Government vs. Anarchy:  
Modeling the Evolution of Institutions  †

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Abstract
This paper gives a general mathematical definition of an institution, and presents an explicit formal method by which to incorporate institutions in a standard general equilibrium model. We illustrate our concept using a modified Prisoner’s dilemma game in which property rights over natural resources emerge from an anarchy-like state of nature. Two players decide voluntarily and non-cooperatively whether to give up some fraction of their personal resource to set up an enforcement mechanism that punishes defecting players (i.e., players that do not opt to cooperate). This enforcement mechanism constitutes a credible threat, and is central to the establishment of bilateral cooperation (i.e., government). We highlight the importance of imperfect information (proposition 1) and risk averse behavior (propositions 2 and 3) for bilateral cooperation to be sustained as the unique Nash-equilibrium. Proposition 1 formalizes an idea of Brennan and Buchanan (1985) that the legitimacy of governments is based on their contribution to reducing uncertainty. Proposition 3 justifies an assumption made by Sened (1997) that rational individuals respect governments dictating specific institutions.

Keywords: Institutions; Imperfect Information; Property Rights; Decision Making; Social Games

JEL classification: C72, D7, D81

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1. Introduction

The importance of institutions to the performance of economies (e.g. as a prerequisite for the functioning of private markets) has been long known to economists, but a “general organizing formalism” (Dixit 1996, p. 17) of institutions has been missing. This paper makes an attempt to fill this gap by first giving a general definition of an institution, and then presenting a formal framework in which institutions are incorporated in a standard general equilibrium model. We illustrate our framework using a modified Prisoners’ dilemma game in which property rights over natural resources emerge from an anarchy-like state of nature. In section 2, we look at prevailing definitions of institutions. We present our own definition of an institution and the general framework in section 3, followed by an illustration of our ideas in section 4. Section 5 concludes the paper.

2. Definitions of Institutions

North (1991) defines institutions as “the humanly devised constraints imposed on human interaction” (p. 4). Examples are laws, constitutions, legal acts, and also norms and conventions. Sened (1997) gives a more formal definition of an institution: “An essential institution is a set of ‘man-made rules’ \( L \), such that \( \text{NE}(\Gamma) \neq \text{NE}(\Gamma | L) \)” (p. 58), where \( \text{NE}(\Gamma) \) denotes the set of Nash-equilibria. Property rights are a key institution in Sened’s game-theoretic approach. He models property rights as granted by a pre-existing government with a monopoly over the use of coercive force (p. 78). He writes, “governments grant property rights whenever the cost of enforcement is lower than the marginal benefit they expect in tax revenues and political support” (p. 85). Sened avoids two fundamental questions in his analysis of institutions: 1) Why should a government exist at all?; and 2) Why should individuals be willing to accept the coercive force of the government? Going beyond the Sened approach in an attempt to answer these questions is the theme of our paper.

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3. The general framework

We model an economy that is populated by \( N \) individuals indexed by \( i \), each characterized by a quantity of a composite personal resource, which includes private information, a time allotment, etc. The quantity \( \phi_i \in \mathbb{R}_+ \) of \( i \)'s composite personal resource cannot be competed away in markets or stolen, and eventually may give rise to economic rents through economic interaction. \( \phi = (\phi_1, \ldots, \phi_N) \in \Phi \subseteq \mathbb{R}^N_+ \) denotes the vector whose elements are the \( N \) individuals’ quantities of the composite personal resource.

The \( N \) individuals organize and regulate their economic interaction by forming three institutions: a property rights institution \( R \), a technology institution \( S \), and an exchange institution \( T \). These institutions are formally modeled as constrained correspondences. Our main interest is in the formation of the property rights institution \( R \), as will be illustrated in the next section.

Economies contain various scarce natural resources, such as supplies of arable land and fresh water, which combine into a single composite natural resource, of which is available a positive aggregate quantity \( \omega_{\text{max}} \). We denote \( \omega_i \) as the natural resource quantity owned by \( i \). We use \( \Omega \) to label the economy’s set of imaginable natural resource allocations \( (\omega_1, \ldots, \omega_N) \). We assume that no natural resource unit is owned by more than one individual, though some units may be owned by no one.

