International Journal of Game Theory (1995) 24: 187–212

On the Origin of Convention: Evidence from Symmetric Bargaining Games

JOHN VAN HUYCK, RAYMOND BATTALIO, SONDIP MATHUR, and PATSY VAN HUYCK
Department of Economics, College of Liberal Arts, Texas A&M University, College Station, TX 77843, USA
ANDREAS ORTMANN
Department of Economics, Bowdoin College, Brunswick, ME 04011, USA

Abstract: We use a dynamical systems approach to model the origin of bargaining conventions and report the results of a symmetric bargaining game experiment. Our experiment also provides evidence on the psychological salience of symmetry and efficiency. The observed behavior in the experiment was systematic, replicable, and roughly consistent with the dynamical systems approach. For instance, we do observe unequal-division conventions emerging in communities of symmetrically endowed subjects.

Key words: convention, symmetry, bargaining, dynamical systems, adaptive learning, human behavior. JEL classification: c720, c780, c920, d830.

1 Introduction

A satisfactory theory of games would not only identify the outcomes that are equilibrium points, but also explain the origin of mutually consistent behavior. When there is a unique equilibrium and the strategic interdependence is not too complicated, one possibility is that people simply deduce the equilibrium from their understanding of the game. However, deductive analysis based on the abstraction assumptions of individual rationality and mutual consistency often fails to determine a unique equilibrium. For example, economists have long known that an analysis of simultaneous bargaining results in multiple equilibria. When equilibrium analysis generates multiple equilibria it fails to prescribe rational behavior in the game or predict the outcome of the game, because it fails to determine which, if any, equilibrium will be selected. Consequently, a theory of equilibrium selection would appear to be an essential complement to the theory of equilibrium points.[1]

It is possible to construct a deductive equilibrium selection theory by introducing abstraction assumptions that go beyond individual rationality and mutual consistency: assumptions like symmetry and efficiency. These additional assumptions imply equal-division in symmetric bargaining games. The coincidence of this result with conventional notions of fairness might be taken as supporting a deductive approach.

[1] A conventional selection theory is that an arbiter makes a common knowledge equilibrium assignment to the players. Van Huyck, Gillette, and Battalio (1992) examine an arbiter's ability to determine the outcome of two-person coordination games. Their subjects did not find the individual rationality and mutual consistency of an equilibrium assignment to be sufficient reason for implementing the arbiter's assignment when doing so conflicts with payoff-dominance or symmetry.

However, if the deductive approach is to provide an accurate theory of observable games, the selection principles of symmetry and efficiency must formalize characteristics that are universally perceived to the psychologically salient.[2]

An alternative approach to the equilibrium selection problem investigates how experience with related games influences people's beliefs about each other's behavior in the current game. Experience with related games leads them to believe that a specific equilibrium outcome is the conventional outcome and they conform to the convention because doing so is in their interest. A convention is a regularity in behavior that is customary, expected, and self-enforcing, see Lewis (1969) or Young (1993).

We model the origin of convention using a dynamical systems approach. We assume that people learning from experience behave adaptively. It is well known that adaptive behavior may eventually allow communities of people interacting repeatedly to coordinate on an equilibrium outcome, see Milgrom and Roberts (1991) or Friedman (1991) for examples and references. This inductive selection theory makes predictions that can be very different from predictions made by a deductive selection theory. For instance, it is possible for adaptive behavior to lead communities of symmetrically endowed people to coordinate on an unequal-division convention, which violates symmetry.

In this paper, we use the experimental method to study the origin of convention in symmetric bargaining games. Our experiment also provides evidence on the psychological salience of symmetry and efficiency. The observed behavior in the experiment was systematic, replicable, and roughly consistent with the dynamical systems approach. For instance, we do observe unequal-division conventions emerging in communities of symmetrically endowed subjects.

2 Analytical Framework

In this paper, we analyze two tacit bargaining games extensively. First, consider a divide-a-dollar game with three feasible divisions: 60–40, 50–50, and 40–60. Without communication, each player chooses a feasible division. If the players choose the same division, they are both paid according to the selected division. Otherwise, they earn zero. This tacit bargaining game can be represented by payoff matrix D, where the units denote dimes and a player's payoff is determined by the row corresponding to his action, either 1, 2, or 3, and the column corresponding to the other player's action.

[2] Harsanyi and Selten (1988) demonstrate that it is possible to construct a deductive equilibrium selection theory for a general class of games. However, Selten views the Harsanyi/Selten solution concept as an exercise in the logic of strategic rationality, rather than as a foundation for a science of strategic behavior. Schelling [1960, (1980)] argues against the psychological salience of symmetry. Roth and Schoumaker's (1983) experiment on reputation provides evidence against equal-division in an asymmetric game, see also Binmore, et al. (1992). Bardhan (1984) reports crop shares for paddy leases varying from 3:1 to 1:3 in the surveyed villages of West Bengal, India, with only two-thirds of the villages using equal-division. Share cropping is not a symmetric game and Bardhan devotes substantial effort to measuring the costs falling on the tenant and the owner.

$$D \equiv \begin{bmatrix} 0 & 0 & 6 \\ 0 & 5 & 0 \\ 4 & 0 & 0 \end{bmatrix}$$

Let p_i denote the probability that player one chooses action i, where $i = 1, 2, 3$, and let p denote the vector (p_1, p_2, p_3). Let q_i denote the probability that player two chooses action i, where $i = 1, 2, 3$, and let q denote the vector (q_1, q_2, q_3). Player one's strategy vector p is an element of the simplex $\mathbf{S}^3 = \{x \in \mathrm{I\!R}^3 \mid x_i \geqq 0, \Sigma x_i = 1, i = 1, 2, 3\}$; as is player two's strategy vector, $q \in \mathbf{S}^3$. The unit coordinate vectors $e_1 \equiv (1, 0, 0), e_2 \equiv (0, 1, 0)$, and $e_3 \equiv (0, 0, 1)$ denote pure strategies: the actions 1, 2, and 3 respectively. In this notation, the 60–40 split is denoted $\{e_1, e_3\}$, the 50–50 split is denoted $\{e_2, e_2\}$, and the 40–60 split is denoted $\{e_3, e_1\}$.

Player one's expected payoff is $p.D.q$ and player two's expected payoff is $q.D.p$. Game D is defined by the following description: $\mathbf{D} \equiv (\{1, 2\}, \{p.D.q, q.D.p\}, \{\mathbf{S}^3, \mathbf{S}^3\})$. Game D is symmetric in that the expected payoff functions are symmetric and the players' feasible strategies are the same.

The second game studied below is related to game D. The only change is that now action 1 pays 30 cents should the players fail to coordinate. This tacit bargaining game can be represented by payoff matrix DS for both players:

$$DS \equiv \begin{bmatrix} 3 & 3 & 6 \\ 0 & 5 & 0 \\ 4 & 0 & 0 \end{bmatrix}$$

The feasible strategies are the same as in game D: $p, q \in \mathbf{S}^3$. Player one's expected payoff is $p.DS.q$ and player two's expected payoff is $q.DS.p$. Game DS is defined by the following description: $\mathbf{DS} \equiv (\{1, 2\}, \{p.DS.q, q.DS.p\}, \{\mathbf{S}^3, \mathbf{S}^3\})$. Game DS is also a symmetric game.

Is it possible to accurately predict how two intelligent players would behave when confronting game D or game DS? Deductive equilibrium concepts attempt to deduce the outcome of the game from information about the expected payoff functions and feasible strategies for the players – that is, from description **D** or **DS** – and from abstraction assumptions about the strategic rationality of the players. Two important examples are Nash equilibrium and strict equilibrium.[3]

Game D has three strict equilibria – $\{e_1, e_3\}, \{e_2, e_2\}, \{e_3, e_1\}$ – and seven Nash equilibria. Game DS has three strict equilibria – $\{e_1, e_3\}, \{e_2, e_2\}, \{e_3, e_1\}$ – and five Nash equilibria. Notice that both games have the same set of strict equilibria. Individual rationality and mutual consistency fail to determine a unique equilibrium in bargaining situations, like games D and DS.

An interesting conjecture is that players may focus on some selection principle to identify a specific equilibrium point in situations involving multiple equilibria. This salient principle would allow players to implement an equilibrium. A salient principle selects an equilibrium point based on its conspicuous uniqueness in some respect.

