COMMUNICATION IN COORDINATION GAMES*

RUSSELL COOPER
DOUGLAS V. DEJONG
ROBERT FORSYTHE
THOMAS W. ROSS

We present experimental evidence on nonbinding, preplay communication in bilateral coordination games. To evaluate the effect of "cheap talk," we consider two communication structures (one-way and two-way communication) and two types of coordination games (one with a cooperative strategy and a second in which one strategy is less "risky"). In games with a cooperative strategy, one-way communication increases play of the Pareto-dominant equilibrium relative to the no communication baseline; two-way communication does *not* always decrease the frequency of coordination failures. In the second type of game, two-way communication always leads to the Pareto-dominant Nash equilibrium, while one-way communication does not.

I. INTRODUCTION

In this paper we consider two types of experimental coordination games with nonbinding, preplay communication. The key characteristic of these simultaneous-move games is the existence of multiple, Pareto-ranked equilibria.

An example of a coordination game is displayed in Figure I. In this game both (1,1) and (2,2) are Nash equilibria, and the latter clearly Pareto dominates the former. Note too that strategy 3 supports the cooperative outcome but is a dominated strategy. Thus, one might view this game as a prisoner's dilemma game with an additional equilibrium. Due to the presence of this cooperative strategy, we refer to this game as a *cooperative coordination game* (CCG).

A second type of coordination game is illustrated in Figure II. This is a simple coordination game with two, Pareto-ranked equilibria and *no* cooperative, dominated strategy. To the extent that there is strategic uncertainty about the likely play of an opponent, strategy 1 is "safe" in that the player receives 800,

*Conversations with Thomas Palfrey about these issues have been quite helpful in formulating this experiment and thinking about our results. We also thank seminar participants at the University of Arizona, Boston University, Michigan State University, the University of Missouri, and the University of Pennsylvania and two anonymous referees. Financial support from the National Science Foundation, the Social Sciences and Humanities Research Council of Canada, and Arthur Young & Co. for this project is gratefully acknowledged. We thank Robert Pearson for providing programming assistance.

The Quarterly Journal of Economics, May 1992

		Column Player's Strategy		
		1	2	3
Row Player's Strategy	1	350,350	350,250	1000,0
	2	250,350	550,550	0,0
	3	0,1000	0,0	600,600

FIGURE I

independent of an opponent's play.[1] One important difference between the games is that the Figure II game does not have a cooperative, dominated strategy. Hence we refer to this as a *simple coordination game* (SCG).

These games represent, in an abstract fashion, the types of interactions prevalent in many recent macroeconomic models of coordination problems as well as models of networks, bank runs, team production problems, etc. For example, in Diamond [1982] the returns to an agent from undertaking a production opportunity is an increasing function of the number of others who have chosen to produce. Similarly, Bryant [1983] characterizes an economy in which the optimal choice of effort by one agent depends in a positive way on the effort level put forth by others. Cooper and John [1988] characterize the nature of the strategic complementarities in these and related examples. For many of these economies the Pareto-efficient equilibrium will be socially suboptimal due to the presence of externalities in payoffs, while for others, such as the economy described by Bryant, the Pareto-efficient equilibrium is also a Pareto-efficient allocation. The games considered in this paper, CCG and SCG, reflect these two theoretical possibilities.

Consideration of these games is also motivated by the simple game theoretic issue of selection in games with multiple equilibria in which the existing refinements are powerless. For example, Harsanyi and Selten [1988] emphasize coordination games in their theory of equilibrium selection.

1. This concept of a "safe" strategy is formalized by Harsanyi and Selten [1988] as a "risk dominant" strategy. Given the strategic uncertainty, the riskiness of strategy 2 might make strategy 1 focal. In fact, they use an example similar to our game (see Harsanyi and Selten, pps. 88–89) to discuss the possible conflict between risk dominance and payoff dominance and the role of preplay communication. We initially considered using the 2 × 2 game obtained by deleting strategy 3 in the game given in Figure I. Without preplay communication, coordination failures were not observed in that game so the game given in Figure II, which highlights strategic uncertainty, was used instead.