Of central importance is correspondence \( R \) ("the property rights institution") that personal resource allocation space \( \Phi \) into natural resource allocation space \( \Omega \). \( R \) is a rule according to the economy’s personal resource allocations are examined, and then by which a natural resource allocation is assigned. Therefore we write \( R(\phi_1, \ldots, \phi_N) = (\omega_1, \ldots, \omega_N) \).

We assume there are \( K \) consumption goods. We label a bundle of such goods consumed by \( i \) as \( x_i^d = (x_{i1}^d, \ldots, x_{iK}^d) \in X_i^d \subseteq \mathbb{R}^K_+ \), where \( x_{i1}^d \) is the quantity of good one consumed by \( i \), etc., and \( X_i^d \).
is i’s consumption goods space. Each individual i is also characterized by a preference ordering $\phi_i$ over all the $x_i^d$ consumption bundles in $\mathbb{R}_+^K$. This $\phi_i$ establishes a utility function $u_i$ over the consumption goods: $u_i: x_i^d \in X_i^d \subseteq \mathbb{R}_+^K \rightarrow \mathbb{R}_+$. Each individual i is assumed to produce a bundle of (private and public) goods $x_i^s = (x_{1i}^s, \ldots, x_{Ki}^s) \in X_i^s \in \mathbb{R}$. All imaginable production possibilities are shown by the unconstrained correspondence $S$ (“the technology institution”): $\Phi \times \Omega \rightarrow X_1^s \times \ldots \times X_N^s$. For some allocation $\phi = (\phi_1, \ldots, \phi_N)$ of personal resources and some allocation $\omega = (\omega_1, \ldots, \omega_N)$ of natural resources, $S(\phi, \omega) \in \mathbb{R}_+^N$ is a set containing all $(x_1^s, \ldots, x_N^s)$ combinations that could be produced by the individuals for a given S. Society can constrain S, for example by adopting environmental laws that prohibit certain technologies. We assume that goods must be produced to be consumed, and therefore $S(\phi, \omega)$ shows all the possible $(x_1^d, \ldots, x_N^d)$ combinations that could be consumed by the individuals.

The relationship between production goods space and consumption goods space is defined by “the exchange institution,” which is a correspondence $T$: $X^s \rightarrow X^d$ where $X^s = (X_1^s, \ldots, X_N^s)$ and $X^d = (X_1^d, \ldots, X_N^d)$. $T$ determines the rules of exchange of production goods into consumption goods (e.g. a price vector in Arrow and Debreu (1954)).

We assume that correspondences S and T give rise to the existence of an indirect utility function $v: v(\phi_i, \omega_i) \equiv u(x_i^d(x_i^s(\phi_i, \omega_i)))$. We define the economy’s “global institution” as a correspondence $L$: $\Phi \rightarrow U \subseteq \mathbb{R}_+^N$ where $U = U_1 \times \ldots \times U_N$. $L$ maps from the economy’s personal resource allocation space directly into utility space. $L$ contains all feasible welfare outcomes for the entire economy for some given allocation of personal resources $\phi = (\phi_1, \ldots, \phi_N)$. The following definition summarizes and formalizes our idea of an institution.
Definition. Institutions

Institutions are defined as constrained correspondences that are mappings between different spaces in an economy (personal resource space, natural resource space, production good space, consumption good space, and utility space). They describe all non-technology constraints imposed on the allocation, production, exchange, and distribution of commodities (resources and goods). All institutions of an economy can be formally expressed by institution $L: \Phi \rightarrow U \subseteq \mathbb{R}^N$, that maps from the economy’s personal resource allocation space into utility space.

Institution $L$ describes all non-technology constraints that underlie economic interactions between individuals. Our definition covers North’s definition as a special case since we, as an extension to North, allow institutions to be “God given”. Our definition exhibits features of Sened’s definition. We will show in the next section that institution $L$ indeed constrains the set of Nash-equilibria.