---

[3] A strategy combination $\{p^*, q^*\}$ is a *Nash equilibrium* if $p^*.A.q^* \geqq p.A.q^*$ for all $p \in \mathbf{S}^3$ and $q^*.A.p^* \geqq q.A.p^*$ for all $q \in \mathbf{S}^3$, where A equals either D or DS. A strategy combination is a *strict equilibrium* if both inequalities are strict for all $p \neq p^*$ and $q \neq q^*$.

The salience of an equilibrium selection principle is essentially an empirical question. Three common sense principles are symmetry, efficiency, and security.

2.1 Symmetry, Efficiency, and Security

In a *symmetric game* the players have the same strategic possibilities. Concepts of strategic rationality usually include the idea that strategically rational players confronting the same strategic situation will act similarly. At least since Nash, game theorists have argued that a reasonable solution concept should select a symmetric equilibrium of a symmetric game. A *symmetric equilibrium* is an equilibrium in which both players use the same strategy, that is, $p^* = q^*$. Harsanyi and Selten (1988; p. 73) argue that symmetry is an "indispensable requirement for any rational theory of equilibrium point selection that is based on strategic considerations exclusively."

The symmetric Nash equilibria of game D are $\{e_2, e_2\}$, $\{(3/5, 0, 2/5), (3/5, 0, 2/5)\}$, and $\{(15/37, 12/37, 10/37), (15/37, 12/37, 10/37)\}$. The symmetric Nash equilibria of game DS are $\{e_2, e_2\}$, $\{(2/5, 3/5, 0), (2/5, 3/5, 0)\}$, and $\{(6/7, 0, 1/7), (6/7, 0, 1/7)\}$. Hence, symmetry does not select a unique Nash equilibria for either game.

Combining both symmetry and payoff-dominance, however, selects $\{e_2, e_2\}$. Hence, a deductive selection theory that gives priority to symmetry and payoff-dominance would select $\{e_2, e_2\}$ as the unique solution to the tacit bargaining games D and DS. (This is the equilibrium selected by the Harsanyi/Selten (1988) solution concept.) This equilibrium is, of course, the one in which the players divide the dollar equally.

While deductive equilibrium analysis predicts equal-division in both game D and DS, there is an important difference between them. A *secure* action is an action whose smallest payoff is at least as large as the smallest payoff of any other feasible action. In game DS, a player's unique secure action is action 1, which insures a player of at least 30 cents; but $\{e_1, e_1\}$ is not a mutual best response outcome. (It is, however, a rationalizable strategy combination, see Berneim 1984.) The salience of the secure action plays an important role in the results reported below.

This section has analyzed the tacit bargaining games D and DS using only the information contained in the descriptions **D** and **DS**. The principles of symmetry and payoff-dominance imply equal-division in both games. Selecting an equilibrium based on deductive principles, however, ignores the context in which the strategic situation arose. In the next section, we examine the possibility that conventions that prescribe an unequal-division may emerge in communities of anonymously interacting players.

2.2 Conventions and their Origin

Repeated interaction may allow players to learn to coordinate on a mutual best response outcome. Following Lewis (1969), we distinguish between historical precedents in repeated games and conventions in evolutionary games. Selecting a mutual best response outcome based on precedent requires actors to focus on some salient analogy to a shared past instance of the present observable game and to expect others to focus on the same analogy.

The concept of a convention attempts to generalize this insight to evolutionary games. In an evolutionary game, the game S is played by n actors randomly drawn from a community C. In general, a community C will consist of heterogenous populations, where this heterogeneity may arise either from strategic asymmetries in S or from non-strategic asymmetries in the matching protocol. Even when S is played by strangers, the knowledge that they are members of C may allow them to coordinate on a mutual best response outcome.

A regularity R in the behavior of members of a community C when they are agents in a recurrent situation S is a *convention* if and only if, in any instance of S among members of C, (1) almost everyone conforms to R; (2) it is mutual knowledge that almost everyone conforms to R; (3) almost everyone prefers to conform to R on condition that almost all of the others do, since uniform conformity to R is a strict equilibrium in S and enough people conform to R to make conforming a strict best response. How do conventions evolve?

An evolutionary analysis focuses on the distribution of actions in populations of anonymously interacting players.[4] Here we consider two random pairwise matching protocols either of which could produce the strategic situation analyzed in section 2. In the one population protocol, players cannot distinguish their role as either a row or a column player. In the two population protocol, players always play the role of either a row or a column player.[5] The protocol describing how players interact plays an important part in determining the dimension of the resulting dynamical system and the stability of the dynamical system's fixed points.

Let k index the interacting populations, which are assumed to be large. As before, let i index the actions available to each member of population k, that is, $i = 1, 2, 3$. Let s_i^k denote the fraction of population k using action i and let s^k denote the vector (s_1^k, s_2^k, s_3^k). All feasible population frequency vectors s^k lie on the simplex $\mathbf{S}^3$. (Notice that this is the same space as an individual player's strategy space.) The state space $\mathbf{S}$ equals $\mathbf{S}^3$ in the one population case and $\mathbf{S}^3 \times \mathbf{S}^3$ in the two population case. Let s denote an element of the state space $\mathbf{S}$.

A dynamical system provides a theory of the origin of convention in the following sense: Given an initial state $s(0)$ with solution curve $s(\mathrm{t})$, the dynamic predicts that after a transition period every state will stay so close to s^* as to be indistinguishable from it. When s^* is consistent with a strict equilibrium of the related game, the dynamic predicts the emergence of the specific convention s^* for any initial condition contained in s^*'s basin of attraction, $\mathbf{B}(s^*)$. Hence, the theory predicts whether and, if so, which convention will emerge using information on the games description, the matching protocol, the initial state $s(0)$, and assumptions about adaptive behavior.

Replicator dynamics arise if the growth rate of a behavior in a population is equal to its relative "fitness". Assume that the "fitness" of an action is equal to its expected payoff in the current state. Recall that A denotes a payoff matrix, either D or DS. The expected payoff to a player using action i with one population is $e_i.A.s$.

[4] See Van Damme (1987), Samuelson and Zhang (1992), and Friedman (1991).

[5] We will continue to use the word symmetric in the strategic sense of symmetric payoff functions and identical strategy spaces. Biologists call the one population protocol a symmetric contest and the two population protocol an asymmetric contest.

The average expected payoff in state s is $s.A.s$. Hence, the replicator dynamic for payoff matrix A with one population is given by the following system of non-linear differential equations:

$$\frac{ds_i}{dt} = s_i(e_i.A.s - s.A.s), \quad i = 1, 2, 3. \tag{1}$$

We are interested in finding the stable fixed points of this system and the basin of attraction of the stable fixed points. From the biology literature, we know that the stable fixed points of the replicator dynamic are a subset of the Nash equilibria of the related game A, see Hofbauer and Sigmund (1988). Rather than attempting to derive closed form solutions for the dynamical systems considered in this paper, we will rely mainly on phase portrait methods and numerical analysis: specifically, the Runge-Kutta method described in Maeder (1990, p. 172).

The stable fixed points of game D under system (1) are the states e_2 and $\{3/5, 0, 2/5\}$, while $\{15/37, 12/37, 10/37\}$ is a saddle point and, hence, unstable. The stable fixed points of game DS under system (1) are the states e_2 and $\{6/7, 0, 1/7\}$, while $\{2/5, 3/5, 0\}$ is a saddle point and, hence, unstable. The stable fixed point e_2 has a straight forward interpretation as the symmetric efficient Nash equilibrium of game D or DS. Since all members of the population are choosing action 2, any pairing has both members choosing action 2. However, the state $\{6/7, 0, 1/7\}$ does not require any player to actually use the mixed strategy $\{6/7, 0, 1/7\}$. Instead, it requires that 6/7ths of the players choose action 1 and 1/7th of the players choose action 3.[6]

Figure one graphs some representative solution curves on the simplex $\mathbf{S}^3$ for game DS. Since extinct actions cannot regenerate under system (1), e_1, e_2, and e_3 are fixed points of the replicator dynamic. Notice that $\{6/7, 0, 1/7\}$ and $\{2/5, 3/5, 0\}$ are also fixed points. However, only e_2 and $\{6/7, 0, 1/7\}$ are stable fixed points, which are denoted with oversized dots. The solution curve that converges to $\{2/5, 3/5, 0\}$ divides the simplex into an "east" region, which is the basin of attraction $\mathbf{B}(e_2)$, and a "west" region, which is the basin of attraction $\mathbf{B}(\{6/7, 0, 1/7\})$.

