)$. Associated with any symmetric Markov perfect equilibrium in the L game is a value function $v_L(g)$ which specifies the expected future payoff of a legislator when the state is g.

Contrary to the Planner's case of the previous section, the policy is now chosen by a self interested proposer who maximizes the utility of his own district. Given v_L, the proposer's problem is:

$$\max_{x,y,s}\left\{\begin{array}{c} x+u(y)+\delta v_L(y) \\ s.t \quad s+u(y)+\delta v_L(y)\geq \frac{W}{n}+u\left[g(1-d)\right]+\delta v_L(g(1-d)) \\ (q-1)s+x+y-(1-d)g\leq W \\ x\geq 0, s\geq 0 \end{array}\right\} \tag{7}$$

where x is the transfer to the proposer. This problem is similar to the planner's problem (2): the second inequality is the budget balance constraint, and the last two inequalities are the feasibility constraints.[11] The first inequality is however new: it is the incentive compatibility constraint that needs to be satisfied if a proposal is to be accepted by $q-1$ other districts.

The solution to (7) is complicated by the fact that the set of binding constraints is state dependent and the value function is not typically concave in g. Because of this we do not have a general existence proof of a pure strategy equilibrium of this game. For the parameters of the experiment, however, a pure strategy equilibrium in which the value function is non-decreasing in g exists and can be easily computed. The algorithm that we use to compute the equilibrium exploits the fact that, as shown in the appendix, given a value function v the optimal reaction function can be represented as a function of two constants y_1^* and y_2^*, with $y_2^* > y_1^*$ when W is sufficiently large (as in the experiments):

$$y_L(g)=\left\{\begin{array}{cc} y_1^* & g\leq g_1(y_1^*) \\ \widetilde{y}(g) & g\in(g_1(y_1^*),g_2(y_2^*)] \\ y_2^* & else \end{array}\right. \tag{8}$$

$$s_L(g)=\max\left\{0,\frac{W}{n}+\Psi\left(g(1-d)\right)-\Psi\left(y_2^*\right)\right\} \tag{9}$$

where $g_1(y_1^*)$, $g_2(y_1^*)$ and $\widetilde{y}(g)$ are given functions of y_1^* and y_2^* and g that we specify in the appendix, and $\Psi(x)=u(x)+\delta v_L(x)$. For $g\leq g_1(y_1^*)$ the proposer acts as if the other districts did not exist: he diverts resources only

[11] It can be verified that the constraint $y\geq 0$ is never binding and therefore it can be ignored without loss of generality.

toward his own district and chooses the investment without internalizing the other districts' welfare. This implies that the proposer can choose y such that

$$y_1^* \in \arg\max_y \{u(y) - y + \delta v_L(y)\} \tag{10}$$

The other districts accept this policy because the investment y_1^*, is sufficiently high to make this policy better than the status quo. When $g \geq g_1(y_1^*)$, the proposer can not afford to ignore the other districts. He first finds it optimal to "buy" their approval by increasing g and investing $\widetilde{y}(g) > y_1^*$ (in the interval $(g_1(y_1^*), g_2(y_2^*)]$): $\widetilde{y}(g)$ is chosen large enough to satisfy the incentive compatibility constraint as an equality. For $g > g_2(y_2^*)$, however, the proposer finds it optimal to provide pork to a minimal winning coalition of districts, and to invest y_2^*. In choosing y, now the proposer must internalize the utility of q legislators, so:

$$y_2^* \in \arg\max_y \{qu(y) - y + \delta q v_L(y)\} \tag{11}$$

To compute an equilibrium we note that there is a two way relationship between the equilibrium value v_L and y_1^*,y_2^*. First, using (8) and (9) we can represent the value function as a function only of y_1^*, y_2^*:[12]

$$v_L(g) = \begin{cases} \frac{1}{n}\left[W - [y_1^* - (1-d)g]\right] + u(y_1^*) + \delta v_L(y_1^*)) & g \leq g_1(y_1^*) \\ \frac{1}{n}\left[W - [\widetilde{y}(g) - (1-d)g]\right] + u(\widetilde{y}(g)) + \delta v_L(\widetilde{y}(g))) & g \in (g_1(y_1^*), g_2(y_2^*)] \\ \frac{1}{n}\left[W - [y_2^* - (1-d)g]\right] + u(y_2^*) + \delta v_L(y_2^*) & else \end{cases} \tag{12}$$

Second, given a value function v_L, we can find y_1^*, y_2^* by solving (10) and (11). If we assume that the state space G is finite with states m, then, for a given y_1^*, y_2^*, (12) is a system of m equations in m unknowns: we can then easily solve for a function $v(g; y_1^*, y_2^*)$. Given this $v(g; y_1^*, y_2^*)$, we can find the (new) optimal y_1^*, y_2^* using (12). An equilibrium corresponds to a fixed point of this

[12] To write the value function for $g \geq g_2$ note that in this range the value function of a proposer is: $W - [y_2^* - (1-d)g] - (q-1)\left[\frac{W}{n} + \Psi((1-d)g) - \Psi(y_2^*)\right] + \Psi(y_A^*)$ and the probability of being a proposer is $1/n$. The value of a legislator who receive pork transfers, on the other hand, is $\left[\frac{W}{n} + \Psi((1-d)g) - \Psi(y_A^*)\right] + \Psi(y_A^*)$, and the probability of receiving a transfer $s(g)$ conditional on not being a proposer is $(q-1)/(n-1)$. Finally, the value of a legislator excluded from transfers is simply $\Psi(y_A^*)$, and the probability of being in this state conditional on not being a proposer is $1 - (q-1)/(n-1)$. The expression in (12) follows from these expressions by taking expectations. The other cases can be computed in a similar way.

correspondence that maps $\Re^2_+$ to itself.

[Figure 2 here]

Figure 2 provides a representation of the equilibrium for one of the two parameter configurations that we use in the experiment (the other case is qualitatively analogous[13]). In all experiments we assume $u(y) = B\frac{1}{\alpha}y^\alpha$ with $\alpha = 0.5$, $B = 1$, $d = 0$, and $\delta = .75$.

Proposition 5. Let $u(y) = B\frac{1}{\alpha}y^\alpha$. *If* $d = 0$, *in equilibrium the steady state in the Legislative mechanism is* $y_L^* = y_2^* = \left(\frac{Bn}{\frac{n}{q}-\delta(1-d)}\right)^{\frac{1}{1-\alpha}}$.

The two treatments are: $n = 3$, $q = 2$, $W = 15$; and $n = 5$, $q = 3$, $W = 20$. In both cases $y_L^* = y_2^* = \left(\frac{Bn}{\frac{n}{q}-(1-d)\delta}\right)^{\frac{1}{1-\alpha}}$: so in the case with $n = 3$ we have $y_2^* = 16$, and in the case with $n = 5$ we have $y_2^* \approx 30$. The figure is for the case with $n = 3$.

The first panel of Figure 2 represents the investment function $I_L(g)$:

$$I_L(g) = \begin{cases} y_1^* - (1-d)g & g \leq g_1 \\ \widetilde{y}(g) - (1-d)g & g \in (g_1, g_2] \\ y_2^* - (1-d)g & else \end{cases} \tag{13}$$

(where for simplicity g_1 is the equilibrium value $g_1(y_1^*)$, and similarly for g_2). It is interesting to note that while in the planner's $I_P(g)$ is a monotonically (weakly) decreasing function (compare (13) with the expression in Proposition 1), in the political equilibrium $I_L(g)$ is not monotonic. The non-monotonicity of the investment function is a consequence of the fact that the incentive compatibility constraint is not always binding and that the value of the status quo is endogenous. When g is small the marginal value of the public good is high. The cost if the bargaining proposal fails is therefore high. In this case the proposer can implement his preferred policy ignoring the incentive compatibility constraint. When this happens (in $g \leq g_1$), the proposer will not accumulate more than y_1^* (except, of course, if forced by the incentive compatibility constraint). When $g \geq g_1$, however, the proposer is forced to internalize the utility of at least a minimal winning coalition of other legislators: and so it will have to invest until the marginal utility of g is at least $1/q$. The final range in which investment is declining linearly corresponds to the region in which accumulating more than y_2^* is not profitable

[13] See Table 1 for details on the equilibrium values for both cases.

even when the $q-1$ utilities of the other members of the minimal winning coalition are internalized (which, not surprisingly, occurs for a much higher level of g).

The second panel of Figure 2 shows the equilibrium proposed level of the public good, as a function of the state, $y_L(g)$. This curve fully describes the dynamics of public good provision and the steady state. The steady state level of public good g^* corresponds to the point where the 45^o line intersects the investment curve. We can have different types of steady states and corresponding equilibria. If $g^* \leq g_2$, in the steady state the proposer can extract transfers from his district without paying any transfer to the other districts; if $g^* > g_2$, instead, in the steady state there is always a minimal winning coalition of legislators who receive positive transfers for their own districts. In Figure 2, as in all our experiments, the steady state is indeed in this case, so $g^* = y_2^*$.

The panels representing the value function and $y_L(g)$ makes clear the complications involved with computing and studying the equilibrium. When g passes from the region in which the incentive compatibility constraint is not binding to the region with a binding incentive compatibility constraint, the expected marginal value of g increases, because the incentive compatibility constraint forces the proposer to internalize the utility of more agents. As can be seen from Figure 2, investment in g increases, thereby reducing the inefficiency, and the value function becomes non concave.

5 Experimental Design

The experiments were all conducted at the Social Science Experimental Laboratory (SSEL) using students from the California Institute of Technology. Subjects were recruited from a pool of volunteer subjects, maintained by SSEL. Eight sessions were run, using a total of 102 subjects. No subject participated in more than one session. Half of the sessions used the Legislative mechanism with simple majority rule, and half used the Autarky mechanism. Half were conducted using 3 person committees, and half with 5 person committees. In all sessions there was zero depreciation ($d = 0$), the discount factor was $\delta = 0.75$, and the current-round payoff from the public good was proportional to the square root of the stock at the end of that round ($\alpha = .5$). In the 3 person committees, we used the parameters $W = 15$, while in the 5 person committees $W = 20$. Payoffs were renormalized so subjects could trade in fractional amounts. Table 1 summarizes the theoretical properties of the equilibrium for the four treatments.

