EMERGENT CONVENTIONS
IN EVOLUTIONARY GAMES

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I. INTRODUCTION

A *convention* is a regularity in behavior amongst members of a community in a recurrent situation that is customary, expected, and mutually consistent.[1] The definition combines facts about an observable situation (customary behavioral regularities) and properties of an abstract game derived from the observable situation (mutually consistent behavior). An example of a mutual consistency condition for an abstract game is Nash equilibrium. A Nash equilibrium is an assignment to each player of a strategy that is optimal for him when the others use the strategies assigned to them. The mutual consistency condition is important because it insures that members of the community have a good reason to conform to the regularity in behavior.

This chapter reports experimental results on the emergence of conventions in evolutionary games. In an *evolutionary* game, a stage game is played repeatedly by random subsets of the community or cohort. Laboratory cohorts are usually chosen to be large enough to make repeated game strategies unrewarding, but small enough to allow a convention to emerge quickly.[2]

A cohort is likely to bring customary and expected behavior into the laboratory that is not mutually consistent given the incentives of the experiment. Widely discussed examples are the salience of efficiency in games with inefficient dominant strategies and the salience of equal division in games with unequal bargaining power. The emergent convention approach to the origin of mutually consistent behavior suggests that such facts reflect the ambient convention into which the experiment is placed. Moreover, if the emergent convention approach is correct, one can design experiments in which inefficient or unequal division conventions emerge.

The chapter begins by reviewing the evolutionary stag hunt game literature in which inefficient conventions emerge systematically. It then focuses on two papers. Van Huyck, Battalio, and Rankin (1997) reported observing emergent conventions based on labels and populations in evolutionary pure coordination (collaboration) games. Van Huyck, *et al.*

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[1] The definition is from Lewis (1969) who demonstrated that it is useful to model people using sounds, gestures, or symbols to communicate things to one another as a coordination game and he used game theory to explain what it means to say that language is a convention. See also Schotter (1982), Sugden (1986, 1989) and Young (1993a, 1993b, 1996).

[2] Experience suggests that one population with eight randomly paired subjects or two populations with seven subjects in each achieves these design parameters for the class of games reviewed here.

(1995) reported observing the emergence of unequal division conventions in cohorts of symmetrically endowed subjects.

II. INEFFICIENT CONVENTIONS

Evolutionary stag hunt games have been widely studied both theoretically and experimentally. The stag hunt game poses the potential conflict between efficiency and security in a simple setting. The 2×2 symmetric stag hunt game is given in Table 1. The game has two strict Nash equilibria, which can be Pareto ranked, and one mixed-strategy equilibrium in which X is played with probability $(D - C)/(A + D - B - C) \equiv k^*$. When $k^* > \frac{1}{2}$ (X,X) is the payoff dominant equilibrium and (Y,Y) is the risk-dominant equilibrium.[3]

	X	Y
X	A,A	C,B
Y	B,C	D,D

A > B, D > C, A > D, B > C

Table 1: 2×2 symmetric stag hunt game

The recent shift from models based on substantive rationality to models of boundedly rational agents has directed attention to learning based theories of equilibrium selection. Deterministic dynamics predict history dependent equilibrium selection. For example, if the frequency of action X in the initial state is less than k^* then both the replicator or the myopic best response dynamic predict that (Y,Y) will emerge as the conventional way to play and if the frequency is more than k^* then (X,X) will emerge as the convention. Such deterministic dynamics divide the state space into two basins of attraction, where k^* is the separatrix between the two basins.

Battalio, Samuelson, and Van Huyck (1997) summarize recent evidence on human behavior in evolutionary stag hunt games in a table reproduced here as table 2. Each row represents a cohort. The cohorts are

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[3]The concepts of payoff dominance and risk dominance are taken from Harsanyi and Selten (1988). The risk-dominance equilibrium in a 2×2 symmetric game is the one with the larger basin of attraction under best-response dynamics.

ordered first by value of the separatrix, k^*, so that the basin of attraction of the risk-dominant equilibrium shrinks as one moves down the table, and second by the size of the scaled earnings difference. The initial and terminal outcomes are reported as the ratio of subjects using the payoff-dominant action to the total number of subjects active in the cohort. The last two columns report the number of periods and the source. The experiments differ in many details such as matching protocol, induced value technique, and the cohort's experience as a group with pretrial games. We don't focus on these differences because we think the results in the literature tell a fairly consistent story.