The shaded polygon in figure one represents those states that satisfy conditions (1) and (3) of our definition of convention. While one would like to know if a state satisfies the mutual knowledge condition (2), for practical purposes it is extremely difficult to observe other people's beliefs and we will not attempt to do so in our experiment. Notice that the only convention that can emerge in game DS with one population is e_2: equal-division.[7]

In the two population case, the expected payoff to a player choosing an action depends on his membership in either the row or column population. Let k equal to

---

[6] Crawford (1989) uses a disaggregated dynamical analysis to demonstrate that only purified states can be stable.

[7] In this paper, we use population dynamics to explain the origin of convention. At this level of aggregation, it is not possible to distinguish between the mixed strategy equilibrium and its purification. For finite populations that allow purification, such as with 14 people (where 12 choose action 1 and 2 choose action 3) the purified mixed strategy equilibrium is a strict equilibrium and, hence, there would be states that satisfy our definition of convention. Since we use 8 people in this treatment, which does not allow purification, we will not consider this complication further.

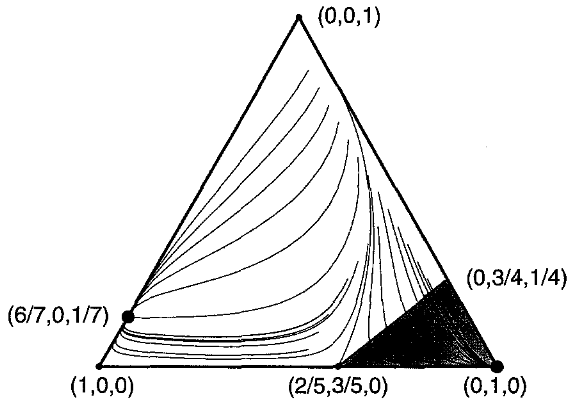

Fig. 1. Game DS with one population

r(c) denote the row (column) population. A row player's expected payoff to action i is $e_i.A.s^c$, while a column player's expected payoff to action i is $e_i.A.s^r$. In state s, the average expected payoff of the row population is $s^r.A.s^c$ and of the column population is $s^c.A.s^r$. Hence, the replicator dynamic for payoff matrix A with two populations is given by the following system of differential equations:

$$\begin{aligned} \frac{ds_i^r}{dt} &= s_i^r(e_i.A.s^c - s^r.A.s^c), \quad i = 1, 2, 3, \\ \frac{ds_i^c}{dt} &= s_i^c(e_i.A.s^r - s^c.A.s^r), \quad i = 1, 2, 3. \end{aligned} \tag{2}$$

The stable fixed points of the dynamical system given by system (2) are $\{e_1, e_3\}$, $\{e_2, e_2\}$, and $\{e_3, e_1\}$ for both game D and DS, which correspond to the strict equilibria of game D and DS. Notice that the set of stable fixed points now includes the 60–40 and 40–60 divisions. Hence, the replicator dynamic predicts that unequal-division is a potential convention for both game D and DS under the two population matching protocol.

In order to illustrate this possibility in two dimensions, suppose that for some reason action 2, equal-division, was extinct. This special case has the desirable property that we can study the phase portrait of the system, which looks similar to phase portraits derived for the Battle-of-the-Sexes game, see for example Friedman (1991, figure 3) or Sugden (1986, figure 3.3).

Figure two graphs paths of system (2) originating from initial conditions of the form $\{(s_1^r, 0, 1 - s_1^r), (s_1^c, 0, 1 - s_1^c)\}$, which can be represented on the unit square. Fixed points are denoted by dots and stable fixed points – $\{e_1, e_3\}$ and $\{e_3, e_1\}$ – by oversized dots. The 45 degree line divides the space into two basins of attraction. Notice that the fixed point $\{(6/7, 0, 1/7), (6/7, 0, 1/7)\}$, which was stable with one population, is now a saddle point and, hence, unstable. (Note that (6/7, 0, 1/7) is approximately equal to (.86, 0, .14).) Should action two become extinct, the replicator dynamic predicts that either $\{e_1, e_3\}$ or $\{e_3, e_1\}$ will emerge as the convention after a transition period. Consequently, the replicator dynamic predicts that with two populations it is not only possible for the 50–50 division to emerge as a convention,

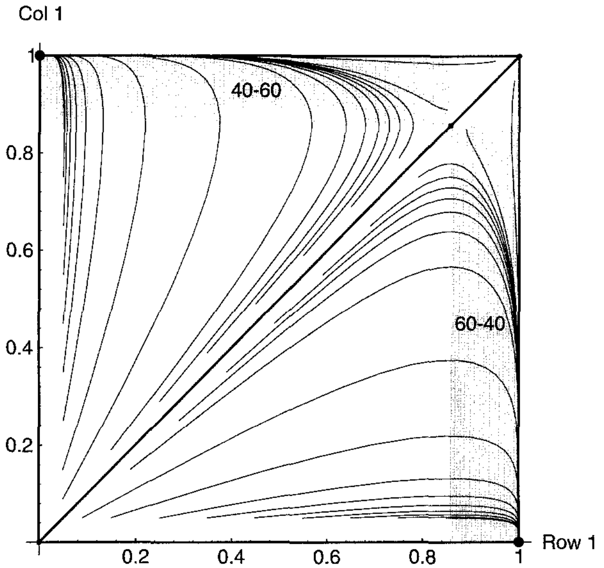

Fig. 2. Game DS with action two extinct and two populations

but it is also possible for either the 60–40 or 40–60 division to emerge as a convention.

The states that satisfy our definition of convention are a subset of a strict equilibrium's basin of attraction. Any state below the horizontal line going through the point (6/7, 6/7) implies that a row player's best response is e_1, while any point to the right of the vertical line going though (6/7, 6/7) implies that a column player's best response is e_3. Hence, the lower right rectangle of figure two includes all of the states with action 2 extinct for which we say that the unequal-division convention $\{e_1, e_3\}$ has emerged in the community of row and column players. Similarly, the upper left rectangle of figure two includes all of the states with action 2 extinct for which we say that the unequal-division convention $\{e_3, e_1\}$ has emerged in the community of row and column players.

3 Experimental Design

Human subjects played either game D or DS under either a one or two population protocol. Eight subjects participated in each session using a one population matching protocol and fourteen subjects participated in each session using a two population matching protocol: seven row and seven column subjects. The subjects had complete information about both their own and everybody else's payoff matrix. They chose actions 1, 2, or 3 each period. The subjects' actions were then randomly paired to determine an outcome for each pair. The subjects were informed that they were being randomly paired. Since outcomes were reported privately, subjects could not use common information about the outcomes in previous periods to coordinate on an equilibrium. Subjects confronted an anonymous participant each period.

Monetary payments were used to induce preferences. The number in the cell $\{i, j\}$ of the payoff matrix, which was either D or DS, denotes the number of dimes earned by a subject given they chose action i and the other participant they were currently paired with chose action j. Under the one population protocol the payoff table only showed their own earnings, and subjects were instructed on how to derive the other participant's earnings from the payoff table. Under the two population protocol a cell in the payoff table, which is formed by A, A^T, gave the earnings for both the row and column participant respectively. The earnings tables used in the experiment are reported in table one.

No preplay communication of any kind was allowed. In sessions one to eleven the subjects communicated using reporting sheets, which were collected by the experimenters. The reporting sheets were paired, transcribed to a result sheet, and the result sheet was returned. Subjects were told that they could check our transcription at the end of the session for accuracy. Hence, subjects knew they were not playing against a machine or against the same subject. This is important because a machine would not be expected to use deductive selection principles as human subjects do, especially if the subjects think the experimenter is attempting to deceive them, and repeated play with the same subject might suggest using repeated game strategies, like attempting to build a reputation for fairness. In sessions twelve through fourteen,

Table 1. Earnings table for one and two population treatments

One Population

OTHER PARTICIPANT'S CHOICE

	1	2	3
	Your Earnings	Your Earnings	Your Earnings
1	30	30	60
2	0	50	0
3	40	0	0

Two Population

COLUMN CHOICE

	1			2			3		
	Row Earnings		Column Earnings	Row Earnings		Column Earnings	Row Earnings		Column Earnings
1	30	;	30	30	;	0	60	;	40
2	0	;	30	50	;	50	0	;	0
3	40	;	60	0	;	0	0	;	0

messages were sent electronically on a PC-network, which allowed us to run more periods in a session. Sessions one through eleven were designed to match subjects 45 times, while sessions twelve through fourteen were designed to match subjects 70 times.