		Column Player's Strategy 1	Column Player's Strategy 2
Row Player's Strategy	1	800,800	800,0
	2	0,800	1000,1000

FIGURE II

An important theme in these coordination games is the possibility that the Pareto-inferior Nash equilibrium is observed; i.e., coordination failures occur. Cooper, DeJong, Forsythe, and Ross [1990] provide experimental evidence on sequences of independent, one-shot coordination games, including CCG, without preplay communication. Except for the early rounds of play, a Nash equilibrium was observed, but the Pareto-dominant equilibrium was not always the experimental outcome. For example, the Pareto-inferior Nash equilibrium was observed for CCG.[2] Moreover, players seem initially to place some positive probability on their rivals being cooperative (i.e., playing strategy 3), even though this is a dominated strategy. As a consequence, altering the payoffs from a rival's play of a cooperative, dominated strategy can influence selection of a Nash equilibrium. In Cooper et al. [1990] we report that once strategy 3 is eliminated from CCG, the (2,2) outcome is observed. Thus, the source of the coordination failure in CCG is the presence of the cooperative strategy.

As reported in this paper, coordination failures always occur in game SCG in the absence of preplay communication. Since that game does not have a cooperative strategy, the source of the coordination failure is different than in CCG. Harsanyi and Selten [1988] suggest that the coordination failures reported here for SCG are associated with the "riskiness" of strategy 2.

One might conjecture that if players could communicate, prior to selecting an action, then the coordination failures would disappear as preplay communication would select a desired outcome. This corresponds to the view that play of a Nash equilibrium is the consequence of nonbinding, preplay communication through which players pick the best outcome from the set of self-enforcing agreements. From this perspective, communication focuses beliefs

2. Van Huyck, Battalio, and Beil [1990] provide independent evidence of coordination problems in a multi-agent, finitely repeated experimental coordination game.

on a particular equilibrium. If communication works to select an equilibrium, communication should overcome any coordination failures observed in experimental games without cheap talk.[3] A theoretical structure in which one can evaluate this role of preplay communication is provided in Section II.

In support of this conjecture Cooper, DeJong, Forsythe, and Ross [1989] present experimental evidence that preplay communication resolves coordination problems in a battle of the sexes game. Allowing one player to send a message to another prior to the choice of actions almost completely resolved coordination problems (ex post disequilibrium) observed in the experimental game without preplay communication. Consistent with theory, coordination problems were reduced but not eliminated when both players simultaneously sent a message prior to selecting their actions. Our interest here is whether or not the coordinating role of preplay communication extends to coordination games.

Our experimental design is described in Section III. It is similar to that used in Cooper et al. [1989], where players could *engage in preplay communication. As in our previous work participants* play a series of one-shot games in which they are anonymously matched with a sequence of opponents.

The results of the cheap talk treatments with one-way and two-way communication are described in Section IV.[4] For CCG, allowing preplay communication by a single player significantly increases the frequency of equilibrium outcomes. Further, play of the (2,2) Nash equilibrium is more frequent relative to the game without preplay communication. Nonetheless, a nontrivial number of coordination failures still arise. However, allowing both players to communicate simultaneously does not resolve the coordination problem: the (2,2) Nash equilibrium is not always observed more frequently than in the game without preplay communication.

3. Of course, this does not mean that the coordination failures explored in the theoretical literature in macroeconomics would necessarily be resolved by allowing such cheap talk. It is important to recognize that our results pertain to bilateral games in which communication is costless and highly structured. Preplay communication is likely to be quite expensive in large economies of the variety studied in macroeconomics.

4. Isaac and Walker [1986] and Palfrey and Rosenthal [1988b] also investigate the effects of cheap talk in experimental games. Isaac and Walker investigate the implications of preplay communication in the context of the voluntary contribution mechanism. They find that communication mattered and increased cooperative play. Palfrey and Rosenthal investigate the implications of allowing cheap talk in a contribution game with incomplete information about preferences. They report that communication improves on coordination of strategies.

Instead, there are frequent plays of the cooperative strategy as well as strategy 1.

For SCG, we find that one-way communication increases play of strategy 2 but leads to the (2,2) equilibrium only 53 percent of the time. However, the (2,2) equilibrium is observed almost 97 percent of the time with two-way communication.