[Table 1 here]

Discounted payoffs were induced by a random termination rule by rolling a die after each round in front of the room, with the outcome determining whether the game continued to another round (with probability δ) or was terminated (with probability $1-\delta$). The $n = 5$ sessions were conducted with 15 subjects, divided into 3 committees of 5 members each. The $n = 3$ sessions were conducted with 12 subjects, divided into 4 committees of 3 members each.[14] Committees stayed the same throughout the rounds of a given match, and subjects were randomly rematched into committees between matches. A match consisted of one multiround play of the game which continued until one of the die rolls eventually ended the match. As a result, different matches lasted for different lengths. Table 2 summarizes the design.

[Table 2 here]

Before the first match, instructions[15] were read aloud, followed by a practice match and a comprehension quiz to verify that subjects understood the details of the environment including how to compute payoffs. The current round's payoffs from the public good stock (called *project size* in the experiment) was displayed graphically, with stock of public good on the horizontal axis and the payoff on the vertical axis. The sample screen in the appendix illustrates this. Subjects could click anywhere on the curve and the payoff for that level of public good appeared on the screen.

For the bargaining/voting mechanism each round had two separate stages, the proposal stage and the voting stage. At the beginning of each match, each member of a committee was randomly assigned a committee member number which stayed the same for all rounds of the match. In the proposal stage, each member of the committee submitted a *provisional budget* for how to divide the budget between the public good, called *project investment*, and private allocations to each member. After everyone had submitted a proposal, one was randomly selected and became the *proposed budget.* Members were also informed of the committee member number of the proposer, but not informed

[14] Two of the $N = 3$ sessions used 9 subjects.

[15] Instructions from one of the sessions are in the appendix.

about the unselected provisional budgets. Each member then cast a vote either for the proposed budget or for the *backup budget* with zero public investment and equal private allocations. The proposed budget passed if and only if it received at least $\frac{n+1}{2}$ votes. Payoffs for that round were added to each subject's earnings and a die was rolled to determine whether the match continued to the next round. If it did continue, then the end-of-round project size became the next round's beginning-of-round project size.

At the end of the last match each subject was paid privately in cash the sum of his or her earnings over all matches plus a showup fee of $10. Earnings ranged from approximately $20 to $50, with sessions lasting between one and two hours. There was considerable range in the earnings and length across sessions because of the random stopping rule.

6 Experimental Results

6.1 Time series of the stock of public good

Figure 3 shows the time series of the stock of public good by treatment.[16] The horizontal axis is the time period and the vertical axis is the stock of the public good. In order to aggregate across committees, we use the median level of the public good from all committees in a given treatment. Similar results hold if we use the mean or other measures of central tendency. Superimposed on the graphs are the theoretical time paths (represented with solid lines), corresponding to the Markov perfect equilibrium.

[Figure 3 here]

These time paths exhibit several systematic regularities, which we discuss below in comparison with the theoretical time paths.

1. **FINDING 1. The Legislative mechanism leads to much greater public good production than the Autarky mechanism.** The median stock of public good is greater in the L mechanism than the A mechanism in every single period in the n=3 and n=5 treatments. With three districts, the median stock of public good is more than five

[16] These and subsequent figures show data from the first ten rounds. Data from later rounds are excluded from the graphs because there were so few observations. The data from later rounds are included in all the statistical analyses.

times greater in the L3 treatment than the A3 treatment, averaged across all 13 rounds for which we have data (31.3 vs. 5.6). In 4 of the 13 rounds, the stock of public good in the L3 is more than 10 times greater than in the A3 treatment. The difference is also very large for the five district treatments. The median stock of public good is more than three times greater in the L5 treatment than the A5 treatment, averaged across all 10 rounds for which we have data (34.7 vs. 9.6). The differences between the L and the A mechanisms are relatively small in the initial round, but they increase sharply as more rounds are played. By round 10, the gaps in the median stock of public good are very large (26.2 vs. 2.5 for three districts and 30.3 vs. 5.5 for five districts).

2. **FINDING 2. Both mechanisms lead to public good levels significantly below the optimal steady state.** The optimal steady state is y*=144 for the three district treatments and y*=400 for the five district treatments. The optimal investment policy is the fastest approach: invest W in every period until y* is achieved. In the L mechanism, the stock of public good levels out at about 30 in both treatments. The median stock averages 30.1 in rounds 7-10 in L3, and 31.8 in rounds 7-10 in L5. *These very inefficient long run public good levels in the L treatment occur in spite of initial round median investment that is fully efficient, with I=W in both treatments.* In the A mechanism, the stock of public good levels out in the single digits in both treatments. The median stock averages 3.8 in rounds 3-10 for A3, and 7.9 in rounds 3-10 for A5.

3. **FINDING 3. In both mechanisms, there is overinvestment relative to the equilibrium in the early rounds, followed by significant disinvestment, approaching the steady state.** The median investment in the first three rounds of L3 are 15,11.2, and 7.2. As a result the median public good stock by the end of round 3 equals 33.4. This compares with the equilibrium investment policies in the first three rounds equal to 5,8, and 3, and a level of stock equal to 16. Thus, in L3, committees overshoot the equilibrium in early rounds by a factor of two. The scenario in early rounds is similar in L5. The median investment in the first three rounds of L5 are 20,10.7, and 9.3. As a result the median public good stock by the end of round

3 equals 40. This compares with the equilibrium investment policies in the first three rounds of L5 equal to 7.8,5, and 7.7, and a level of stock equal to 20.5. Thus, in L5, committees also overshoot the equilibrium in early rounds by a factor of two. This overshooting is largely corrected in later rounds. The stock of public good then declines over the later rounds. In the L5 treatment, convergence is especially close to equilibrium, with the difference between the median public good levels and the equilibrium public good levels in the last 4 rounds of data measuring less than 2 units of the public good (31.79 vs. 29.83). A similar pattern of overshooting in the A mechanisms is also evident. The median aggregate investment in the first two rounds of A3 are 7.9 and 3.5. As a result the median public good stock by the end of round 2 equals 11.4. This compares with the equilibrium aggregate investment in the first two rounds equal to 1.8 and 0, with a equilibrium level of stock at the end of round 2 equal to 1.8. The median aggregate investment in the first two rounds of A5 are 12.6 and 4.1. As a result the median public good stock by the end of round 2 equals 16.8. This compares with the equilibrium aggregate investment in the first two rounds equal to 1.4 and 0, with a equilibrium level of stock at the end of round 2 equal to 1.4. Beginning in round 3, the stock of public good in both A treatments declines sharply, with the median public good stock averaging 3.8 in rounds 3-10 of the A3 treatment and 7.9 in rounds 3-10 of the A5 treatment.

4. **FINDING 4. The L mechanism leads to lower levels of the durable public good for n=3 than n=5.** The stock of public good in L3 is predicted to be less than L5 in every round, and we find that the median stock of public good is less in 8 out of 10 rounds. For L5, equilibrium is equal to 29.8, and this closely approached in the long run (median in round 10 equals 30.3). For L3, equilibrium is equal to 16, and after overshooting, declines to about 26 in round 10. This is less than what we observe in the L5 groups, but still somewhat above the equilibrium long run stead state of 16.

5. **FINDING 5. The A mechanism leads to lower levels of the durable public good for n=3 than n=5.** The median level of public good is less in all of the first 10 rounds of the A3 treatment, compared to the A5 treatment. The differences, however, are not large

in magnitued. In the last three rounds for which we have data for both treatments (rounds 11-13), the difference is negligible (less than 1.2 units of the public good).

6.2 Proposed public good investment

The data consisting of proposed public good investment is somewhat richer than the data for the stock of public good, because our design was able to elicit proposals from non-proposers as well as proposers. (The proposal data also includes some failed proposals.). The results mirror the data for the state variable, y. Early round proposals offer significant overinvestment relatively to equilibrium, declining to equilibrium levels in later rounds. See figure 4.

[Figure 4 here]

6.3 Coalitions: Types of proposals

We now turn to the analysis of the proposed allocation of pork, as a function of g and n in the L mechanism. Tables 3-4 display a categorization of the proposal types, and their acceptance rates. For this analysis we focus primarily on the number of members receiving significant amounts of pork in the proposed allocation, and whether the proposals had negative investment in the public good. We break down the proposed allocations into 4 canonical types. These types are: (1) *Invest W*: 100% allocation to the public investment; (2)*Proposer only*: The allocation divided between public investment and private consumption of the proposer only; (3)*Minimum Winning Coalition (MWC)*: The allocation divided between public investment and a minimum winning coalition that includes the proposer (2 if n=3; 3 if n=5); (4)*Universal*: Positive private allocations to all n members.[17] The last two categories are further broken down by whether investment in the public good is positive, zero, or negative.

[Tables 3 and 4 here]

The first column of the table lists the various proposal types. The second column lists the number of observations of each proposal type. There are two

[17]For L5, there is a fifth residual category, not shown in the table, where pork is offered to exactly 4 members. There were only 14 such proposals observed and the acceptance rate was 100%.

numbers in this column: the number in parenthesis gives the total number of proposals of this type *that were actually voted on*. The other number is the total number of provisional budget proposals of this type. Because of the random recognition rule, in L3 there are three times as many provisional budget proposals as budget proposals that are actually voted on. For L5 there are five times as many provisional budget proposals as budget proposals that are actually voted on. The final column gives the proportion of proposals of each type that passed when they were voted on.

FINDING 6. Most proposals are either (i) invest the entire budget; or (ii) universal private allocations with positive investment.