4. The Formation of the Property Rights Institution $R$

Consider a political economy comprised by two individuals, Kari and Ola, who are endowed with personal resource quantities $\phi_K$ and $\phi_O$ respectively, and who bargain over a set of scarce natural resource units $(0, \omega_{\text{max}}]$, as is illustrated in figure 1. Initially, natural resource units are not owned by anybody (Hobbesian state of nature), and so the players have to figure out a way to allocate the natural resource set between themselves. Following an idea of Dixit and Olson (1997) to model games of voluntarily participation, we choose a two-stage game. In the first stage, Kari and Ola decide whether to cooperate or to defect. Cooperation for player $i$ at the first stage means that $i$ devotes an amount $\varepsilon_i \phi_i$ with $\varepsilon_i \in [0,1]$ of his/her personal resource quantity $\phi_i$ to set up a credible enforcement mechanism that punishes the opponent should the opponent defect. We may think of this enforcement mechanism as simply as a brick wall, the height of which depends on the amount $\varepsilon_i \phi_i$. The wall is a deterrent to defection for the opponent—it is built over the opponent’s road to the natural resources. For example,
say Kari decides to cooperate. Then she spends some personal resources to build a wall over Ola’s road to the natural resources, and then sits down to bargain over distribution of the natural resources. If Ola then also cooperates, he also builds a wall over Kari’s road to the natural resources, and then sits down to bargain. If both players cooperate, we have the case of bilateral cooperation, which we call the *establishment of government*, and the game enters a second stage in which they cooperatively decide on a sharing rule $\lambda \in [0,1]$ which determines how $(0, \omega^{\text{max}}]$ is allocated between them.\(^1\)

Another possibility for players’ strategies is unilateral defection. Say that Ola decides to defect and Kari decides to cooperate, then Ola by-passes the bargaining table, and heads straight along his road to the natural resources. But to dismantle the wall Kari has built, he has to spend just as much energy (personal resources) as Kari spent to build the wall, this amount being $\varepsilon_{K}\phi_{K}$. After dismantling the wall, Ola continues along the road to the natural resources, and acquires all of them. Kari is left at the bargaining table, and gets no natural resources. We will call this outcome *feudalism*.

A third possibility is bilateral defection, which we will call *anarchy*. Under anarchy, no walls are built, and no one sits down to bargain (i.e., there is no enforcement mechanism formed). Both players travel directly along their roads to the natural resource. When they get there, they meet each other, and “fight to the death,” trading blow for blow (personal resource for personal resource), until one is dead (has no personal resources remaining). The player remaining alive acquires the entire natural resource bundle. We will show that anarchy is seldom a Nash equilibrium, and that feudalism is the Nash equilibrium if bilateral cooperation fails. The game can be placed into the class of Prisoners’ dilemma-type games that are frequently used to model social decisions.

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\(^1\) We will show that $\lambda$ does not need to be predetermined in the first stage. A feasible $\lambda$ will always exist if both players choose to cooperate (i.e., if the game reaches the second stage).
4.1. **Perfect information**

We motivate our propositions by starting with perfect information. We limit our analysis to showing that under perfect information bilateral cooperation (C,C) cannot be sustained as a Nash equilibrium.

Table 1 shows the payoffs at the first stage as elements of a monotone increasing utility function. ²

<table>
<thead>
<tr>
<th></th>
<th>Ola cooperates</th>
<th>Ola defects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kari cooperates</td>
<td>( \lambda \omega + (1-\varepsilon_K)\phi_K, (1-\lambda)\omega + (1-\varepsilon_O)\phi_O )</td>
<td>( (1-\varepsilon_K)\phi_K, \omega + \phi_O - \varepsilon_K \phi_K )</td>
</tr>
<tr>
<td>Kari defects</td>
<td>( \omega + \phi_K - \varepsilon_O \phi_O, (1-\varepsilon_O)\phi_O )</td>
<td>( d(\omega + \phi_K - \phi_O), (1-d)(\omega + \phi_O - \phi_K) )</td>
</tr>
</tbody>
</table>

\( d \) is a dummy variable with \( d = 1 \) if \( \phi_K \geq \phi_O \), and \( d = 0 \) if \( \phi_K < \phi_O \).