The subjects were recruited from undergraduate economic classes at Texas A&M University. A total of 172 subjects participated in the experiment. After reading the instructions, but before the session began, the subjects filled out a questionnaire to determine that they understood how to read payoff tables. In the forty-five period sessions, which take about three hours to conduct, a subject has the opportunity to divide $45 dollars and would earn $22.50 if subjects always choose the 50–50 division. In the seventy period sessions, which take about two hours to conduct, a subject has the opportunity to divide $70 and would earn $35 if subjects always choose the 50–50 division. Table two summarizes the experimental design.

4 Experimental Results

4.1 Divide-a-Dollar

Sessions one and two used payoff matrix D and two populations. Equal-division was a salient selection principle in this treatment. In the final five periods of sessions one and

Table 2. Experimental design

Session	Game	Protocol	Periods
1	D	Two Populations	45
2	D	Two Populations	45
3	DS	One Population	45
4	DS	One Population	45
5	DS	One Population	45
6	DS	One Population	45
7	DS	Two Populations	45
8	DS	Two Populations	45
9	DS	Two Populations	45
10	DS	Two Populations	45
11	DS	Two Populations	45
12	DS	Two Populations	70
13	DS	Two Populations	70
14	DS	Two Populations	50[1]

[1] A network failure occurred in period 52. We truncate the data in period 50 so that periods are divisible by 5.

two, all 70 pairings resulted in equal-division.[8] Hence, everyone in both communities conformed to the equal-division convention in the final state.

In session one, the initial state was $\{2, 30, 3, 6, 25, 4\}$ and dividing by 35 gives the frequency distribution. Action two is a row player's strict best response against the column frequency distribution of $\{0.17, 0.71, 0.12\}$ and action two is a column player's strict best response against the row frequency distribution $\{0.06, 0.85, 0.09\}$. Hence, enough people conformed to the equal-division convention in state one to say that equal-division was the convention in the initial state of session one. A similar analysis reveals that equal-division was the convention in the initial state of session two. The fact that almost everyone conformed to the equal-division convention from the very beginning of sessions one and two is consistent with either a strategic analysis or with the idea that subjects brought the equal-division convention into the experiment from some larger community.[9]

4.3 Divide-a-Dollar with Security and One Population

Sessions three through six used payoff matrix DS and one population. Figures three through six graph the data for sessions three through six. We aggregate the data over five period intervals, for example, point one represents the population frequency of the respective actions in period 1 to 5, point two represents the population frequency of the respective actions in period 6 to 10, and so on. We time aggregate the data to reduce idiosyncratic noise.

All four sessions start in basin of attraction $\mathbf{B}(\{6/7, 0, 1/7\})$. While action 2 does become extinct as predicted, none of the sessions converge to the state $\{6/7, 0, 1/7\}$. Instead, there are too many subjects choosing action 3 and not enough subjects choosing the secure action, 1. Moreover, this phenomena appears to be systematic and behaviorally stable.

States evolve away from the stable fixed point $\{6/7, 0, 1/7\}$ about one-third of the time, which violates the predictions of the replicator dynamic. These violations occur even though we have time aggregated the data in order to reduce this kind of noise. This data is inconsistent with a deterministic dynamical system model of the population frequencies.

The only convention that could have emerged in this treatment was $\{e_2\}$: equal-division. However, the equal-division action quickly became extinct. The replicator dynamic accurately predicts that this convention would not emerge given the observed initial state. Security completely undermines the salience of symmetry and efficiency in sessions three through six.

---

8 A data appendix reports the raw data for all fourteen experiments.

9 An alternative interpretation, which is often used in the sequential bargaining literature, is that subjects have a taste-for-fairness, see Ochs and Roth (1989) and references cited there. Hoffman and Spitzer (1985) demonstrate that a taste-for-fairness can be systematically influenced by experimental treatments. Binmore *et al.* (1991) suggest that understanding the salience of equal-division will require a theory of limited rationality and rules-of-thumb, see also Johnson *et al.* (1991).

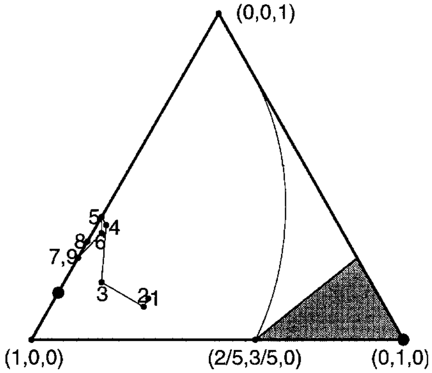

Fig. 3. Time aggregated session three data

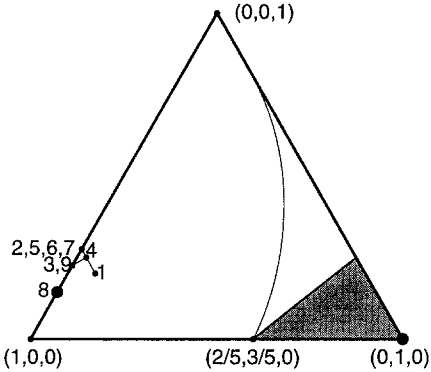

Fig. 4. Time aggregated session four data

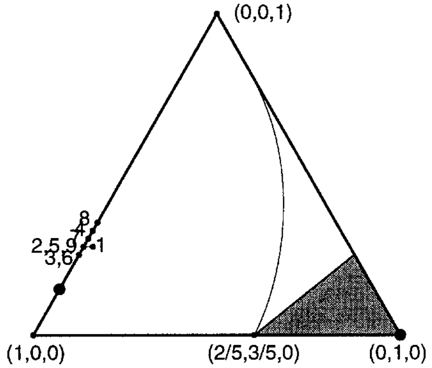

Fig. 5. Time aggregated session five data

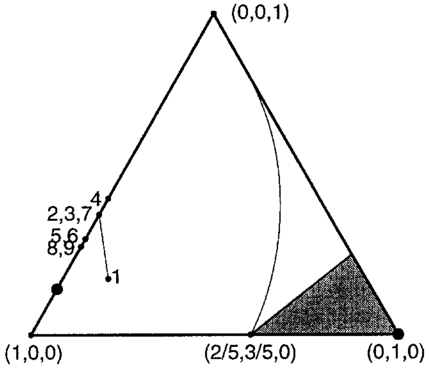

Fig. 6. Time aggregated session six data

4.2 Divide-a-Dollar with Security and Two Populations

Sessions seven through fourteen used payoff matrix DS and two populations. Figures seven through fourteen graph the data for sessions seven through fourteen. We aggregate the data over five period intervals. The number of times action 1 was chosen by row subjects in a five period interval, which can range from 0 to 35, is measured on the horizontal axis and the number of times action 1 was chosen by column subjects in a five period interval, which can range from 0 to 35, is measured on the vertical axis. Point one is for periods 1 to 5, point two is for periods 6 to 10, and so on.