In both L3 and L5, most proposals were to either invest W or universal allocations with a positive amount of investment. In L3, these two proposal types account for 75% of all budget proposals (including provisional budget proposals); in L5, these two types account for 63%. Of the remaining proposals, approximately half were MWC proposals (17% of all provisional budgets in L5 committees and 12% in L3 committees). Proposals that offered private allocation to the proposer only were quite rare in both treatments. Proposals with zero or negative investment occured 21% of the time in L5 committees and 16% of the time in L3 committees. In contrast to the data, the Markov perfect equilibrium proposals should have been concentrated in the two categories: "proposer only" and MWC.

6.4 Voting Behavior

Tables 3-4 also display the probability the proposal passes for each type of proposal. Tables 5-6 display additional results about voting outcomes in the $L3$ and $L5$ treatments respectively. The top part of the each table shows the proposal passage probabilities as a function of round. The middle part of each table shows the proposal passage probabilities as a function of g. The observed frequencies and acceptance rates of proposals are broken down by three ranges of g are in bold. In the first range, beginning at $g = 0$, the equilibrium proposal type assigns strictly positive allocation to investment in the public good and private allocation to the proposer, but zero private allocation to all other committee members. This corresponds to region of the state space below g_2 in which the proposer does not provide pork to the other members. Between g_3 and y^*, the proposer is constrained and finds it optimal to "buy off" the other committee members by investing up to y^* and also paying off some to minimum winning coalition of other committee member(s). After y^*, the equilibrium involves negative investment of the public good, and becomes a divide the dollar ultimatum game, which requires the proposer to give sidepayments to a minimum winning coalition (one other member in $L3$ and two other members in $L5$)

[Tables 5 and 6 here]

FINDING 7. The vast majority of proposals pass. Overall, 84% of the L5 proposals and 91% of the L3 proposals receive majority committee support. Many of these are unanimously supported, especially the "invest W" proposals and the universal proposals with positive investment.[18] Furthermore, the probability of acceptance declines with g. When $g \leq y^*$, proposals are accepted 98% of the time by L3 commitees and 90% of the time in L5 committees. In contrast, when $g > y^*$, proposals are accepted 88% of the time by L3 commitees and only 70% of the time in L5 committees.

Acceptance rates differ by type of proposal. Some kinds of proposals are rejected somewhat frequently. This is particularly true for proposals with negative investment. In L3 committees, only 68% of proposals with negative investment pass and in L5 committees, only 59% pass. Proposals that give private allocation only to the proposer also fare relatively poorly, passing 63% of the time in L3 committees and 71% of the time in L5 committees. The most common proposal types, "invest W" and "universal with positive investment" nearly always pass. The acceptance rates for proposals to invest everything are 98% and 95% for the L5 and L3 treatments, respectively. The corresponding acceptance rates for universal proposals with positive investment are 93% and 97%. One surprise in the data is the relatively low acceptance rates for MWC propopals in L5.

Table 7 looks at the voting data through a different lense, and displays the results from logit regressions where the dependent variable is vote (0=no; 1=yes). An observation is a single voter's vote decision on a single proposal. The proposer's vote is excluded.[19] The data is broken down according to the

[18] In L5, 67% of the "invest all" proposals pass unanimously, and 82% of such proposals pass unanimously in L3. The corresponding percentages of unanimous ballots for universal proposals with positive investment are 40% and 65%.

[19] Proposers vote for their own proposals nearly 100% of the time (517 times out of 519).

treatment (n=3 or n=5). The independent variables are: *EU(status quo)*, the expected value to the voter of a "no" outcome (including the discounted continuation value); *EU(proposal)*, the expected value to the voter of a yes outcome; and *pork*, the amount of private allocation offered to the voter under the current proposal. Theoretically, a voter should vote yes if and only if the expected utility of the proposal passing is greater than or equal to the expected utility of the status quo. This would imply a negative coefficient on *EU(status quo)* and a postive coefficient on *EU(proposal)*, with the magnitudes of these coefficients being approximately equal. The effect of pork should be fully captured by *EU(proposal)* and therefore, we do not expect a significant coefficient on *pork*.

[Table 7 here]

FINDING 8. Voters are forward looking. The results of the vote regression are clear. The main effect on voting is through the difference between the expected utility of the status quo and the proposal. The signs of the coeffiecients are highly significant, large in magnitude, and not significantly different from each other in absolute value. The residual effect of pork is nonexistent in $L3$ committees, and significant but small in magnitude in $L5$ committees. The constant term is not significantly different from zero, suggesting that voters are not a priori inclined to favor or disfavor proposals.

6.5 Evidence of non-Stationary strategies

6.5.1 L mechanism

While we observe only small departures from the predicted stationary equilibrium behavior in the L games, at least two findings suggest a deeper analysis.

The first is the overinvestment in the public good, expecially in early periods. For instance, in the L3 treatment, the median level of public good peaked in round 6 at nearly three times the equilibrium long run steady state, before declining to slightly above equilibrium levels by rounds 9 and 10.

The second interesting observation is that most proposals are either to invest everything or, if not, to give positive allocations to all members of the committee. In fact, we rarely see proposals where the proposer is the only member receiving a private allocation, even though the equilibrium path predicts such proposals in the early rounds. One possible explanation that may be consistent with both of these observations is that, rather than playing a stationary equilibrium, some committees are supporting more efficient allocations by using non-stationary strategies. Because this is an infinitely repeated game with a low-probability random stopping rule, a natural conjecture is that there are equilibria that can support higher levels of public good provision than the Markov equilibrium we characterize in the theoretical section of the paper.

Similarly, there could be punishment strategies imposed on proposers who do not share the residual budget with any other committee members. Such proposals would be rejected as part of the punishment, or possibly even accepted, but then punished by ostracism in the future.

We next take a look at the data to see if there is evidence of punishment strategies. We look at both voting behavior and proposal behavior. Table 8 reports the results of a logit regression of voting behavior on the same variables a table 3, but includes three additional variables that could in principle indicate some degree of punishment or reward behavior being used to affect proposals and support equilibrium outcomes that differ from the computed stationary solutions, in the two ways described above.

The first way would be the prevalence of proposals for higher investment in the public good relative to equilibrium (more efficient), leading to overshooting the equilibrium steady state. In terms of voting behavior, such equilibrium behavior could be supported by voting against proposals that do not offer enough public good. Thus, we include the proposed investment, I_t, in the vote regression, and expect the sign to be positive if this sort of behavior is occuring.

Second, the outcomes tend to be more fair (universal) than the theory predicts. While this is not a big effect, it is clearly seen in the data. We include two variables that capture different notions of fairness. The first is a herfindahl index, h, to indicate how unequal the proposed division of pork is across committee members. We expect the sign on this to be negative, in the sense that proposals with greater dispersion of the private proposals receive more negative votes.[20] The second variable is "greed" which is measured by the amount of own-private allocation by the proposer, an indicator of how slanted the private allocations are toward the proposer. We expect the sign on this to be negative also, in the sense that greedier proposals are punished

[20] Note however, that the sign on the herfindahl index is automatically negative if there are more members in the winning coalition, so this may not be an indication of punishment/reward at all, but simply myopic selfish optimizing.

with more negative votes.

[Table 8 here]

The results are presented in Table 8. For the $L3$ treatment, all the "nonstationary" variables are highly signficant with the expected sign. More efficient proposals receive greater support, as do proposals that are more fair or less greedy. The negative sign of the effect, however, is consistent with equilibrium behavior;[21] and its size is too small to provide evidence in favor of an equilibrium in which non markovian strategies reward efficient behavior. The coefficients on $EU(statusquo)$ and $EU(proposal)$ still have the correct (opposite) signs and are not significantly different from each other, but they are no longer signficantly diffrerent from 0. The coefficient on $pork$ is now highly significant, and together with I, has soaked up most of the effect of $EU(statusquo)$ and $EU(proposal)$. This is not surprising. $pork$ and I are the main determinants of the difference between $EU(statusquo)$ and $EU(proposal)$. Because of this, we are reluctant to conclude that the significant coefficient on I is indicative of nonstationary behavior. On the other hand the significance of the coefficients on the fairness variables demonstrates the existence of voting behavior that rewards exactly the types of proposals we see more of relative to the equilibrium predictions (invest W and universal).

Results for the $L5$ treatment are similar, all three of the new variables have the expected sign, and two are highly significant (I and $greed$). As in $L3$, more efficient proposals receive greater support, as do proposals that are more fair or less greedy. The coefficients on $EU(statusquo)$ and $EU(proposal)$ still have the correct (opposite) signs and are not significantly different from each other, and they are signficantly diffrerent from 0, but their magnitude has dropped by about one-third. This parallels the finding in $L3$: the coefficient on $pork$ is now highly significant and much greater in magnitude than in $Table$ 3. The variables $pork$ and I again soak up most of the effect of $EU(statusquo)$ and $EU(proposal)$.

As a final check for nonstationary strategies, we look at how current proposals treat the proposer of the previous round, depending on how a

[21] In equilibrium we should expect a higher level of investment to be associated with a higher probability that a random voters votes yes to a proposal. This because when g is small, the equilibrium predicts a high investment level and a unanimous yes vote; when g is high investment is predicted to be smaller, and proposal are predicted to pass by minimal winning coalitions.

current proposer was treated by the last proposer. The hypothesis is that how well the current proposer treats the previous proposer is increasing in how well the previous proposer treated him; i.e. there is a version of tit for tat behavior. Because the only way the current round's proposer can target a punishment or reward for the previous round's proposer is with pork, we run a regression where the dependent variable is the current proposal's private allocation to the previous round's proposer. For observations, we use all current round provisional budgets beginning in round 2, excluding the provisional budget of the previous round's proposer. The key independent variable we use for how well the previous round's proposer treated the current round proposer is $EUratio_{t-1}$, which is the lagged ratio of $EU(proposal)$ and $EU(statusquo)$, and we control for the current level of public good, g. We report two different regressions in table 5. The first two columns include only the above variables. The second column checks for more detailed punishment/reward effects, by including lagged versions of the I, h, and $greed$ variables. In other words, we check whether there are lagged effects of efficiency or fairness of the previous proposal on the current proposal's private allocation to the previous proposer.