First, the payoff dominant action is usually the modal initial choice even when k^* takes on extreme values. Changing the scaled earnings difference has little discernable influence on initial conditions. Efficiency seems to be the ambient equilibrium selection convention for this sort of coordination problem.[1]

Second, the experimental subjects typically approach a mutual best response outcome, that is, the cohort converges to a customary way to solve their strategy coordination problem that is based on their experience within the cohort. The emergent convention is usually the inefficient, risk-dominant equilibrium when $k^* > 0.75$ and the efficient, payoff-dominant equilibrium when $k^* < 0.5$. For $0.5 < k^* < 0.75$, results are mixed.

Third, in most cases the terminal outcome is accurately predicted by the location of the initial outcome in the respective equilibrium's basin of attraction. The kind of separatrix crossings predicted by stochastic dynamics occur, but are rare.

Finally, the earnings difference between the two actions influences the frequency of observed separatrix crossings. Battalio, Samuelson, and Van Huyck (1997) observed separatrix crossings as they varied the relative earnings difference holding k^* equal to 0.8. This phenomena is predicted by probabilistic choice learning models.

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[1]Rankin, Van Huyck, and Battalio (1997) report an experiment in which payoff dominance emerges as a deductive selection principle in sequences of similar but not identical stag hunt stage games. Payoff dominance salient even when some stage games have extreme values for k^*, such as 0.97. So in some cohorts players can become very confident in the mutual salience of payoff dominance. Studying the emergence of conventions in payoff perturbed games may eventually explain why efficiency and equal division are ambient conventions.

Table 2: Recent Evidence on Human Behavior in Evolutionary Stag Hunt Games.

N	Game = {A, C} {B, D}	R(k)	k*	Initial Outcome	Terminal Outcome	Periods	Source
1	{45,0},{35,40}	(10k - 8)/9	0.80	5/8	1/8	75	Battalio, *et al.* (1997)
2	{45,0},{35,40}	(10k - 8)/9	0.80	4/8	0/8	75	Battalio, *et al.* (1997)
3	{45,0},{35,40}	(10k - 8)/9	0.80	5/8	0/8	75	Battalio, *et al.* (1997)
4	{45,0},{35,40}	(10k - 8)/9	0.80	3/8	0/8	75	Battalio, *et al.* (1997)
5	{100,0},{80,80}^{T}	(5k - 4)/5	0.80	6/10	0/10	22	Cooper, *et al.* (1992)
6	{100,0},{80,80}^{T}	(5k - 4)/5	0.80	6/10	0/10	22	Cooper, *et al.* (1992)
7	{100,0},{80,80}^{T}	(5k - 4)/5	0.80	5/10	1/10	22	Cooper, *et al.* (1992)
8	{100,0},{80,80}^{T}	(5k - 4)/5	0.80	7/20	4/20	10	Clark, *et al.* (1996)
9	{100,0},{80,80}^{T}	(5k - 4)/5	0.80	5/20	2/20	10	Clark, *et al.* (1996)
10	{100,0},{80,80}^{T}	(5k - 4)/5	0.80	4/10	0/10	9	Straub (1995)
11	{45,0},{40,20}	(5k - 4)/9	0.80	6/8	1/8	75	Battalio, *et al.* (1997)
12	{45,0},{40,20}	(5k - 4)/9	0.80	5/8	0/8	75	Battalio, *et al.* (1997)
13	{45,0},{40,20}	(5k - 4)/9	0.80	6/8	5/8	75	Battalio, *et al.* (1997)
14	{45,0},{40,20}	(5k - 4)/9	0.80	6/8	0/8	75	Battalio, *et al.* (1997)
15	{45,0},{42,12}	(5k - 4)/15	0.80	4/8	3/8	75	Battalio, *et al.* (1997)
16	{45,0},{42,12}	(5k - 4)/15	0.80	6/8	8/8*	75	Battalio, *et al.* (1997)
17	{45,0},{42,12}	(5k - 4)/15	0.80	6/8	8/8*	75	Battalio, *et al.* (1997)
18	{45,0},{42,12}	(5k - 4)/15	0.80	6/8	2/8	75	Battalio, *et al.* (1997)
19	{100,20},{80,80}^{T}	(4k - 3)/5	0.75	2/10	0/10	9	Straub (1995)
20	{5,-1},{3,3}	(6k - 4)/5	0.67	5/12	3/12	10	Friedman (1996)
21	{5,-1},{4,1}	(3k - 2)/5	0.67	7/12	3/12	10	Friedman (1996)
22	{5,-1},{4,1}	(3k - 2)/5	0.67	7/12	3/12	16	Friedman (1996)
23	{5,-1},{4,1}	(3k - 2)/5	0.67	6/10	3/10	16	Friedman (1996)
24	{5,-1},{4,1}	(3k - 2)/5	0.67	2/12	3/12	10	Friedman (1996)
25	{5,-1},{4,1}	(3k - 2)/5	0.67	3/12	2/12	10	Friedman (1996)
26	{80,10},{70,30}^{T}	(3k - 2)/8	0.67	9/10	9/10	9	Straub (1995)
27	{100,20},{60,60}^{T}	(4k - 2)/5	0.50	7/10	10/10	9	Straub (1995)
28	{5,0},{4,1}	(2k - 1)/5	0.50	6/12	9/12	10	Friedman (1996)
29	{55,25},{35,35}^{T}	(6k - 2)/11	0.33	9/10	10/10	9	Staub (1995)