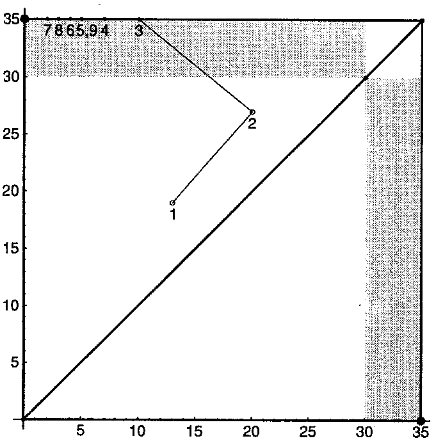

Fig. 7. Time aggregated session seven data

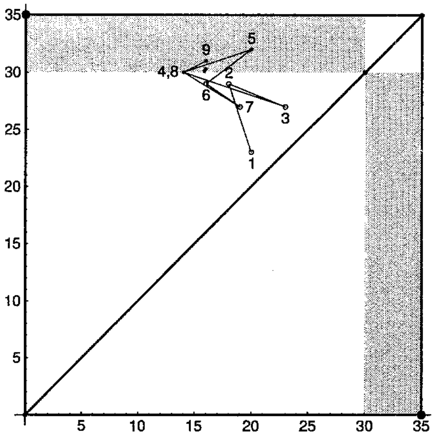

Fig. 8. Time aggregated session eight data

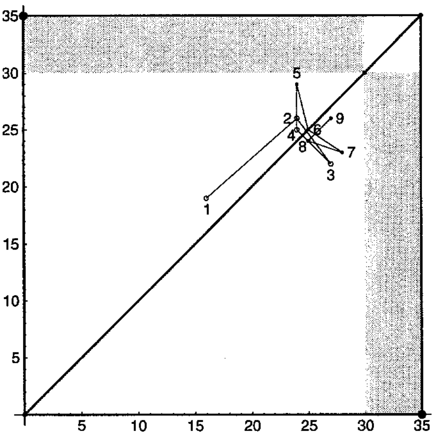

Fig. 9. Time aggregated session nine data

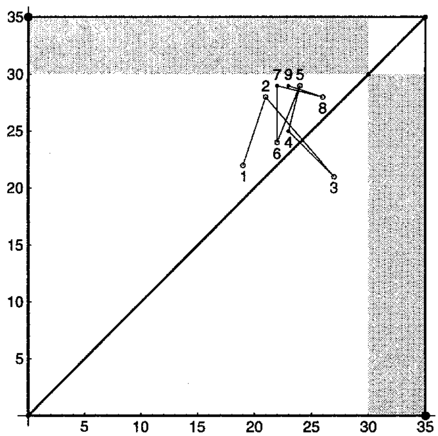

Fig. 10. Time aggregated session ten data

Solid points denote points in which action 2 was extinct in both the row and column populations. Circles denote states in which at least one subject chose action 2 in one of the five periods represented by the circle. Several numbers next to a point indicates that that point was repeated.

In session seven, the initial state was $\{13, 13, 9, 19, 14, 2\}$, see figure seven. The replicator dynamic predicts that the 40–60 convention will emerge given this initial state.[10] Notice that states 3 through 9 are denoted with solid points, which indicates

[10] It is not possible to see this in the figure since action 2 is not extinct in the initial state. However, using state one as an initial condition for system (2) it can be easily checked. All of the statements about the initial states being contained in a basin of attraction were checked this way.

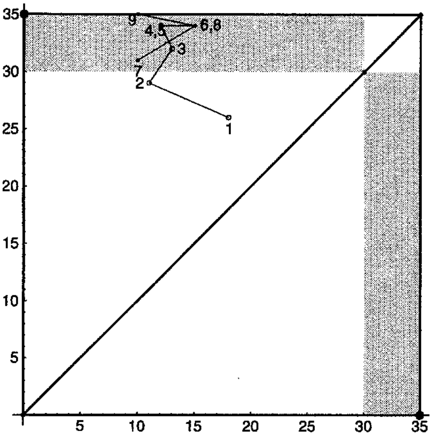

Fig. 11. Time aggregated session eleven data

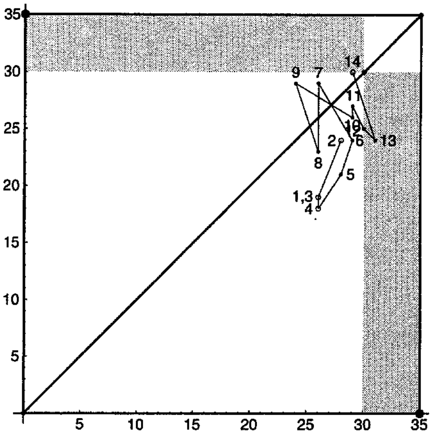

Fig. 12. Time aggregated session twelve data

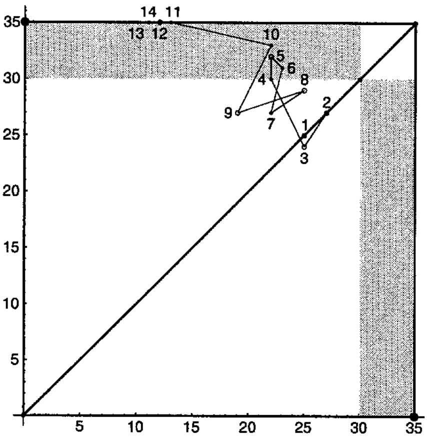

Fig. 13. Time aggregated thirteen session data

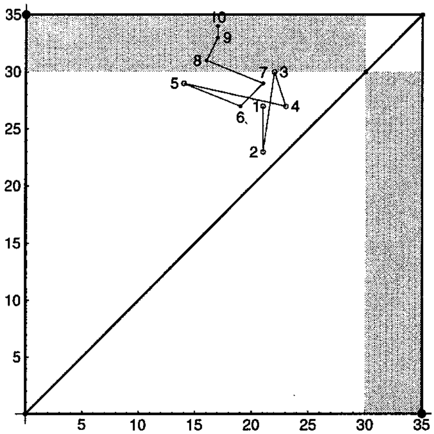

Fig. 14. Time aggregated session fourteen data

that action 2 – equal-division – is extinct in this community. The evolution of states eight and nine away from $\{e_3, e_1\}$ can be entirely accounted for by the behavior of a single row subject. Since it is a strict best response to conform to the 40–60 convention for both row and column subjects, an unequal-division convention has emerged in this community.

In session eight, state one is contained in $\mathbf{B}(\{e_3, e_1\})$, see figure eight. However, the evolution of states does not closely track the path predicted by the replicator dynamic. Nevertheless, by state nine action two is extinct and the predicted unequal-division convention has emerged in this community.

While sessions seven and eight roughly conform to the predictions of the replicator dynamic, session nine does not. State one of session nine lies in the basin of attraction $\mathbf{B}(\{e_3, e_1\})$. Action two becomes extinct by state five, but the states do not evolve towards either $\{e_1, e_3\}$ or $\{e_3, e_1\}$, see figure nine. No convention emerged after forty-five periods of play. State nine is closest to the unstable equilibrium $\{(6/7, 0, 1/7), (6/7, 0, 1/7)\}$. Symmetry appears to have been a salient selection principle to the subjects in session nine.

In session ten, state one is contained in $\mathbf{B}(\{e_3, e_1\})$. Action 2 is extinct in states four, seven and nine, see figure ten. No convention emerged in session ten even after forty-five periods of play. [It was our concern that if the session had continued the predicted convention would have emerged that lead us to conduct the 70 period treatments on the computer.]

In session eleven, state one is contained in $\mathbf{B}(\{e_3, e_1\})$. Action 2 becomes extinct by state six, see figure eleven. The unequal-division convention $\{e_3, e_1\}$ emerged in session eleven.

In session twelve, state one is contained in $\mathbf{B}(\{e_1, e_3\})$. Action 2 becomes extinct by state five, see figure twelve. While state thirteen satisfies our definition of a convention – and it is the predicted convention, state fourteen does not. State fourteen is very close to the unstable equilibrium $\{(6/7, 0, 1/7), (6/7, 0, 1/7)\}$. Symmetry seems to have been a salient selection principle in the final state of session twelve.

In session thirteen, state one is contained in $\mathbf{B}(\{e_3, e_1\})$. Action 2 is extinct in states four, six, seven, eleven, thirteen, and fourteen, see figure eleven. While no convention had emerged after forty-five periods of play, the extra twenty-five periods allows the unequal-division convention $\{e_3, e_1\}$ to eventually emerge in session thirteen as predicted.

In session fourteen, state one is contained in $\mathbf{B}(\{e_3, e_1\})$. Action 2 becomes extinct by state six, see figure twelve. The unequal-division convention $\{e_3, e_1\}$ emerges by state eight.[11]

4.4 Statistical Tests for Stability, Symmetry, and Mixed Strategy Equilibrium

An important question is whether the observed outcomes are behaviorally stable. Table three reports Fisher's exact (two-tail) tests for stability with respect to time. Whether contrasting the last five periods versus the preceding five periods or the last ten periods versus the preceding ten periods, we fail to reject the hypothesis of stable behavior in the final periods of any session.