[Table 9 here]

The coefficient on $EUratio_{t-1}$ is significant in both treatments. There is a significant effect of the the lagged greed variable in $L5$. We conclude from this analysis that there is significant evidence of the use of nonstationary strategies.

FINDING 9. There is evidence of nonstationary behavior in the L mechanism. In voting behavior, controlling for their own private allocation, voters punish proposals that are either too greedy or too unfair. We find this in both the $L3$ and the $L5$ committees. In proposal behavior, current proposals discriminate against previous proposers who were too greedy and reward previous proposers who treated them well. This nonstationarity in behavior seems to be motivated by fairness rather than by efficiency considerations. There is evidence that voting behavior rewards proposals that have higher investment levels: but this effect is consistent with equilibrium behavior, and too small to support an efficient outcome.

6.5.2 A mechanism

Under the A mechanism, public good levels also exhibited a time path of early overproduction followed by negative investment, converging toward the equilibrium steady state. In nearly all goups, the public good levels are consistently very low. However, because the general pattern is qualitatively similar to what we observed under the L mechanism, it is suggestive of some small amount of cooperation that may be accountable in part by non-stationary strategic behavior involving punishments and rewards.

The tools by which players in the A mechanism can reward or punish the other districts are more limited than with the L mechanism. For one thing, punishments cannot be "targeted". In contrast, under the L mechanism a proposal specifies an individual side payment to each legislator, which allows current proposers to punish specific other members of the committee (for example by giving nothing to a previously greedy proposer). In the A mechanism, an individual district can punish/reward other districts only by investing less/more in the public good in the current period. With this in mind, we regress current individual investment decisions on last period's average investment in their group (lagAVE), controlling for the level of public good (G) and experience, measured by how many games they have played so far (EXP). A positive coefficient would be consistent with some sort of non-stationary behavior such as collective punishments and rewards. We also include last period's *variance* of investment decisions (lagVAR) in their group, as a high variance will indicate the presence of shirkers in their group, which could trigger (untargeted) punishments. A negative coefficient would be consistent with untargeted punishment of individual shirking behavior. Table 10 shows the results for the A3 and A5 treatments.

[Table 10 here]

The results are virtually identical for the two treatments. Both "punishment" variables, lagAVE and lagVAR, have the predicted sign and are statistically significant. There are no significant experience effects (EXP) nor significant effects of the level of the public good, g. We conclude that there is evidence of non-stationary behavior that may be consistent with strategic attempts to maintain higher-than-equilibrium investment levels. As with the the L mechanism, to the extent that these attempts may have increased investment levels, the magnitude of such an increase is rather small.

6.5.3 Variation across committees

Because of possibility of nonstationary equilibria, and in light of some evidence of nonstationary voting and proposing strategies, we expect a fair amount of variation across committees. The figure showing the time path of the stock of public good could mask some of this heterogeneity. Do some comittees reach full efficiency? Are some committees at or below the equilibrium? We turn next to these questions.

L committees The next figure displays the entire set of all time paths of y for all committees. See Figure 5, panels (a), (b) for the n=3 and n=5 L treatments, respectively.

[Figure 5 here]

There was remarkble consistency across committees, especially considering this was a complicated infinitely repeated game with many non-Markov equilibria. There were a few committees who invested significantly more heavily than predicted by the Markov perfect equilibrium, but this only happened rarely, and nearly always such cooperation fell apart in later rounds. The most efficient committee in $L5$ invested W in each of the first 7 rounds, resulting in a public good level of 140. That committee did not invest anything in any later rounds. Recall that the first best level of $L5$ is 400, so even this very successful committee did not come close to efficiency. In $L3$ only two committees reached levels above 60 (first best is 144) and not a single committee contributed W for more than 4 consecutive rounds.

Many committees overshoot and then fall back to approximately equilibrium levels. However, it is also true that some committees never exceed the long run steady state. One $L5$ committee, in a 6 round match, starts out at a public good level of 20 and declines from there. One $L3$ committee, also in a 6 round match, starts out at a public good level of approximately 3 and gradually increases, but only reaches 11 by the end of round 6.

A committees In the A mechanism, there was also a lot of uniformity across committees, again with a few exceptions. See Figure 5, panels (c) and (d), for the $A3$ and $A5$ treatments, respectively.

7 Discussion and Conclusions

This paper proposed a framework for comparing the performance of different political institutions in terms of efficient provision of durable public goods, such as public infrastructure. We analyze the first best solution which is characterized by an equilibrium steady state and a fast-as-possible trajectory for reaching that steady state. There are two possible kinds of inefficiency that can arise, one with respect to the steady state, and the other with respect to the trajectory, or "building phase".

With respect to the first, an institution may result in an inefficient equilibrium steady state of the stock of the durable public good. For all of the institutions we look at, the direction of this inefficiency is, perhaps not surprisingly, underprovision rather than overprovision. Under qualified majority rule, efficiency is worst when proposals require few votes in order to pass, and the inefficiency is lessened when the quota is increase. In the limit, when the quota is 100% (unanimity), the equilibrium steady state is fully efficienct. Under a fully decentralized solution, which we model as "autarky", the outcome is equivalent to the worst possible qualified majority rule, which requires only *one* vote to pass a proposal. Thus complete decentralizion, or autarky, yields equilibrium outcomes in our model that are equivalent to pure dictatorship.

With respect to the second source of inefficiency, we find that under the L mechanism, the equilibrium building trajector proceeds too *slowly* relative to the efficient trajectory. This is because under majority rule (or qualified majority rule), in the early building phases the proposer can get away with "skimming" some of the budget for his own consumption rather than investing the entire budget (the efficient decision). In the A mechanism, the steady state is so low that it is reached in one period, so the question of inefficient trajectories is moot.

The laboratory experiments are largely confirmatory of the long-run predictions of the theory, and the comparative static predictions. In the long run, the public good levels approximate the Markov equilibrium steady state, although slightly higher in some treatments. The treatment effects are confirmed. The A mechanism leads to much worse outcomes than the L mechanism, and the inefficiencies (observed long run levels of public good compared to the efficient level) are higher for N=5 than N=3. Investment is generally lower for N=3 than N=5, as predicted. The *relative* inefficiencies (observed long run levels of public good *compared to* the efficient level) are higher for

N=5 than N=3.

The observed trajectories, or time paths of the building up the stock of the durable public good, exhibit a clear pattern in all four treatments, and this pattern is different from the equilibrium trajectories. There are two interesting phenomena here. First, we observe "overshooting" of the steady state; that is, investment in early periods exceeds the Markov equilibrium investment amounts (in all treatments) leading temporarily to a stock of the public good that is higher than the equilibrium steady state. Second, this overshooting is corrected in the long run. After overshooting, there is typically a disinvestment process that shrinks the stock of the public good in the direction of the steady state.

There are many possible directions for the next step in this research. One is to consider different classes of mechanisms. For example, our political process does not have elections and parties, there is no executive branch or "president" to oversee the general interest common to all districts. Elections, parties, and non-legislative branches are all important components of any political economy, and incorporating such institutions into our framework would be a useful and challenging direction to pursue. There are some smaller next steps that could be taken more quickly. For example, on the experimental side, our design was intentionally very simple and used a limited set of treatments. The theory has interesting comparative static predictions about the effect of other parameters of the model, such as the size of the qualified majority, the discount factor, the production technology, preferences, endowments, and depreciation rates. On the theoretical side there are open issues about generalizing the framework to allow for a richer set of allocations, such as allowing debt financing or multiple public goods.

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9 Appendix 1

9.1 Proof of Proposition 2

Two cases are possible. The first case is when in the steady state $y(y_P^*) = y_P^*$ and $x(y_P^*) > 0$. Since $y(g)$ is constant for $g \geq \max\left\{\frac{y_P^*-W}{1-d}, 0\right\}$, it is straightforwardly to show that the derivative of the value function is in this region is $v'(g) = \frac{\partial}{\partial g}\left[W + (1-d)g - y_P^* + B\frac{1}{\alpha}n\left(y_P^*\right)^\alpha + \delta v_P(y_P^*)\right] = (1-d)$. Using the first order condition we must have $Bn\left(y_P^*\right)^{\alpha-1} + \delta(1-d) = 1$, so

$$y_P^* = \left(\frac{Bn}{1-\delta(1-d)}\right)^{\frac{1}{1-\alpha}} \tag{14}$$

for such an equilibrium to exist we need that $y_P^* > g_P$, so:

$$(1-d)\left(\frac{Bn}{1-\delta(1-d)}\right)^{\frac{1}{1-\alpha}} > \left(\frac{Bn}{1-\delta(1-d)}\right)^{\frac{1}{1-\alpha}} - W$$

that is $\left(\frac{Bn}{1-\delta(1-d)}\right)^{\frac{1}{1-\alpha}} < \frac{W}{d}$, or $1-\delta(1-d) > Bn\left(\frac{d}{W}\right)^{1-\alpha}$. Assume now that the steady state g_P^{SS} satisfies $g_P^{SS} = y(g_P^{SS}) \leq y_P^*$. In this case $W+(1-d)g = g$, so $g_P^{SS} = W/d$. For this case to be possible we need that $\left(\frac{Bn}{1-\delta(1-d)}\right)^{\frac{1}{1-\alpha}} \geq W/d.$, or $1-\delta(1-d) \leq Bn\left(\frac{d}{W}\right)^{1-\alpha}$. ■

9.2 Proof of Proposition 3

The fact that a concave equilibrium has the property stated in the proposition follows from the discussion in the text. Here we prove existence. Let $y_A^* = \left[u^{-1}\right]'(1-\delta\frac{1-d}{n})$, and $g_A^1 = \frac{y_A^*-W}{1-d}$. For any $g > g_A^1$ define a value function $v_A^1(g) = \frac{W-(y_A^*-(1-d)g)}{n} + \frac{u\left(y_A^*\right)}{1-\delta}$. Note that this function is continuous, non decreasing, and differentiable with respect to g, with $\frac{\partial}{\partial g}v_A^1(g) = \frac{1-d}{n}$. Let $g_A^2 = \frac{g_A^1-W}{1-d}$, and define:

$$v_A^2(g) = \begin{cases} v_A^1(g) & g > g_A^1 \\ u((1-d)\,g + W) + \delta v_A^1((1-d)\,g + W) & g \in (g_A^2, g_A^1] \end{cases}$$