R(k) - scaled earnings difference given k, the probability of X: R(k) = ({k A + (1-k) C} - {k B + (1-k) D})/A

k* - separatrix, zero earnings difference, mixed strategy equilibrium.

T - payoff dominant equilibrium in the lower right cell of subjects earnings table.

* - Separatrix crossings between initial and terminal outcome.

III. COORDINATION CONVENTIONS: LABELS & POPULATIONS

Van Huyck, Battalio, and Rankin (1997) investigate the influence of labels and populations on the ability of subjects in an evolutionary coordination game to adopt a conventional way to play. Their labels treatments investigate the abstraction assumptions that underlie the concept of a strategy, while their population treatments investigate the attraction of alternative mutually consistent ways to play under adaptive behavior. They observed conventions emerging in communities with one population and labels and with two populations and no labels, but the most effective treatment was two labeled populations.

Table 3 reports the earnings tables used in the experiment. The main difference between the two earnings tables is how they are labeled. In the no labels treatment, the rows are labeled "your choice" and the columns are labeled "other participant's choice". In the labels treatment, subjects were labeled either row or column and the earnings table described their potential earnings according to "row choice" and "column choice".

	No Labels				Labels	

No Labels — Earnings Table

		Other Participant's Choice	
		1	2
Your Choice	1	0	40
	2	40	0

Labels — Earnings Table

		Column Choice	
		1	2
Row Choice	1	0,0	40,40
	2	40,40	0,0

Table 3: Earnings table for no labels and labels treatments: Game CO.

Making the usual abstraction assumptions gives a 2×2 game, call it CO, with two efficient but asymmetric pure strategy equilibria, (1,2) and (2,1), and an inefficient but symmetric mixed strategy equilibrium.

Labels may serve as a focal point that solves the strategy coordination problem, if their significance is established and recognized by members of the community, see Sugden (1995). Alternatively, changing the matching protocol from one to two populations changes the state space of models of population dynamics and for many population dynamics this change has the implication that only strict equilibria are asymptotically stable, see Weibull (1995). Consequently, inefficient but symmetric mixed strategy equilibria are no longer asymptotically stable.

Figure 1*a* graphs the vector field under the continuous time limit of the two population logit response dynamic with the noise parameter, λ, set equal to 1. The axes measure the frequency of action 1 in the first and second population respectively. The points (1,0) and (0,1) represent pure strategy equilibria in which everyone in one population takes the action opposite to the action taken by everyone in the second population. The mixed equilibrium in the center of the space is unstable, but vectors forcing the populations away from the center are small. (As the vector's color goes from black to red it represents smaller values. The tail of the vector is also proportional to size, but the head is not.) Note also that the logit equilibria with λ equal 1, denoted by red dots, are shifted slightly towards the center of the space. The shift will be more dramatic in the bargaining game reviewed next. The grey shading represents states in which all players have a pecuniary incentive to conform to the emerging convention.[2]

Figure 1*b* graphs results of three sessions under a no labels two population treatment, which is the same case as the vector field although with seven subjects per population. The data points, denoted *states* below, are five period sums of action 1 in the two respective populations and can sum to at most 35 (seven subjects playing 1 in all five periods of a state). State 1 is the sum for periods 1 to 5 and so on.