Consider the choice of Ola. He must build a wall big enough such that \( \varepsilon_O \phi_O \geq (1-\lambda)\omega + \varepsilon_K \phi_K \) in order to induce Kari to cooperate. But in this case, Ola’s best response is to defect, and bilateral cooperation cannot be sustained as a solution. Neither can anarchy be sustained, since the weaker player has an incentive to cooperate by announcing that he/she will sit down to bargain but spend

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² The payoffs at the second stage can be found by replacing \( \lambda \) with a number between 0 and 1.
nothing to build a wall—he/she knows that it is a waste to spend any personal resources to try to deter the stronger player from obtaining all the natural resources.

**Proposition 1:**

*Bilateral cooperation cannot be sustained as a Nash equilibrium in the two stage game with complete and perfect information.*

Mittenzwei and Bullock (1999) provide a proof of proposition 1. Proposition 1 has important implications for any study of political economy. Under perfect information, feudalism is the probable outcome. The strong have no incentive to cooperate with the weak. The existence of imperfect information becomes a necessary condition for the establishment of government. Any study of political economy assuming certainty should consider this important aspect of government’s existence.

4.2. *Imperfect information*

We assume that imperfect information enters the game as uncertainty about the opponent’s level of personal resources. Following Harsanyi (1967), we introduce nature as a player that draws a specific level of personal resources, \( \phi_i \), for each player \( i \) from a probability distribution \( F \) with mean \( \mu \). We assume that nature reveals \( \mu \) to both players, but \( \phi_i \) to player \( i \) only. Both players face the same kind of uncertainty, in not knowing the opponent’s level of personal resources.

We use the risk premium concept to evaluate behavior under risk. A risk averse player \( i \) is characterized by a positive risk premium \( \pi_i(.) > 0 \). Let \( \pi_i(\varepsilon_j \phi_j) \) denote the risk premium for player \( i \) being faced with the (stochastic) height of the opponent player’s wall \( \varepsilon_j \phi_j \). Player \( i \) expects the height of the wall to be \( \varepsilon_j \mu \). A risk averse player \( i \) is indifferent between tearing down a wall of (stochastic) height \( \varepsilon_j \phi_j \) and tearing down a wall of (certain) height \( \varepsilon_j \mu \) plus giving up risk premium \( \pi_i(\varepsilon_j \phi_j) \): \( U_i(\varepsilon_j \phi_j) = U_i(\varepsilon_j \mu - \pi_i(\varepsilon_j \phi_j)) \). In the case of bilateral defection (*anarchy*), \( i \) faces the opponent’s personal resource quantity \( \phi_j \). The payoff from winning the fight is \( U(\omega + \phi_i - \phi_j) \) where \( \phi_j \) is stochastic to player \( i \). Let
The payoff from winning the fight can now be written as: $U(\omega + \phi_i - \mu - \pi_i(\phi_j))$. Let $q_i = \text{prob}(\phi_i \geq \phi_j)$. Applying the concept of the risk premium once more, we define $q_i U(\omega + \phi_i - \mu - \pi_i(\phi_j)) + (1-q_i) U(0) \equiv U(q_i(\omega + \phi_i - \mu - \pi_i(\phi_j)) - \pi_i(\omega + \phi_i - \phi_j))$. A risk averse player $i$ is indifferent to facing the stochastic payoff and facing the expected payoff while forfeiting the risk premium $\pi_i(\omega + \phi_i - \phi_j)$. To ensure that all relevant risk premia for $i$ are positive if one is positive, we define $\pi_i \equiv \min \{\pi_i(\epsilon_j \phi_j), \pi_i(\phi_j), \pi_i(\omega + \phi_i - \phi_j)\}$.

The payoff matrix of the game with imperfect information is shown in Table 2. The payoffs are now stated as arguments of an expected utility function in the von Neumann-Morgenstern sense. We use $\pi_i$ to make the payoffs comparable. This simplification makes the payoffs from defection potentially higher, depending on the functional choice of the risk premium.