Note that $v_A(g)$ is continuous and differentiable in $g \geq g_A^2$, except at most at g_A^1 To see that it is also concave in this interval, note that it is concave in $(g_A^2, g_A^1]$. Moreover, for any $g \in (g_A^2, g_A^1]$ and $g' \geq g_A^1$ we have:

$$\begin{aligned}\frac{\partial}{\partial g} v_A^2(g) &= u'(((1-d)\,g + W) + \delta v_A'((1-d)\,g + W) \\ &> u'(y_A^*) + \delta v_A'(y_A^*) = 1 > \frac{1-d}{n} = \frac{\partial}{\partial g} v_A^2(g')\end{aligned}$$

So $v_A^2(g)$ is concave in $g > g_A^2$. Assume that we have defined a concave, continuous, differentiable (except at g_A^1) value function $v_A^n(g)$ for $g > g_A^n$ with $g_A^n \leq g_A^2$. Define $g_A^{n+1} = \frac{g_A^n - W}{1-d}$, and

$$v_A^{n+1}(g) = \begin{cases} v_A^n(g) & g > g_A^n \\ u((1-d)\,g + W) + \delta v_A^n((1-d)\,g + W) & g \in \left(g_A^{n+1}, g_A^n\right] \end{cases}$$

We can easily show that this function is concave, continuous, differentiable (except at g_A^1). We can therefore define inductively a value function $v_A(g)$ for any $g \geq 0$ that is continuous, concave and differentiable almost everywhere, in particular at y_A^*. Define now the following strategies:

$$y_A(g) = \min \left\{ W + (1-d)g, y_A^* \right\}, \text{ and } x_A(g) = \frac{W + (1-d)g - y_A(g)}{n}.$$

We will argue that $v_A(g), y_A(g), x_A(g)$ is an equilibrium. To see this note that by construction, if the agent use strategies $y_A(g), x_A(g)$, then $v_A(g)$ describe the expected continuation value function of an agent. To see that $y_A(g), x_A(g)$, are optimal given $v_A(g)$ note that for $g \geq g_A^1$, $y_A(g)$ maximizes (5) when all the constraints except the first are ignored, and satisfies all the remaining constraints. For $g < g_A^1$, we must have $y_A(g) = W + (1-d)g$. So $y_A(g)$ is an optimal reaction function. Given this the optimal choice of x must be $x_A(g)$. ■

9.3 Proof of Proposition 4

Two cases are possible. The first case is when in the steady state $y(y_A^*) = y_A^*$ and $x(y_A^*) > 0$. Since $y(g)$ is constant for $g \geq \max\left\{\frac{y_A^* - W}{1-d}, 0\right\}$, it is straightforwardly to show that the derivative of the value function is in this region is $v'(g) = \frac{(1-d)}{n}$. Using the first order necessary and sufficient condition we must have $B\left(y_A^*\right)^{\alpha-1} + \delta\frac{(1-d)}{n} = 1$, so

$$y_A^* = \left(\frac{Bn}{n - \delta(1-d)}\right)^{\frac{1}{1-\alpha}} \tag{15}$$

for such an equilibrium to exist we need that $y_A^* > g_A$, $n - \delta(1-d) > Bn\left(\frac{d}{W}\right)^{1-\alpha}$. Assume now that the steady state g_A^{SS} satisfies $g_A^{SS} = y(g_A^{SS}) \leq y_A^*$. In this case $W + (1-d)g = g$, so $g_A^{SS} = W/d$. For this case to be possible we need that $\left(\frac{Bn}{n-\delta(1-d)}\right)^{\frac{1}{1-\alpha}} \geq W/d.$, or $n - \delta(1-d) \leq Bn\left(\frac{d}{W}\right)^{1-\alpha}$. ■

9.4 Proof of Proposition 5

To be added. ■

9.5 Optimal policies in the Legislative game

In this section we first show that without loss of generality, when W is sufficiently large an optimal reaction function of a proposer to a non decreasing value function v can be expressed as in (8) and (9). We then use the characterization, to construct an algorithm to compute the equilibrium .

9.5.1 The proposer's reaction function

Consider the Proposer's problem (7). One of two cases is possible. First, the incentive compatibility constraint is not binding, so the proposer can effectively ignore the other legislators. Second, the incentive compatibility constraint binds and so the proposer has either to modify the level of public good, or provide pork transfers to a minimal winning coalition or both.

Non binding IC. Assume first that we can ignore the incentive compatibility constraint and set $s = 0$. The problem becomes:

$$\max_y \left\{ \begin{array}{c} W - [y - (1-d)g] + u(y) + \delta v_L(y) \\ s.t.\ \ W - y + (1-d)g \geq 0 \end{array} \right\} \tag{16}$$

If we ignore the constraint in (16), then it is optimal (without loss of generality) to choose y_1^* such that:

$$y_1^* = \max\left\{ y \,\middle|\, y \in \arg\max_{y'} \left\{u(y') - y' + \delta v_L(y')\right\} \right\} \tag{17}$$

We select the max of $\{y\,|y \in \arg\max_{y'} \{u(y') - y' + \delta v_L(y')\}|\}$ because this is the value that maximizes the set in which the incentive compatibility constraint is not binding. Given this choice, it is easy to see that at $y_L(g) = y_1^*$ we have $x_L(g) \geq 0$ if and only if g is greater than or equal to the threshold $g_0(y_1^*)$, defined as:

$$g_0(y_1^*) = \max\left\{\frac{y_1^* - W}{1-d}, 0\right\} \tag{18}$$

Since the state space is bounded, we can assume without loss of generality that for W sufficiently high, $g_0(y_1^*) = 0$, so the case in which $x_L(g) = 0$ is not possible (this will always be the case in our experiments). Given this, the incentive compatibility constraint is satisfied if and only if:

$$u(y_1^*) + \delta v_L(y_1^*) \geq \frac{W}{n} + u\left[g(1-d)\right] + \delta v_L(g(1-d)) \tag{19}$$

Condition (19) requires the legislators to vote for the proposal even if they receive no consumption good and only $y_L(g) = y_1^*$. Monotonicity of v_L, together with (19) implies that there is a threshold $g_1(y_1^*) \geq 0$ such that this condition is satisfied if and only if $g \leq g_1(y_1^*)$. If $g \leq g_1(y_1^*)$, we can therefore select $y_L(g) = y_1^*$.

Binding IC constraint. When $g > g_1(y_1^*)$ the incentive compatibility constraint can not be ignored. In this case, the problem solved by the proposer is:[22]

$$\max_{y,s}\left\{\begin{array}{c} [W - [y-(1-d)g] - (q-1)s] + u(y) + \delta v_L(y) \\ s.t. s + u(y) + \delta v_L(y) \geq \frac{W}{n} + u\left[g(1-d)\right] + \delta v_L(g(1-d)) \\ s \geq 0 \end{array}\right\} \tag{20}$$

There are two possibilities. First, the proposer continues to provide no consumption to the districts of other legislators, but he increases the provision of the public good $y_L(g)$ in order to satisfy the incentive compatibility constraint (no transfer case). Second, he provides consumption to the districts of $q-1$ other legislators and to his own district (transfers case).

Consider the second case first, assuming $s > 0$. We can write (20) as:

$$\max_{y}\left\{\begin{array}{c} W - [y-(1-d)g] \\ -(q-1)\left[\frac{W}{n} + \Psi((1-d)g) - \Psi(y)\right] + \Psi(y) \end{array}\right\} \tag{21}$$

[22] Because v is not necessarily concave, the inequality is not necessarily binding even if $g > g_1(y_1^*)$. It is binding if $s > 0$. Note that the constraint $x \geq 0$, is superfluous since it is not difficult to show that $x \geq s$.

where $\Psi(x) = u(x) + \delta v_L(x)$. Choosing an optimum in problem (21) is equivalent to choosing an optimum in problem: $\max_y \{q\Psi(y) - y\}$. So an optimal choice for the proposer is to propose $y_L(g) = y_2^*$ such that:

$$y_2^* = \min\left\{ y \left| y \in \arg\max_{y'} \{q\Psi(y') - y'\} \right| \right\} \tag{22}$$

In this case we select the min of $\{y\,|y \in \arg\max_{y'}\{u(y') - y' + \delta v_L(y')\}|\}$ because this is the value that maximizes the set in which the $s \geq 0$ constraint is not binding. This case is feasible only if $s = \frac{W}{n} + \Psi(g(1-d)) - \Psi(y_2^*) \geq 0$, that is if and only if $g \geq g_2(y_2^*)$ where $g_2(y_2^*)$ is defined as the solution of:

$$\frac{W}{n} + \Psi(g(1-d)) = \Psi(y_2^*)\,. \tag{23}$$

In the case in which $g \in [g_1, g_2]$ then the public good must solve:

$$\widetilde{y}(g) \in \max_y \left\{ \begin{array}{c} W - [y - (1-d)g] + u(y) + \delta v_L(y) \\ s.t. u(y) + \delta v_L(y) \geq \frac{W}{n} + u\left[g(1-d)\right] + \delta v_L(g(1-d)) \end{array} \right\} \tag{24}$$

clearly if $g_1(y_1^*) > 0$, then $\widetilde{y}(g_1(y_1^*)) = y_1^*$, and similarly if $g_2(y_2^*) > 0$, then $\widetilde{y}(g_2(y_2^*)) = y_2^*$. For a general v_L we can not say if the constraint in (24) is binding; the constraint is binding when v_L is sufficiently close to a concave function. In this case $\widetilde{y}(g)$ is given by $u(\widetilde{y}(g)) + \delta v_L(\widetilde{y}(g)) = \frac{W}{n} + u\left[g(1-d)\right] + \delta v_L(g(1-d))$. This is always the case for the cases in our experiments.