The principle of symmetry suggests that row and column subjects should behave similarly, since they are similarly endowed. Table four reports Fisher's exact (two-tail) tests of the hypothesis of symmetric row and column behavior. In the initial five periods, we fail to reject the hypothesis of symmetric behavior for any two population session at the five percent level of statistical significance; although, sessions seven and

[11] Van Huyck, et al. (1989) report an experiment in which 30 subjects were randomly matched each period to play game DS with two populations and this was repeated for fifteen periods. Only 2 out of 225 pairs coordinated on the equal division equilibrium. Most subjects chose their secure action. This experiment led us to expect the results reported in this paper.

Table 3. Fisher's exact (two-tail) tests for stability with respect to time

Session	Last five vs. preceding five periods: (Prob.).	Last ten vs. preceding ten periods: (Prob.).
1	0.866	1.000
2	1.000	1.000
3	0.803	0.861
4	0.568	0.260
5	0.630	0.729
6	1.000	0.493
7	0.766	0.865
8	0.961	0.429
9	0.931	0.984
10	0.887	0.843
11	0.476	0.470
12	0.387	0.952
13	1.000	0.731
14	1.000	0.232

Table 4. Fisher's exact (two-tail) tests: Symmetric row and column behavior

Session	Periods	
	First five (Prob.)	Last five (Prob.)
1	0.275	1.000
2	0.478	1.000
7	0.068	*0.000*
8	0.782	*0.000*
9	0.806	1.000
10	0.801	0.171
11	0.057	*0.000*
12	0.219	1.000
13	0.695	*0.000*
14	0.312	*0.000*

eleven are very close. However, in the last five periods, we can reject the hypothesis of symmetric behavior for sessions seven, eight, eleven, thirteen, and fourteen, which are the sessions in which unequal-division conventions emerged.

We fail to reject the hypothesis of symmetric behavior in the last five periods of sessions nine, ten, and twelve. The observed symmetric behavior suggests treating sessions nine, ten, and twelve as if subjects ignored their labels, and, hence, as if there was only one population.

Table 5. Fisher's exact (two-tail) tests: Observed frequencies in the last ten periods versus the mixed strategy equilibrium: $\{.86, 0, .14\}$

Session	Probability
3	*0.049*
4	0.521
5	*0.013*
6	*0.049*
9	*0.011*
10	*0.048*
12	0.420

The equal-division convention never emerged in any of the one population sessions using payoff table DS – sessions three through six – which is the only possible convention for this treatment. Instead, action 2 became extinct and behavior clustered near the mixed strategy equilibrium $\{6/7, 0, 1/7\}$. Table five reports Fisher's exact (two-tail) tests of the hypothesis that the observed behavior in the last ten periods was generated by the mixed strategy equilibrium $\{6/7, 0, 1/7\}$ for the DS one population sessions and the DS two population sessions that pass the symmetry test. We can reject convergence to the mixed strategy equilibrium $\{6/7, 0, 1/7\}$ for sessions three, five, six, nine, and ten. These five sessions are all biased in the same direction: there are too few subjects playing their secure action.[12]

5 Summary

Table six summarizes our results. The results for our divide-a-dollar treatment conform to the findings of previous researchers: equal-division is an accurate predictor of behavior. However, the divide-a-dollar-with-security treatments demonstrate that security is a more salient principle than equal-division: at least for the parameters used in our experiment. In eleven of twelve sessions, the equal-division action is extinct by the end of the session.

In the four sessions using game DS and one population, the only convention that can emerge is equal-division. Given the initial state, the replicator dynamic predicts that the equal-division convention will not emerge and it does not. In eight sessions using game DS and two populations, the replicator dynamic predicts that an unequal-division convention will emerge and in five of them the predicted unequal-division convention does emerge. The experiment demonstrates the importance of the matching protocol in determining the outcome of symmetric bargaining games.

[12] A similar bias away from the mixed strategy equilibria is present in Cooper et al's (1991) battle-of-the-sexes experiments and in Ochs (1990) matching experiments both of which use the Roth/Malouf technique to control risk preference.

Table 6. Summary

Ses.	Initial State: First five periods.	Predicted Conven.	Final State: Last five periods.	Actual Conven.	Avg. earnings per period by population
1	$\{2, 30, 3, 6, 25, 4\}$	$\{e_2, e_2\}$	$\{0, 35, 0, 0, 35, 0\}$	$\{e_2, e_2\}$	$\{46, 47\}$
2	$\{3, 30, 2, 4, 26, 5\}$	$\{e_2, e_2\}$	$\{0, 35, 0, 0, 35, 0\}$	$\{e_2, e_2\}$	$\{47, 47\}$
3	$\{25, 10, 5\}$	None	$\{30, 0, 10\}$	None	$\{35\}$
4	$\{29, 3, 8\}$	None	$\{31, 0, 9\}$	None	$\{35\}$
5	$\{28, 1, 11\}$	None	$\{29, 0, 11\}$	None	$\{36\}$
6	$\{28, 5, 7\}$	None	$\{29, 0, 11\}$	None	$\{36\}$
7	$\{13, 13, 9, 19, 14, 2\}$	$\{e_3, e_1\}$	$\{5, 0, 30, 35, 0, 0\}$	$\{e_3, e_1\}$	$\{36, 50\}$
8	$\{20, 5, 10, 23, 4, 8\}$	$\{e_3, e_1\}$	$\{16, 0, 19, 31, 0, 4\}$	$\{e_3, e_1\}$	$\{33, 39\}$
9	$\{16, 13, 6, 19, 11, 5\}$	$\{e_3, e_1\}$	$\{27, 0, 8, 26, 0, 9\}$	None	$\{33, 33\}$
10	$\{19, 8, 8, 22, 6, 7\}$	$\{e_3, e_1\}$	$\{23, 0, 12, 29, 0, 6\}$	None	$\{32, 34\}$
11	$\{18, 8, 9, 26, 7, 2\}$	$\{e_3, e_1\}$	$\{10, 0, 25, 35, 0, 0\}$	$\{e_3, e_1\}$	$\{32, 43\}$
12	$\{26, 3, 6, 19, 4, 12\}$	$\{e_1, e_3\}$	$\{29, 1, 5, 30, 0, 5\}$	None	$\{35, 33\}$
13	$\{25, 3, 7, 25, 5, 5\}$	$\{e_3, e_1\}$	$\{11, 0, 24, 35, 0, 0\}$	$\{e_3, e_1\}$	$\{34, 40\}$
14	$\{21, 9, 5, 27, 6, 2\}$	$\{e_3, e_1\}$	$\{17, 0, 18, 34, 0, 1\}$	$\{e_3, e_1\}$	$\{32, 38\}$

While the gross predictions of the dynamical systems approach are consistent with the data, that data cannot support the conclusion that the replicator dynamic is a satisfactory explanation of the observed behavior. Our principle finding is that behavior conforms to the inductive rather than deductive approach. The replicator dynamic is a tractable example of this alternative approach. We have also studied numerous dynamics including the linear dynamic and the migration dynamic. However, our data does not discriminate between these alternative dynamics. In some related research, we have examined the predictions of the replicator dynamic for an augmented Rock-Paper-Scissors game and found that the discrete replicator dynamic makes particularly bad predictions. In our view, discovering the dynamic that provides robust predictions of strategic behavior in repeated or evolutionary games is an exciting area of future research.

The sixth column of table six reports average earnings per period by population. If subjects always divided the dollar equally, they would have earned 50 cents each period. The average subject whether labeled row or column earns almost 50 cents per period in the two divide-a-dollar sessions. In the four sessions using DS and one population, subjects' inability to coordinate on the equal-division convention costs the average subject about 14 cents per period or about \$6.30 per session. The losses are even larger for the three two population sessions in which no convention emerged: sessions nine, ten, and twelve. In the five sessions in which an unequal-division convention emerged, the average favored subject earned between 6 and 14 cents per period or between \$2.70 and \$6.30 per session more than the average disadvantaged subject.

Appendix A

One Population Instructions

General: You are about to participate in an experiment in the economics of decision making. If you follow the instructions and make appropriate decisions, you may make an appreciable amount of money. These earnings will be paid to you in cash at the end of the experiment.

This is a scientific experiment. As part of the scientific method in this experiment it is important that you remain *SILENT* and *DO NOT LOOK AT OTHER PEOPLES' WORK.* If you have any questions or need assistance of any kind, please raise your hand and an experimenter will come to you. IF YOU TALK, LAUGH, SIGH, GIGGLE, EXCLAIM OUT LOUD, OR MAKE NOISES OF ANY KIND, YOU WILL BE ASKED TO LEAVE THE EXPERIMENT, AND you will *NOT* be paid. We expect and appreciate your cooperation.