### Table 2. Payoff matrix with imperfect information

<table>
<thead>
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<td>Kari defects</td>
<td>$\omega + \phi_K - \epsilon_O \mu - \pi_K$, $(1-\epsilon_O)\phi_O$</td>
</tr>
</tbody>
</table>

$q_i = \text{prob}(\phi_i \geq \phi_j)$ is the probability held by $i$ that he/she is “stronger” than $j$.

The payoffs from cooperation are identical to those in Table 1, while the payoffs from defection depend now on the expected value $\mu$ and the players own risk premium.

**Proposition 2: A sufficient condition for bilateral cooperation**

$\pi_i \geq \omega + \epsilon_i \phi_i$, $i=K, O$, $i \neq j$ (i.e. a “high enough” risk premium) is a sufficient condition to sustain bilateral cooperation as the unique Nash-equilibrium in pure strategies in the two stage game with two individuals and imperfect information about the level of personal resources.

A proof of proposition 2 can be found in Mittenzwei and Bullock (1999). Proposition 2 is straight-forward: If every player is sufficiently risk averse, bilateral cooperation will be sustained as the unique Nash-equilibrium. The risk premium has to be higher than the one’s enforcement costs and the
value of the natural resource. In this case, the payoffs from defection become negative while the payoffs from cooperation are always positive.

All we require so far is risk averse behavior implying that bilateral cooperation could be achieved with zero enforcement costs (with no walls built). We investigate the conditions that require positive enforcement costs in order to sustain bilateral cooperation in proposition 3 below.

It remains to show the feasibility of sharing rule $\lambda$. We need to show that $\pi_K + \pi_O > \omega + \epsilon_K \phi_K - \epsilon_K \mu + \epsilon_O \phi_O - \epsilon_O \mu$ which is satisfied by proposition 2. Letting $\lambda^L = (\omega + \epsilon_K \phi_K - \epsilon_O \mu - \pi_K) / \omega$ and $\lambda^H = (\epsilon_K \mu + \pi_O - \epsilon_O \phi_O) / \omega$, the feasible range of sharing rule $\lambda$ becomes $\lambda \in (\lambda^L, \lambda^H)$.

**Proposition 3: A sufficient condition for bilateral cooperation with positive enforcement costs**

*Conditions (3 I) and (3 II) are sufficient to sustain bilateral cooperation with positive enforcement costs as the unique Nash-equilibrium in pure strategies in the two stage game with two players and imperfect information about the level of personal resources.*

(3 I): $(1 - \lambda) \omega > \pi_K > (1 - \lambda) \omega + \epsilon_K \phi_K - \epsilon_O \mu$ and $\lambda \omega > \pi_O > \lambda \omega + \epsilon_O \phi_O - \epsilon_K \mu$

(3 II): $(1 - \lambda) > q_K > \epsilon_O (1 - \epsilon_O) \text{ and } \lambda > q_O > \epsilon_K (1 - \epsilon_K)$

Mittenzweii and Bullock (1999) provide proof of proposition 3. Condition (3 I) introduces a lower and an upper bound on the risk premium. Condition (3 II) states that the probability of being “stronger” than the opponent must be smaller than the share of the resource the opponent would get in the case of bilateral cooperation. Manipulating (3 I), it can be shown that $\mu^2 > \phi_K \phi_O$. If the levels of personal resources of both players are higher than the expected value $\mu$, bilateral cooperation cannot be sustained with positive enforcement costs.

4.4. Welfare implications

The welfare implications for the two players under imperfect information with positive enforcement costs depend mainly on the sharing rule. For simplicity, we consider $\lambda = \lambda^L$. The case of $\lambda = \lambda^H$ works
similarly. If $\lambda = \lambda^L$, Kari’s welfare becomes $\omega - \epsilon_o \mu - \pi_K + \phi_K$. In this situation, Kari is in fact indifferent between cooperation and defection if Ola cooperates. Ola’s welfare becomes $\epsilon_o \mu - \epsilon_K \phi_K + \pi_K + (1 - \epsilon_o) \phi_o$. Total welfare amounts to $\omega + (1 - \epsilon_K) \phi_K + (1 - \epsilon_o) \phi_o$, where $\epsilon_K \phi_K + \epsilon_o \phi_o$ are the total enforcement costs to sustain bilateral cooperation. They represent the difference to a situation in which bilateral cooperation is achieved costlessly (e.g. Arrow and Debreu 1954). The feasible range of $\lambda$ together with the enforcement costs constitute the institution that sustains bilateral cooperation given sufficiently risk averse individuals. Formally, we have shown the existence of $R(\phi_K, \phi_o) = \{ (\lambda \omega, (1 - \lambda) \omega) \mid (3 \ I), (3 \ II) \}$.