The "red" session in figure 1*b* converges to perfect conformity with the convention everyone in the row population plays 2 and everyone in the column population plays 1. The same convention is emerging in the "blue" session. No convention emerges in the "green" session, which results in subjects losing half their potential earnings.

Figure 1*d* graphs the results of three sessions under a two labeled population treatment. The "blue" session in figure 1*d* converges to perfect conformity with the convention everyone in the row population play 1 and everyone in the column population play 2. The alternative convention is emerging in the "red" and "green" sessions. Conventions emerged most consistently with two labeled populations.

Figure 1*c* graphs the results of three sessions under a one population with labels treatment, that is, eight subjects are randomly labeled either row or column and then randomly paired each period. Hence, a state denotes the sum of action 1 played by four subjects for five periods and ranges from 0 to 20. No convention appears to be emerging in the "blue" session. The "green" session is in an area where all subjects have a pecuniary incentive

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[2] See McKelvey and Palfrey (1995) for an introduction to logistic equilibria and Fudenberg and Levine (1997) for an introduction to the continuous time logistic response dynamic.
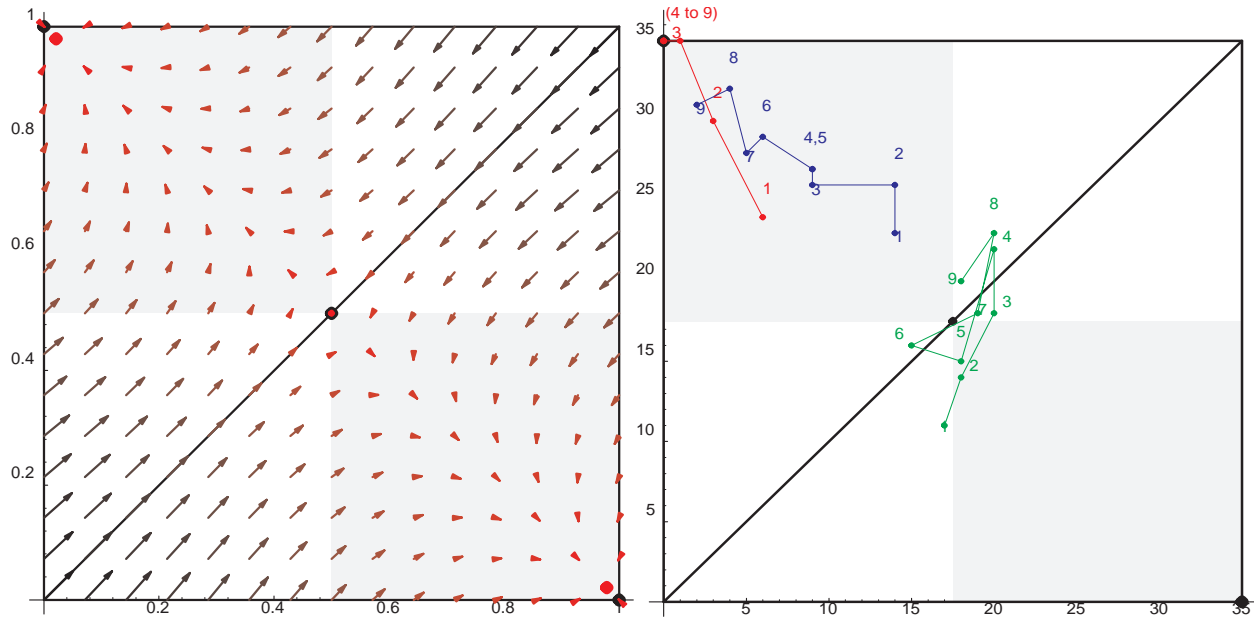
A. Logistic Response Vector Field: Game CO.