Specific: The experiment consists of forty-five separate decision making periods. In each period you will be randomly paired with one other participant. There will be 8 participants including yourself in the experiment. *Each period* you will be randomly matched with another participant. Hence, you will have a 1 in 7 chance of being matched with an individual participant.

At the beginning of each period, everyone will choose an action. An earnings table is provided which tells you the earnings you receive given the action you chose and the action the other participant you are currently matched with chose. The actions a participant may choose are 1, 2, or 3. Please look at this earnings table now. All participants have the same earnings table.

The earnings each period will be found in the box determined by the action you chose and the action the other participant you are currently matched with chose. Your action determines the row and the other participant's action determines the column of the earnings table. The value in the box determined by the intersection of the row and column chosen is the amount of money that you earn in the current period. For example:

- If you chose 2 and the other participant chose 1, then you earn 0 cents. [Notice that you can calculate how much the other participant earns by reversing your positions. The other participant chose 1, which determines the row of the other participants earnings table, and you chose 2, which determines the column. Hence, the other participant earns 30 cents.]
- If you chose 1 and the other participant chose 2, then you earn 30 cents. [Again, notice that by reversing positions you can calculate that the other participant earns 0 cents.]

Reporting and Result Sheets: At the *BEGINNING* of every period, each participant will write on their REPORTING SHEET:

(1) their participant number,
(2) the current period,
(3) their choice [circle the number you wish to choose].

This reporting sheet will be picked up by the experimenter every period.

Each period the experimenter will then match your choice with the choice of the other participant you are randomly paired with for this period. The experimenter will then return to you a RESULT SHEET which contains the action chosen by the participant you are currently paired with. You will then calculate your earnings.

Recording Procedures: Your *RECORD SHEET* assigns you a participant number. Your record sheet has the following entries: PERIOD, BALANCE, YOUR CHOICE, OTHER'S CHOICE, and YOUR EARNINGS. At the *beginning* of each period, record:

(1) the current period,
(2) your choice,
(3) your balance.

At the *END* of each period you will record your earnings on your RECORD SHEET:

(1) the choice of the participant you were randomly paired with that period
(2) your earnings for this period, which is found using the earnings table
(3) your balance for next period.

In the first period your BALANCE is zero. In the second period your BALANCE is the value of your earnings in the first period. In the third period your BALANCE is the value of your BALANCE in the second period plus the value of your earnings in the second period, and so on.

Please keep accurate records throughout the experiment. If you have any questions, please raise your hand now.

To be sure that everyone understands the instructions please fill out the QUESTIONS SHEET. An experimenter will come by to pick it up. DO NOT PUT YOUR NAME OR PARTICIPANT NUMBER ON THE QUESTION SHEET. If there are any mistakes on any of the question sheets the experimenter will go back over this part of the instructions again.

Again, the experiment will last for forty-five periods, and will use the earnings table in this packet. It is important that you remain silent and do not look at other peoples' work. If you have a question please raise your hand.

WE WILL BEGIN THE EXPERIMENT NOW.

Two Population Instructions

General: You are about to participate in an experiment in the economics of decision making. If you follow the instructions and make appropriate decisions, you may make an appreciable amount of money. These earnings will be paid to you in cash at the end of the experiment.

This is a scientific experiment. As part of the scientific method in this experiment it is important that you remain *SILENT* and *DO NOT LOOK AT OTHER PEOPLES' WORK.* If you have any questions or need assistance of any kind, please raise your hand and an experimenter will come to you. IF YOU TALK, LAUGH, SIGH, GIGGLE, EXCLAIM OUT LOUD, OR MAKE NOISES OF ANY KIND, YOU WILL BE ASKED TO LEAVE THE EXPERIMENT, AND you will *NOT* be paid. We expect and appreciate your cooperation.

Specific: The experiment consists of forty-five separate decision making periods. In each period you will be randomly paired with one other participant. You will be designated as either a row participant or a column participant below. There will be 7 row participants and 7 column participants. *Each period* you will be randomly assigned to a participant, either a column participant if you are a row participant or a row participant if you are a column participant. Hence, you will have a 1 in 7 chance of being matched with an individual participant.

At the beginning of each period, you and the other participant will choose an action. An earnings table is provided which tells you the earnings you receive given the action you and the other participant chose. The actions a row player may choose are row 1, row 2, or row 3. Similarly, the actions the column player may choose are column 1, column 2, or column 3. Please look at this earnings table now.

The earnings each period – both for you and the participant you are currently paired with – will be found in the box determined by the row and column action. Notice there are two values in each box. The first value in the earnings box is the amount of money the row participant earns, and the second value in each earnings box is the amount of money that the column participant earns. For example:

- If the row participant chooses row 2 and the column participant chooses column 1, then the row participant earns 0 cents and the column participant earns 30 cents.
- If the row participant chooses row 1 and the column participant chooses column 2, then the row participant earns 30 cents and the column participant earns 0 cents.

Reporting and Result Sheets: At the *BEGINNING* of every period, each participant will write on their REPORTING SHEET:

(1) their participant number,

(2) the current period,
(3) their choice [circle the number you wish to choose].

This reporting sheet will be picked up by the experimenter every period. Each period the experimenter will then match your choice with the choice of the other participant you are matched with for this period. The experimenter will then return to you a RESULT SHEET which contains the action chosen by the participant you are currently paired with. You will then calculate your earnings.

Recording Procedures: Your *RECORD SHEET* designates you as a ROW or COLUMN participant and assigns you a participant number. Your record sheet has the following entries: PERIOD, BALANCE, YOUR (Row/Column) CHOICE, OTHER'S (Column/Row) CHOICE, and YOUR EARNINGS. At the *beginning* of each period, record:

(1) the current period,
(2) your choice,
(3) your balance.

At the *END* of each period you will record your earnings on your RECORD SHEET:

(1) the choice of the participant you were randomly paired with that period
(2) your earnings for this period, which is found using the earnings table
(3) your balance for next period.

In the first period your BALANCE is zero. In the second period your BALANCE is the value of your earnings in the first period. In the third period your BALANCE is the value of your BALANCE in the second period plus the value of your earnings in the second period, and so on.
Please keep accurate records throughout the experiment. If you have any questions, please raise your hand now.

To be shure that everyone understands the instructions please fill out the QUESTIONS SHEET. An experimenter will come by to pick it up. DO NOT PUT YOUR NAME OR PARTICIPANT NUMBER ON THE QUESTION SHEET. If there are any mistakes on any of the question sheets the experimenter will go back over this part of the instructions again.

Again, the experiment will last for forty-five periods, and will use the earnings table in this packet. It is important that you remain silent and do not look at other peoples' work. If you have a question please raise your hand.

WE WILL BEGIN THE EXPERIMENT NOW.

Appendix B

Raw Data

Session One

	Row			Column		
Period	1	2	3	1	2	3
1 to 5	2	30	3	6	25	4
6 to 10	0	34	1	2	32	1
11 to 15	0	35	0	1	34	0
16 to 20	0	35	0	0	34	1
21 to 25	0	35	0	1	33	1
26 to 30	0	35	0	1	33	1
31 to 35	0	35	0	1	34	0
36 to 40	0	35	0	1	33	1
41 to 45	0	35	0	0	35	0

Session Two

	Row			Column		
Period	1	2	3	1	2	3
1 to 5	3	30	2	4	26	5
6 to 10	0	34	1	3	31	1
11 to 15	0	35	0	0	34	1
16 to 20	0	35	0	0	35	0
21 to 25	0	35	0	0	35	0
26 to 30	0	35	0	0	35	0
31 to 35	0	35	0	0	35	0
36 to 40	0	35	0	0	35	0
41 to 45	0	35	0	0	35	0

Session Three

	Action		
Period	1	2	3
1 to 5	25	10	5
6 to 10	26	10	4
11 to 15	29	4	7
16 to 20	25	1	14
21 to 25	25	0	15
26 to 30	26	1	13
31 to 35	30	0	10
36 to 40	28	0	12
41 to 45	30	0	10

Session Four

	Action		
Period	1	2	3
1 to 5	29	3	8
6 to 10	29	0	11
11 to 15	31	0	9
16 to 20	29	1	10
21 to 25	29	0	11
26 to 30	29	0	11
31 to 35	29	0	11
36 to 40	34	0	6
41 to 45	31	0	9