To provide a numerical example, let $\omega = 10$, $\lambda = 1/2$, $\epsilon_K = 1/4$, $\epsilon_o = 1/2$, $\phi_K = 6$, $\phi_o = 1$, $\mu = 5$, $\pi_K = 4.5$, $\pi_o = 4.5$. We set $q_K = q_o = 1$ to maximize the payoff from bilateral defection for both players, and to allow for erroneous behavior (i.e. Ola’s belief should be $q_o = 0$). The feasible range of $\lambda$ becomes $\lambda \in (0.45, 0.525)$. Institution $R$ becomes: $R(6, 1) = \{ (10 \lambda, 10(1 - \lambda)) \ s.t. \ \lambda \in (0.45, 0.525) \mid (3 \ I), (3 \ II) \}$, while institution $L$ is given by: $L(6, 1) = \{ (v_K, v_o) \ s.t. \ (v_K \in (9, 9.75), v_o \in (5.25, 6) \mid (3 \ I), (3 \ II), S, T \}$ assuming some given institution $S$ and $T$. 

![Graph showing effects of positive enforcement costs](image)
Figure 2. Institution L restricts the set of feasible welfare outcomes.

The numerical example is graphed in figure 2. The straight (dotted) line shows Pareto-optimal bilateral cooperation outcomes with $\varepsilon_K = \varepsilon_O = 0$ ($\varepsilon_K = 1/4$, $\varepsilon_O = 1/2$). Also shown are the particular outcomes for $\lambda = 1/2$, $\lambda^L = .45$ and $\lambda^H = .525$ with positive enforcement costs. First consider the outcomes of unilateral defection (“threat points”) in the case of zero enforcement costs. In order to achieve bilateral cooperation, the payoffs for each of the players must be at least as high as the payoff the players would receive if they had defected unilaterally. This requirement compares to an individual rationality constraint. Kari (Ola) receives 11.5 (6.5) “utils” if she (he) defects unilaterally. It is easy to see that there is no point on the straight line that satisfies the individual rationality constraint for both players simultaneously. Hence, bilateral cooperation is not possible.

The introduction of positive enforcement costs shifts the “Pareto-frontier” and the outcomes of unilateral defection (“threat points”) leftwards, indicating that enforcement cost reduce “consumable” welfare. The relationship between the $\lambda$s and the “threat points” becomes clearer. For example, Kari’s unilateral defection payoff (if Ola cooperates) is identical to her payoff in the bilateral cooperation outcome with $\lambda = \lambda^L$ (9 “utils”). The situation is analogous for Ola with $\lambda = \lambda^H$. The two “threat points” determine the feasible range $\lambda \in [\lambda^L, \lambda^H]$.

The dotted line segment between $\lambda^L$ and $\lambda^H$ shows all individual rational and Pareto-optimal welfare outcomes defined by institution L with positive enforcement costs. The points on that line segment are identical to the Core. Further value judgement criteria are required to determine a particular point within the Core. The way $\lambda$ is determined by individuals, could be called the political
process. If government is viewed as an agent of public (private) interests, one could apply a social welfare function [SWF] (policy preference function [PPF]).

5. Conclusions

This paper presents an approach to incorporate institutions explicitly in a general equilibrium model. We propose a formal model of an economy with scarce natural resources, individuals who are endowed with personal resources, and institutions that are defined as constrained correspondences between different spaces in the economy. A two stage game, in which two individuals bargain over a composite natural resource illustrates our general model. Our model constitutes a first step towards formally analyzing and evaluating institutions and institutional change.

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3 See Song (1998) for an improvement of SWFs, and Bullock (1994) for a critical assessment of PPFs.
References