From the analysis before, therefore, a proposer facing a value function v_L, will find optimal to react according to (8) and (9).

9.5.2 Computation of Equilibrium

In the experiment the state space is a discrete set $G = \{g_1, ..., g_m\}$ of values that range from 0 to 65 for n=3 and from 0 to 140 for n=5. Consistently with this, we compute an equilibrium assuming a discrete state space G. Then we followed the following algorithm:

Step 1. For an initial value function v_0, find y_1^*, y_2^* from (17) and (22); $g_1(y_1^*)$, $g_2(y_2^*)$, from (19) and (23); and $\widetilde{y}_j(g_j)$ for any $g_j \in (g_1(y_1^*), g_2(y_2^*))$ from (24). Let $\mathbf{y}$ be the vector of these parameters. These parameters fully describe the equilibrium investment strategy and will be our initial guess.

Step 2. Given $\mathbf{y}$, we can solve the system (12) of m equations in the m unknowns $(v(g_1), ..., v(g_m))$, and find a value function $v_L(g; \mathbf{y})$ for any $g \in G$.

Step 3. Given $v_L(g; \mathbf{y})$, we can reestimate the vector of parameters $\mathbf{y}'$ given $v_L(g; \mathbf{y})$. We now have a correspondence $\mathbf{y}' \in Y(\mathbf{y})$. We can therefore find the equilibrium solving for the fixpoint $\mathbf{y} \in Y(\mathbf{y})$.

We solved for the fixpoint by iterating Steps 1-4. This procedure always converged with the parameters of our experiments. Because the state space is discrete and the proposer's choices are strict in correspondence to the obtained fixpoint, the associate strategies and valued function are a Nash equilibrium.

Mechanism	**n**	**B**	**W**	**g=(g$_1$,g$_2$)**	**y^*_1**	**y^*_2**	**g_A**	**y^*_A**	**g_p**	**y^*_p**
Legislative	3	2	15	(1,7)	5	16				
Legislative	5	√3	20	(4.83,18.5)	7.83	29.83				
Autarky	3	2	15				0	1.77		
Autarky	5	2	20				0	1.38		
Planner	3	2	15						129	144
Planner	5	2	20						380	400

Table 1: Experimental parameters and equilibrium

Mechanism	**n**	**# Committees**	**# Subjects**
Legislative	3	70	21
Legislative	5	60	30
Autarky	3	70	21
Autarky	5	60	30

Table 2: Experimental Design

Proposal Type	Observations	% accepted
INVEST W	277(97)	0.95
PROPOSER ONLY	21(8)	0.63
MWC		
*with positive inv	66(20)	0.90
*with no inv	14(1)	1.00
*with negative inv	30(11)	0.55
UNIVERSAL		
*with positive inv	428(138)	0.97
*with no inv	52(14)	0.93
*with negative inv	57(26)	0.73

Table 3: L3 Proposal Types

Proposal Type	Observations	% accepted
INVEST W	431(88)	0.98
PROPOSER ONLY	57(7)	0.71
MWC		
*with positive inv	71(16)	0.69
*with no inv	48(13)	0.54
*with negative inv	57(9)	0.56
UNIVERSAL		
*with positive inv	212(40)	0.93
*with no inv	24(6)	0.17
*with negative inv	52(9)	0.44

Table 4: L5 Proposal Types

Round	Observations	% of accepted
1	210(70)	0.97
2	159(53)	0.94
3	120(40)	0.93
4	9(33)	0.91
5	75(25)	0.88
6	66(22)	0.77
7	57(19)	0.89
8	45(15)	0.80
9	45(15)	0.93
10	33(11)	0.91
11	12(4)	1.00
12	12(4)	0.75
13	12(4)	1.00
overall	945(315)	0.91

g	Observations	% of accepted
$0 \leq g \leq 7$ (g_2)	264(88)	0.97
$7 < g \leq 16$ (y*)	69(23)	1.00
g >16	612(204)	0.88
Overall	945(315)	0.91

G	Observations	% of accepted w/ inv<0
$0 \leq g \leq 7$ (g_2)	2(0)	.
$7 < g \leq 16$ (y*)	7(2)	1.00
g >16	78(35)	0.66
overall	87(37)	0.68

Table 5: L3 Proposal Acceptance Rates

Round	Observations	% of accepted
1	300(60)	0.95
2	240(48)	0.90
3	150(30)	0.60
4	90(18)	0.83
5	75(15)	0.93
6	60(12)	0.50
7	30(6)	0.83
8	30(6)	0.83
9	30(6)	0.83
10	15(3)	1.00
overall	1020(204)	0.84

g	Observations	% of accepted
$0 \leq g \leq 18.5$ (g_2)	465(93)	0.92
$18.5 < g \leq 29.83$ (y^*)	240(48)	0.85
$g > 29.83$	315(63)	0.70
overall	1020(204)	0.84

g	Observations	% of accepted w/ inv<0
$0 \leq g \leq 18.5$ (g_2)	9(3)	0.33
$18.5 < g \leq 29.83$ (y^*)	32(4)	0.50
$g > 29.83$	83(15)	0.67
overall	124(22)	0.59

Table 6: L5 Proposal Acceptance Rates

	(1)	(2)
Treatment	*L3*	*L5*
EU(status quo)	−0.082***(0.02)	−0.22***(0.02)
EU(proposal)	0.080*** (0.02)	0.22*** (0.02)
pork	0.007(0.007)	0.07***(0.02)
constant	1.06(0.81)	0.1(0.97)
Observations	490	576

Table 7: Logit estimates. Dependent variable: Pr {vote=yes}

Notes: Standard errors in parentheses; * significant at 10% level; ** significant at 5% level; *** significant at 1% level

	(1)	(2)
Treatment	*L3*	*L5*
EU(status quo)	0.01(0.02)	−0.15*** (0.03)
EU(proposal)	-0.02(0.03)	0.14*** (0.03)
pork	0.14***(0.03)	0.17***(0.04)
I	0.06***(0.01)	0.03***(0.01)
h	-2.81***(0.80)	-1.20(1.07)
greed	-3.02***(0.95)	-2.05***(0.71)
constant	1.48***(0.01)	0.62(0.99)
Observations	490	576

Table 8: Logit estimates. Pr {vote=yes}. Including *i*, *h*, and greed

Notes: Standard errors in parentheses; * significant at 10% level; ** significant at 5% level; *** significant at 1% level

	(1)	(2)	(3)	(4)
Treatment	*L3*	*L5*	*L3*	*L5*
g	0.118***(0.02)	0.014(0.013)	0.112***(0.02)	0.01(0.01)
EUratio_{t-1}	293.49***(98.95)	265.29**(119.21)	282.85***(103.41)	232.09**(113.06)
I_{t-1}			-0.02(0.02)	-0.015(0.024)
h_{t-1}			-9.74(8.21)	6.06(10.1)
greed_{t-1}			-10.44(13.2)	-27.01***(7.09)
constant	-101***(33.42)	-53.45**(23.85)	-93.03***(35.62)	-41.27*(22.67)
Observations	384	384	384	384

Table 9: TOBIT estimates for L treatments. Dependent variable: Private allocation offered to previous round's proposer.

Notes: standard errors in parenthesis are clustered by individual; *=significant at p<0.10 ***=significant at p<0.01.

	(1)	(2)
Treatment:	*A3*	*A5*
lagAVE	0.234*** (0.062)	0.140* (0.076)
lagVAR	-0.025***(0.007)	-0.045***(0.006)
g	-0.044 (0.029)	0.016 (0.023)
EXP	-0.210 (0.238)	0.374 (0.232)
constant	4.278*** (1.568)	1.591 (1.374)
Observations	495	930

Table 10: TOBIT estimates for A treatments. Dependent variable: Individual investment decisions.

Notes: standard errors in parenthesis are clustered by individual; *=significant at p<0.10 ***=significant at p<0.01.

Round	Groups	Average(y)	Median(y)	Average(inv)	Median(inv)
1	70	7.88	7.93	7.88	7.93
2	46	11.38	11.89	4.13	4.09
3	31	5.00	9.72	-2.00	-1.91
4	24	5.50	8.96	-0.63	-1.18
5	21	3.00	7.29	0.00	-0.69
6	10	4.63	6.83	1.25	0.85
7	7	3.00	4.18	0.50	0.00
8	7	3.00	4.32	0.25	0.14
9	7	4.00	4.68	0.50	0.36
10	3	2.50	4.00	-1.50	-2.42
11	3	7.25	5.42	0.25	1.42
12	3	7.75	6.67	1.00	4.44
13	3	7.75	7.58	0.00	0.92

Table 11: Median and average stock of public good and investment per round, Autarky mechanism, treatment n=3, all matches.

Round	Groups	Average(y)	Median(y)	Average(inv)	Median(inv)
1	60	12.63	11.85	12.63	11.85
2	48	16.75	17.55	4.88	4.74
3	33	8.50	14.99	-2.25	-2.23
4	24	5.63	12.77	-1.75	-3.50
5	21	6.75	10.57	-1.75	-4.02
6	15	8.00	12.65	0.50	0.95
7	12	9.13	9.15	-0.13	-2.96
8	12	10.63	11.13	2.13	1.98
9	6	8.88	8.00	-2.50	-2.42
10	6	5.50	7.21	-0.75	-0.79
11	3	6.00	6.00	4.25	4.17
12	3	10.75	7.67	4.75	1.67
13	3	9.25	7.92	0.25	0.25

Table 12: Median and average stock of public good and investment per round, Autarky mechanism, treatment n=5, all matches.