B. Two Populations No Labels
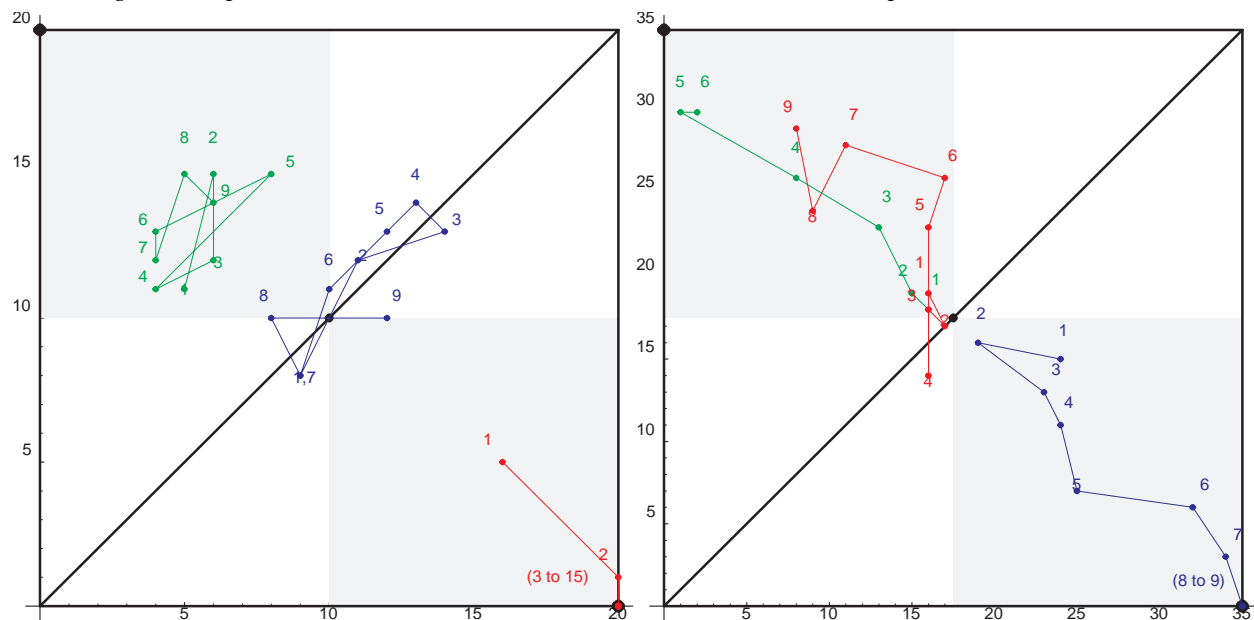
C. One Population with Labels

D. Two Labeled Populations

Figure 1: Evolutionary Game CO; numbers order five period sums or states, sessions denoted by color.

7

to conform to the emergent convention, but a high degree of conformity with the convention doesn't emerge within the 45 periods of the session. The "red" session in figure 1*c* converges to perfect conformity with the following convention: when labeled row play 1 and when labeled column play 2.

III. UNEQUAL DIVISION BARGAINING CONVENTIONS

Van Huyck, *et al.* (1995) discovered an evolutionary bargaining game in which unequal division conventions emerge amongst symmetrically endowed subjects. They call it *DS*:

	1	2	3
1	3,3	3,0	6,4
2	0,3	5,5	0,0
3	4,6	0,0	0,0

Table 4: Game form *DS*

DS is symmetric. Units denote dimes. If both players choose 2 they divide a dollar equally. If one player chooses action 1 and the other chooses action 3, the first earns $0.60 and the other earns $0.40. Game *DS* is unusual in that the aggressive demand is also the secure demand. Using action 1 insures earning $0.30. While the stage game is symmetric, Van Huyck, *et al.* (1995) used a two labeled population protocol, which as we have just seen, allows some cohorts to use labels and populations to break the symmetry of the stage game in the evolutionary game.

Figure 2*a* graphs the logistic response vector field for the game that results when action 2 becomes extinct in game *DS*, which will be denoted *BOS*. The black dots denote Nash equilibria and the red dots denote logistic equilibria (again with λ equal 1). The grey shaded regions indicate states in which everyone has a pecuniary incentive to conform to the emerging convention.

It is not obvious from the figure or from logistic response theory why action 2 goes extinct, but one expects it to depend on the initial condition. Once action 2 is extinct, however, the vector field implies that one of the two unequal division conventions emerge. Van Huyck, *et al.* discovered

that the equal division action always goes extinct.[3] Security was a more salient and convincing selection principle than equal division.

Figure 2*b* graphs the results for five sessions run by hand and figure 2*c* graphs the results for three sessions run by computer. Again the points denote five period sums of action 1 for the row and column population. The sums can range from 0 to 35 (seven subjects choosing action 1 for five periods). Dots denote states in which the equal division action is extinct and circles denote states in which it is not. Numbers sequence the states by the time order they were observed.