Session Five

	Action		
Period	1	2	3
1 to 5	28	1	11
6 to 10	29	0	11
11 to 15	30	0	10
16 to 20	27	0	13
21 to 25	29	0	11
26 to 30	30	0	10
31 to 35	28	0	12
36 to 40	26	0	14
41 to 45	29	0	11

Session Six

	Action		
Period	1	2	3
1 to 5	28	5	7
6 to 10	25	0	15
11 to 15	25	0	15
16 to 20	23	0	17
21 to 25	28	0	12
26 to 30	28	0	12
31 to 35	25	0	15
36 to 40	29	0	11
41 to 45	29	0	11

Session Seven

Period	Row 1	Row 2	Row 3	Column 1	Column 2	Column 3
1 to 5	13	13	9	19	14	2
6 to 10	20	7	8	27	7	1
11 to 15	10	0	25	35	0	0
16 to 20	7	0	28	35	0	0
21 to 25	5	0	30	35	0	0
26 to 30	4	0	31	35	0	0
31 to 35	2	0	33	35	0	0
36 to 40	3	0	32	35	0	0
41 to 45	5	0	30	35	0	0

Session Ten

Period	Row 1	Row 2	Row 3	Column 1	Column 2	Column 3
1 to 5	19	8	8	22	6	7
6 to 10	21	0	14	28	3	4
11 to 15	27	0	8	21	4	10
16 to 20	23	0	12	25	0	10
21 to 25	24	0	11	29	1	5
26 to 30	22	0	13	24	1	10
31 to 35	22	0	13	29	0	6
36 to 40	26	0	9	28	1	6
41 to 45	23	0	12	29	0	6

Session Eight

Period	Row 1	Row 2	Row 3	Column 1	Column 2	Column 3
1 to 5	20	5	10	23	4	8
6 to 10	18	4	13	29	0	6
11 to 15	23	0	12	27	1	7
16 to 20	14	0	21	30	0	5
21 to 25	20	0	15	32	0	3
26 to 30	16	0	19	29	1	5
31 to 35	19	1	15	27	2	6
36 to 40	14	0	21	30	0	5
41 to 45	16	0	19	31	0	4

Session Eleven

Period	Row 1	Row 2	Row 3	Column 1	Column 2	Column 3
1 to 5	18	8	9	26	7	2
6 to 10	11	8	16	29	0	6
11 to 15	13	3	19	32	2	1
16 to 20	12	5	18	34	0	1
21 to 25	12	1	22	34	0	1
26 to 30	15	0	20	34	0	1
31 to 35	10	0	25	31	0	4
36 to 40	15	0	20	34	0	1
41 to 45	10	0	25	35	0	0

Session Nine

Period	Row 1	Row 2	Row 3	Column 1	Column 2	Column 3
1 to 5	16	13	6	19	11	5
6 to 10	24	3	8	26	4	5
11 to 15	27	1	7	22	1	12
16 to 20	24	1	10	25	0	10
21 to 25	24	0	11	29	0	6
26 to 30	25	0	10	25	0	10
31 to 35	28	0	7	23	0	12
36 to 40	25	0	10	24	0	11
41 to 45	27	0	8	26	0	9

Session Twelve

Period	Row 1	Row 2	Row 3	Column 1	Column 2	Column 3
1 to 5	26	3	6	19	4	12
6 to 10	28	1	6	24	1	10
11 to 15	26	3	6	19	1	15
16 to 20	26	1	8	18	1	16
21 to 25	28	0	7	21	0	14
26 to 30	29	0	6	24	0	11
31 to 35	26	0	9	29	0	6
36 to 40	26	0	9	23	0	12
41 to 45	24	0	11	29	0	6
46 to 50	29	0	6	26	0	9
51 to 55	29	0	6	27	0	8
56 to 60	30	0	5	25	0	10
61 to 65	31	0	4	24	0	11
66 to 70	29	1	5	30	0	5

Session Thirteen

Period	Row 1	Row 2	Row 3	Column 1	Column 2	Column 3
1 to 5	25	3	7	25	5	5
6 to 10	27	1	7	27	2	6
11 to 15	25	0	10	24	1	10
16 to 20	22	0	13	30	0	5
21 to 25	22	1	12	32	0	3
26 to 30	23	0	12	31	0	4
31 to 35	22	0	13	27	0	8
36 to 40	25	1	9	29	0	6
41 to 45	19	1	15	27	2	6
46 to 50	22	0	13	33	0	2
51 to 55	13	0	22	35	0	0
56 to 60	12	1	22	35	0	0
61 to 65	10	0	25	35	0	0
66 to 70	11	0	24	35	0	0

Session Fourteen

Period	Row 1	Row 2	Row 3	Column 1	Column 2	Column 3
1 to 5	21	9	5	27	6	2
6 to 10	21	6	8	23	3	9
11 to 15	22	5	8	30	4	1
16 to 20	23	1	11	27	1	7
21 to 25	14	1	20	29	0	6
26 to 30	19	0	16	27	0	8
31 to 35	21	0	14	29	0	6
36 to 40	16	0	19	31	0	4
41 to 45	17	0	18	33	0	2
46 to 50	17	0	18	34	0	1

Acknowledgements: Eric Battalio programmed the computer enhanced treatments. Vince Crawford, Dan Friedman, Tom Palfrey, Charles Plott, Andy Schotter, Joel Sobel and seminar participants at Cal Tech, UCSC, NYU, and TAMU made constructive comments on a previous draft of this paper. The NSF and TEES provided financial support.

References

Bardhan PK (1984) Land, labor, and rural poverty: Essays in development economics. New York, Columbia University Press

Bernheim BD (1984) Rationalizable strategic behavior. Econometrica 52(4): 1007–1028

Binmore K, Morgan P, Shaked A, Sutton J (1991) Do people exploit their bargaining power? An experimental study. Games and Economic Behavior 3(3): 295–322

Binmore K, Proulx C, Swiezbinski J (1992) Focal points and bargaining. Working paper

Cooper RW, DeJong DV, Forsythe R, Ross TW (1991) Forward induction in the battle-of-the-sexes game: Working paper

Crawford JP (1989) Learning and mixed-strategy equilibria in evolutionary games. Journal of Theoretical Biology 140: 537–550

Friedman D (1991) Evolutionary games in economics. Econometrica 59(3): 637–666

Harsanyi JC, Selten R (1988) A general theory of equilibrium selection in games, Cambridge MA, MIT Press

Hofbauer J, Sigmund K (1988) The theory of evolution and dynamical systems: Mathematical aspects of selection. Cambridge UK, Cambridge University Press

Hoffman E, Spitzer M (1985) Entitlements, rights, and fairness: An experimental examination of subjects' concepts of distributive justice. Journal of Legal Studies 14: 259–297

Johnson EJ, Camerer C, Sen S, Rymon T (1991) Behavior and cognition in sequential bargaining. Working paper

Lewis D (1969) Convention: A philosophical study. Cambridge MA, Harward University Press

Maeder R (1990) Programming in mathematica. Redwood City, Addison-Wesley

Milgrom P, Roberts J (1991) Adaptive and sophisticated learning in normal form games. Games and Economic Behavior 3(1): 82–101
Ochs J (1990) The coordination problem in decentralized markets: An experiment. Quarterly Journal of Economics 105(2): 545–561
Ochs J, Roth AE (1989) An experimental study of sequential bargaining. American Economic Review 79: 355–384
Roth AE, Schoumaker F (1983) Expectations and reputations in bargaining: An experimental study. American Economic Review 73: 362–373
Samuelson L, Zhang J (1992) Evolutionary stability in asymmetric games. Journal of Economic Theory 57(2)
Schelling TC (1980) The strategy of conflict. Harvard University Press Cambridge
Sugden R (1986) The economics of rights, co-operation, and welfare. Oxford: Basil Blackwell
Van Damme E (1987) Stability and perfection of nash equilibria. Springer-Verlag Berlin
Van Huyck JB, Gillette AB, Battalio RC (1992) Credible assignments in coordination games. Games and Economic Behavior 4(4): 606–626
Van Huyck J, Battalio R, Jacobs D, Johnson P, Scott J (1989) Equity, efficiency, and security in tacit bargaining games. Working paper
Young HP (1993) The evolution of conventions. Econometrica 61(1): 57–84

Received ??
revised version ??