Round	Groups	Average(y)	Median(y)	Average(inv)	Median(inv)
1	80	12.79	15.00	15.00	15.00
2	64	23.06	26.25	10.41	11.25
3	56	30.65	33.38	8.59	7.50
4	48	33.33	37.50	5.67	7.50
5	32	33.57	31.50	2.03	3.75
6	32	35.24	42.88	-1.21	3.75
7	32	39.84	37.50	-3.65	2.25
8	24	29.67	34.00	-5.10	2.25
9	24	26.13	22.50	1.72	3.75
10	16	29.46	26.25	2.64	3.75
11	16	32.06	28.25	4.98	4.38
12	8	28.00	30.13	1.15	3.75
13	8	39.25	41.38	3.75	3.75

Table 13: Median and average stock of public good and investment per round, Legislative mechanism, treatment n=3, all matches.

Round	Groups	Average(y)	Median(y)	Average(inv)	Median(inv)
1	60	16.39	20.00	17.09	20.00
2	48	27.43	30.67	13.73	18.33
3	30	36.27	40.00	6.44	6.67
4	18	42.63	42.50	3.40	3.33
5	15	48.93	45.00	3.87	3.33
6	12	47.67	41.67	0.36	0.00
7	6	52.17	29.00	-0.61	0.00
8	6	57.72	35.17	7.07	5.83
9	6	54.78	32.67	0.44	0.00
10	3	54.56	30.33	7.24	8.00
11	0	-	-	-	-
12	0	-	-	-	-
13	0	-	-	-	-

Table 14: Median and average stock of public good and investment per round, Legislative mechanism, treatment n=5, all matches.

Round	mdn(y)L3	mdn(y)L5	mdn(y)A3	mdn(y)A5
1	15.00	20.00	8.00	11.75
2	26.25	36.67	11.25	19.50
3	33.75	40.00	4.75	9.25
4	39.00	40.00	4.50	6.38
5	41.25	42.17	3.00	6.38
6	44.25	48.33	4.25	7.38
7	36.75	29.00	3.00	9.13
8	31.38	35.17	3.00	10.63
9	14.50	32.67	4.00	8.88
10	18.75	30.33	2.50	5.50
11	28.25	-	7.25	6.00
12	30.13	-	7.75	10.75
13	41.38	-	7.75	9.25

Table 15: Median stock of public good per round, all mechanisms, all treatments n=5, last 6 matches.

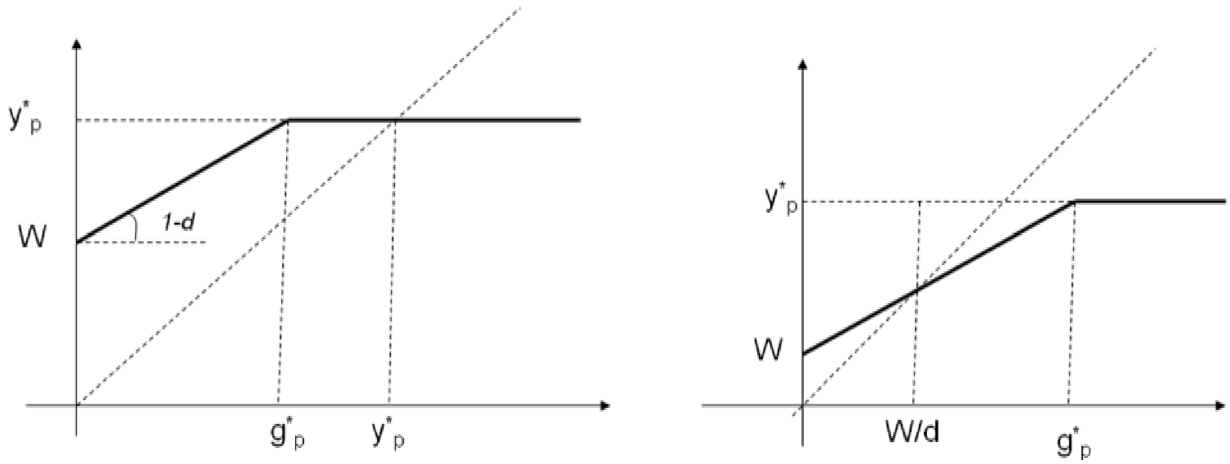

Figure 1: The Planner's problem

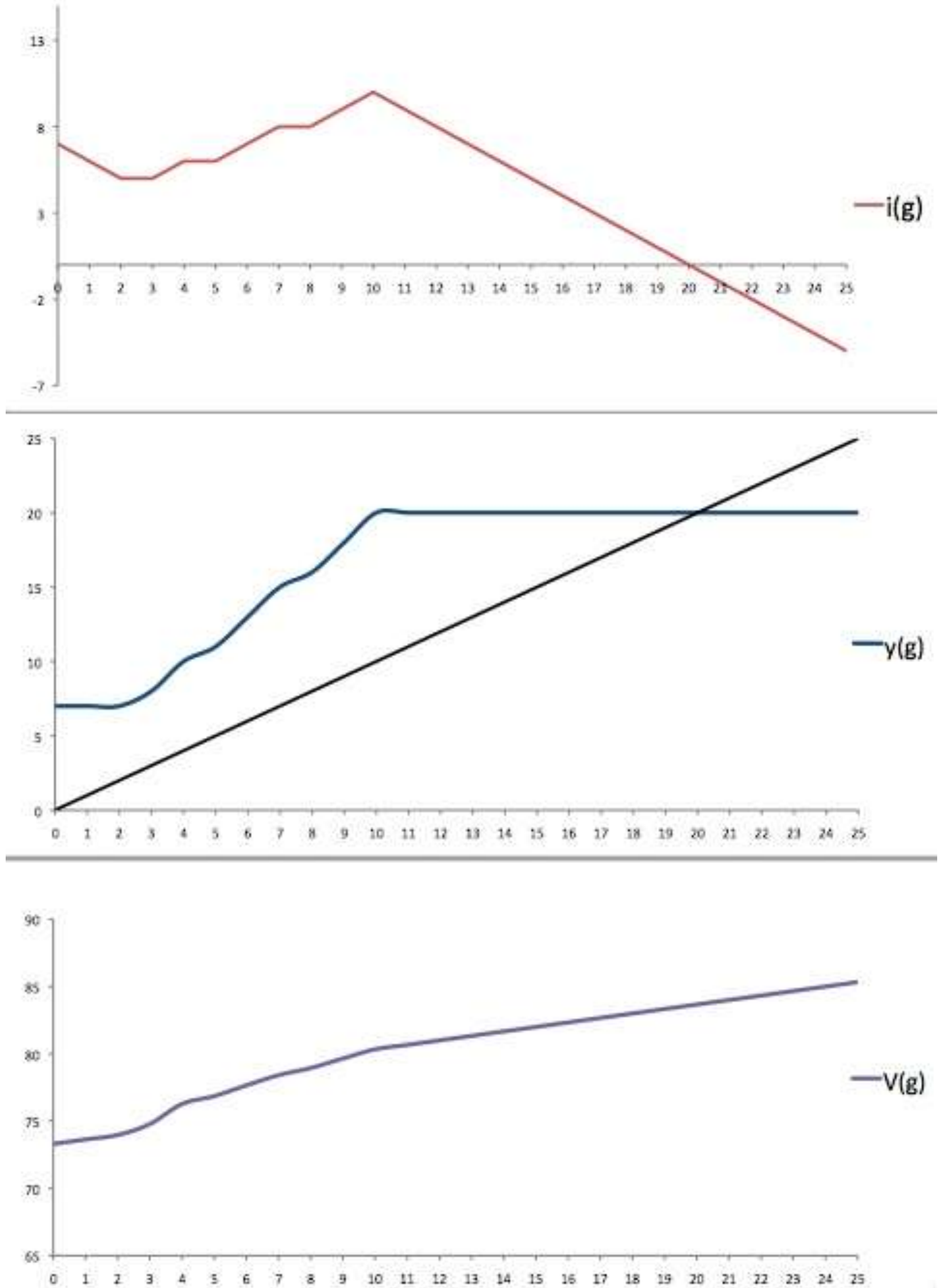

Figure 2: Legislative mechanism with n=3, i(g), y(g) and V(g)