An unequal division convention emerges in five of eight sessions. The "red", "light blue", and "green" sessions in figure 2*b* and the "red" and "blue" session in figure 2*c*. In these five sessions, 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.

Van Huyck, *et al.* (1995) used the replicator dynamic to inform their behavioral predictions. It provides a formal way to show that the symmetric mixed equilibrium is unstable and to check that unequal division equilibria have large basins of attraction. The fixed points of the replicator dynamic are the Nash equilibrium illustrated in figure 2*a*. The logistic response dynamic can be calibrated to fit the data better. Specifically, the logistic response dynamic with the noise parameter set to 1 makes more accurate predictions of the regions of the state space with little motion (especially around the shifted equilibria) and the direction of the expected motion than the replicator dynamic.

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[3] Andreas Ortmann has examined how robust this is to changes in the earnings scale. In a one population design, he found some cohorts that converged to equal division when the relative security of the agressive action was reduced, but when payoffs were scaled down to 1/5th their value he essentially replicated the results reported in Van Huyck, *et al.* (1995) for one population protocols.
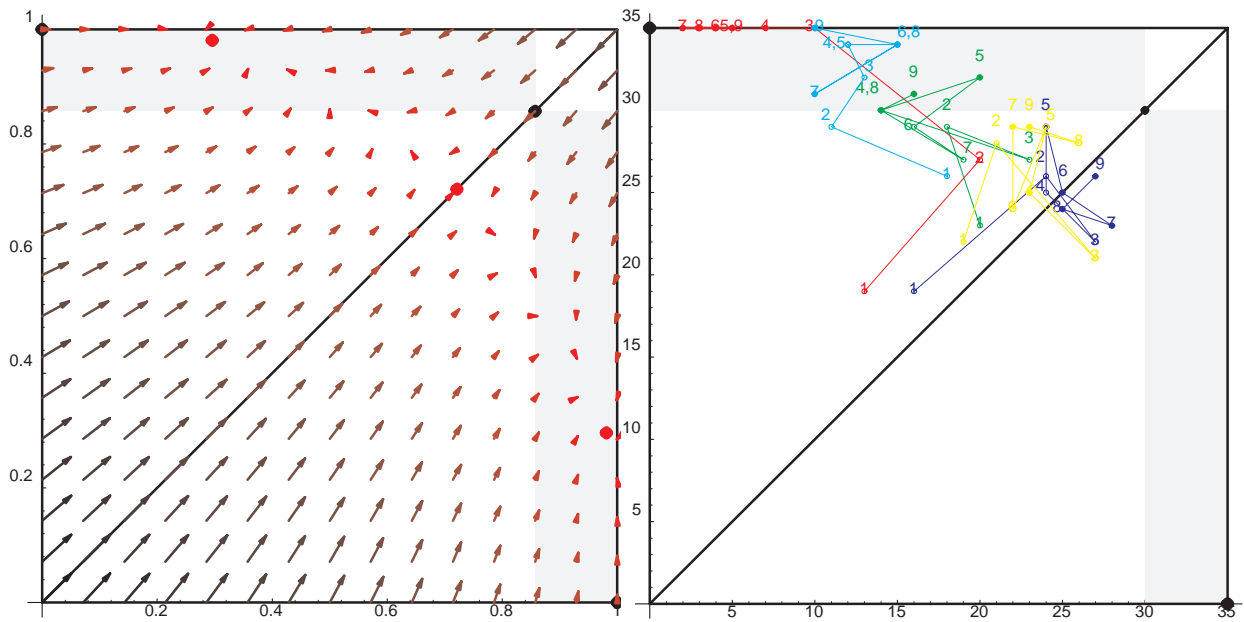
A. Logistic Response Vector Field: BOS.