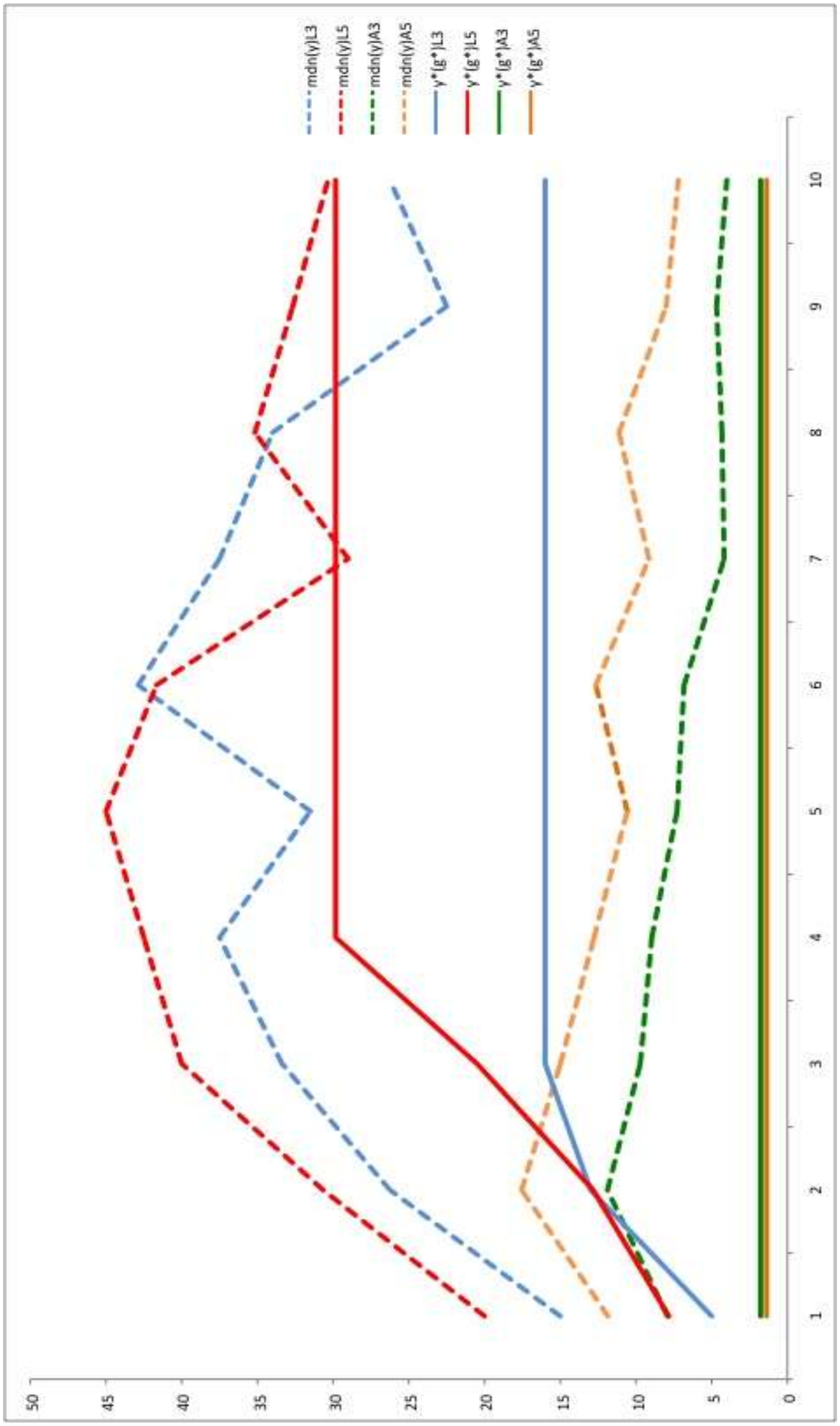

Figure 3: Median time paths of the stock of g, all mechanisms, all treatments.

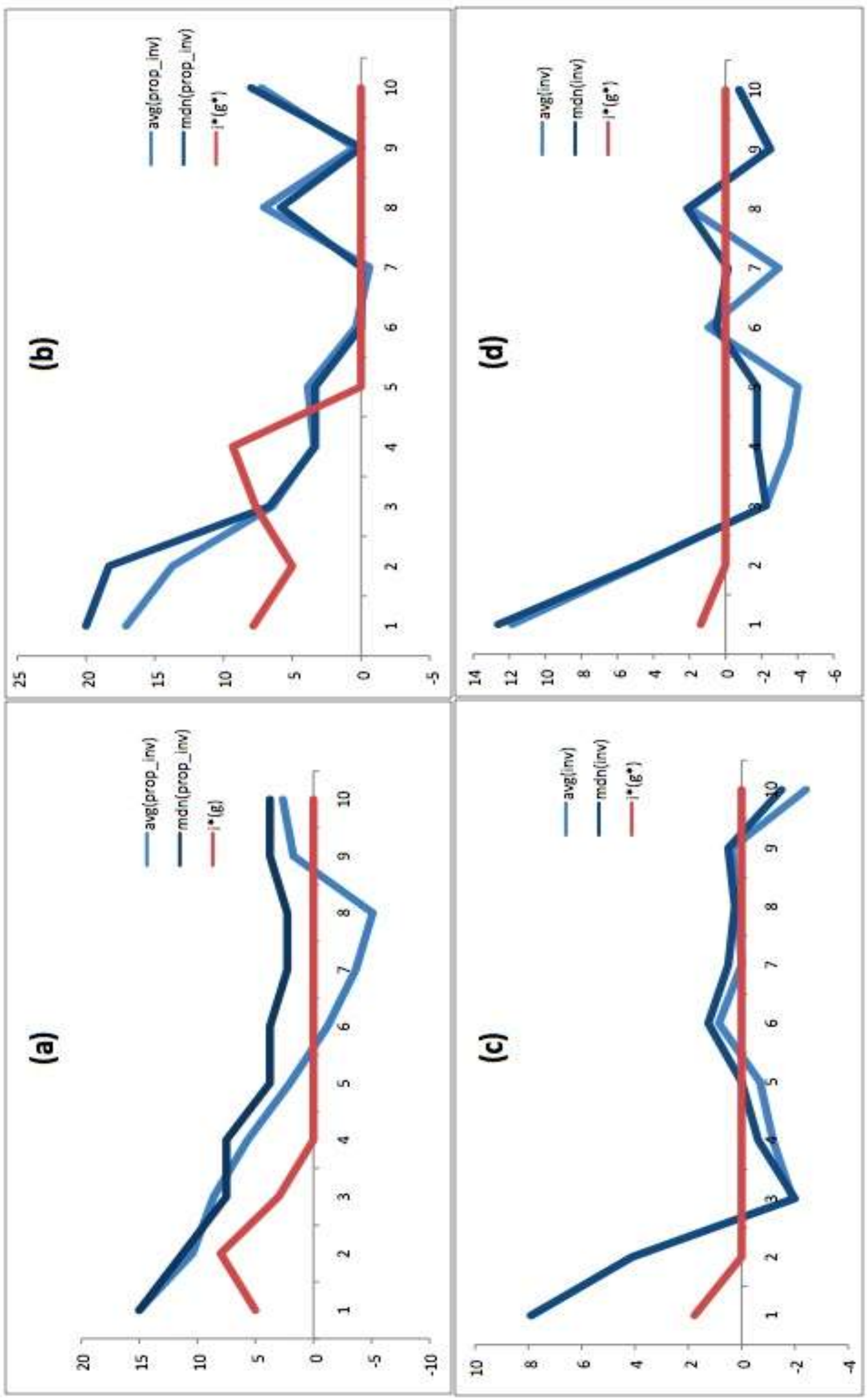

Figure 4: Investment per round, (a) 3-district L mechanism, (b) 5-district L mechanism, (c) 3-district A mechanism, (d) 5-district A mechanism.

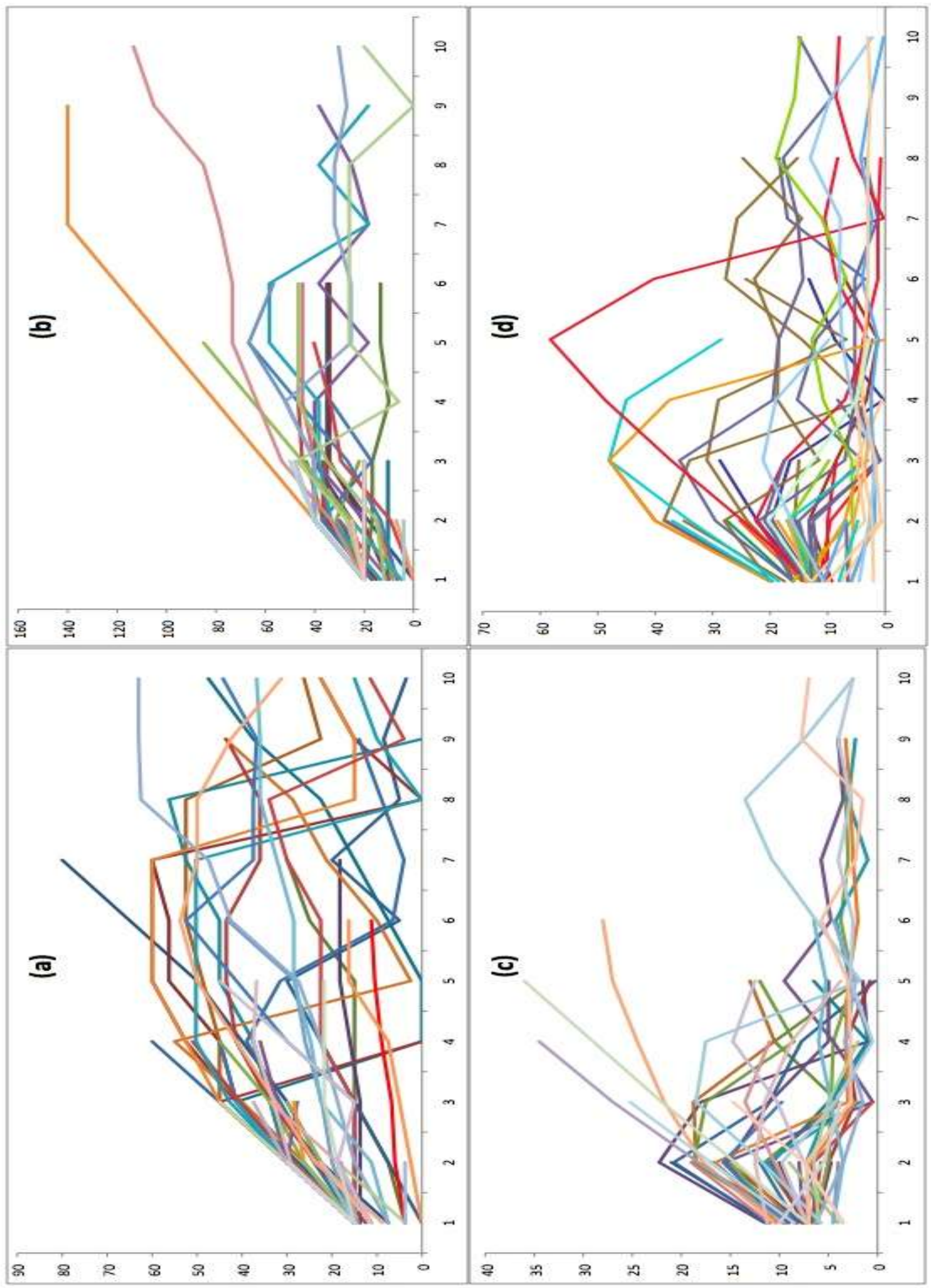

Figure 5: Time paths of g for all committees, (a) 3-district L mechanism, (b) 5-district L mechanism, (c) 3-district A mechanism, (d) 5-district A mechanism.