B. Two Labeled Populations: DS run by hand.
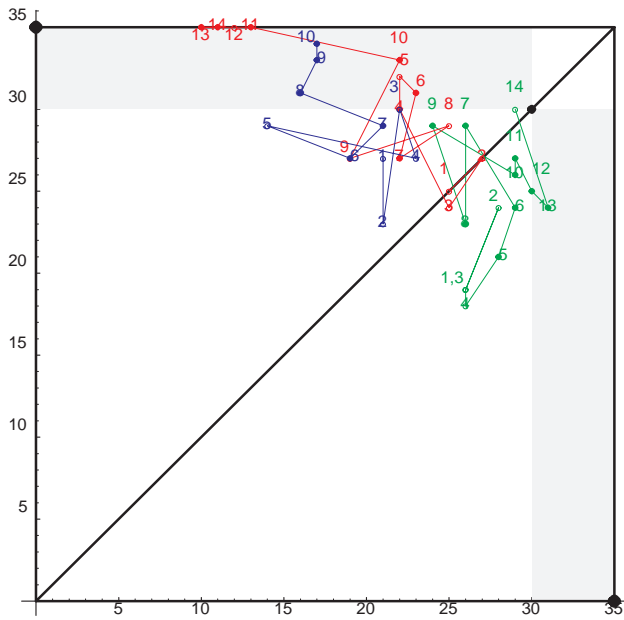
C. Two Labeled Populations: DS run by computer.

Figure 2: Evolutionary Game DS; numbers order five period sums, color denote sessions.

REFERENCES
Hypertext links checked January 14, 1998

Raymond Battalio, Larry Samuelson, and John Van Huyck, "Risk Dominance, Payoff Dominance, and Probabilistic Choice Learning," laser-script, November 1997; http://econlab10.tamu.edu/JVH_gtee /c4.htm.

Ken Binmore, John Gale, and Larry Samuelson, "Learning to be Imperfect: The Ultimatum Game," *Games and Economic Behavior* 8, 1995, 56-90.

Kenneth Clark, Stephen Kay and Martin Sefton, "When are Nash Equilibria Self-Enforcing? An Experimental Analysis," laser-script, May 1996.

Russell Cooper, Douglas V. DeJong, Robert Forsythe, and Thomas W. Ross, "Communication in coordination games," *Quarterly Journal of Economics*, 107:739-773, 1992.

Daniel Friedman, "Equilibrium in evolutionary games: Some experimental results," *Economic Journal*, 106:1-25, 1996.

Drew Fudenberg and David K. Levine, *Theory of Learning in Games*, laser-script December 1996; http://levine.sscnet.ucla.edu/Papers /book1.pdf

John C. Harsanyi and Reinhard Selten, *A General Theory of Equilibrium Selection in Games*, MIT Press, Cambridge, Massachusetts, 1988.

Lewis, David, *Convention: a philosophical study*, (Cambridge,MA: Harvard University Press, 1969).

Richard D. McKelvey and Thomas R. Palfrey, "Quantal Response Equilibria for Normal Form Games," *Games and Economic Behavior*, 10(1) July 1995, 6-38; http://www.hss.caltech.edu/~rdm/qrew.html

Frederick Rankin, John Van Huyck, and Raymond Battalio, "Strategic Similarity And Emergent Conventions: Evidence from Scrambled Payoff Perturbed Stag Hunt Games", laser-script, July 1997; http://Econlab10.tamu.edu/JVH_gtee/c3.htm.

Roth, A.E. and I. Erev "Learning in Extensive-Form Games: Experimental Data and Simple Dynamic Models in the Intermediate Term," *Games and Economic Behavior*, 8, January 1995, 164-212; http://www.pitt.edu/~alroth/lowgame.html

Sugden, Robert, *The Economics of Rights, Co-operation, and Welfare*, (Oxford,UK: Basil Blackwell, 1986).

Robert Sugden, "A Theory of Focal Points," *The Economic Journal*, 105(430), May 1995, 533-550.

Paul Straub, "Risk Dominance and Coordination Failure in Static Games,"

The Quarterly Review of Economics and Finance, 35(4) Winter 1995, 339-363.

J.B. Van Huyck, R.C. Battalio, S. Mathur, A. Ortmann and P.P. Van Huyck, "On the Origin of Convention: Evidence from symmetric bargaining games," *International Journal of Game Theory* 24(2) 1995, 187-212.

John B. Van Huyck, Raymond C. Battalio, and Frederick Rankin, "On the Origin of Convention: Evidence from Coordination Games," *Economic Journal* 107(442) May 1997, 576-597.

Peyton Young, "The evolution of conventions," *Econometrica*, 61: 57-84, 1993.

Peyton Young, *Individual Strategy and Social Structure: An evolutionary theory of institutions*, laser-script, 1997.

Jorgen W. Weibull, *Evolutionary Game Theory*, (Cambridge, MA: The MIT Press, 1995).