Section V relates these findings to the model analyzed in Section II. Except for two-way communication in SCG, we reject that model since we fail to see play of the (2,2) Nash equilibrium as frequently as that theory predicts. This is in marked contrast to the results for the battle of the sexes game, reported in Cooper et al. [1989], where the effects of preplay communication were quite close to the theoretical predictions. We argue that the results for SCG are consistent with the theory of "risk dominance" and preplay communication proposed by Harsanyi and Selten [1988]: it requires both players to send messages that they intend to play strategy 2 before the players are willing to accept the "risk" of playing that strategy.

To better understand the results obtained in CCG, Section VI presents a game of incomplete information with egoists and altruists. Our consideration of altruism is motivated by a number of factors. First, there are frequent announcements and plays of the cooperative strategy in this coordination game without preplay communication. Second, Cooper et al. [1990] argue that the cooperative strategy is important in observed coordination failures. Third, since preplay communication has been shown to exacerbate attempts at cooperation in prisoner's dilemma games, the same effect might be important in understanding why coordination failures persist despite the introduction of preplay communication.[5] We find that in the game of incomplete information preplay communication might encourage attempts at cooperation which could then lead to either disequilibrium play or coordination failures. We argue that this model improves our understanding of the data generated in our cheap-talk experiments. We also present data from games in which we attempted to control for altruism.

Section VII offers some concluding comments and discusses extensions of our work. This includes a comparison of these results with those reported in Cooper et al. [1989] and some additional discussion of the role of altruism in our experimental work.

5. See, for example, the discussion in Dawes [1980].

II. Communication and Coordination

The coordination game with communication is a two-stage game between two players. In the first stage player(s) communicate by sending messages to one another. In the second stage actions are chosen. Since the payoffs are independent of the actual messages, this is a game of "cheap talk." Nonetheless, the messages may influence actual play by affecting the beliefs that agents hold about their opponents.

We restrict the messages in the first stage to lie in the set of strategies available to the agents. Two alternative communication structures are examined. First, only one player sends a nonbinding message of his intention to play a certain (pure) strategy. This structure is called one-way communication. Second, both players send messages to each other simultaneously. This is called two-way communication. After the round of communication, players simultaneously choose actions in the second stage of the game.

Here we explicitly analyze CCG; once reference to strategy 3 is eliminated, the analysis holds for SCG as well. The equilibria of the two-stage game can be quite complicated as they depend, in part, on the interpretation of the messages sent by the players. Let $\sigma^i(m_R,m_C)$ be the action chosen by player $i = R,C$ when the messages sent by the row and column player are given by (m_R,m_C).[6] For each pair of messages, $\sigma^i(\cdot)$ represents a mixed strategy over the three possible actions. The equilibrium of the game is given by $\sigma^{*i}(m_R,m_C)$ for $i = R,C$ coupled with a decision on what announcements to make in the first stage of the game, (m^*_R,m^*_C), such that the announcements and the actions, conditional on announcements, are best responses.

One equilibrium for this game is for the players to randomly send messages and for these messages to be ignored: $\sigma^{*i}(m_R,m_C)$ is independent of the messages sent for $i = R,C$. In this "babbling" equilibrium, messages are irrelevant. Hence, we know that any outcome of the one-stage game without communication is also an equilibrium for the game with communication. Cheap talk does not reduce the set of equilibria. However, recent work on nonbinding communication by Farrell [1985, 1987], Myerson [1987], and others has identified conditions under which it is possible for credible announcements to be made. These conditions involve restrictions on beliefs about the meaning of messages.

6. When communication is only one-way, then only one element of this vector is relevant. Here $i = R(C)$ refers to a row (column) player.

For *one-way communication* it is assumed (see Farrell [1985]) that if it would be optimal for the row player to honor his announcement if the column player believed the row player would honor it, then the announcement will be believed and honored. Thus, in CCG if the sender announces either strategy 1 or 2, this is the predicted equilibrium action for both players. Since strategy 3 is dominated, an announcement of 3 should be ignored, and play would then continue as if no announcement had been made.

If saying 2 leads to the play of 2, announcing and playing strategy 2 is a dominant strategy for the row player in the two-stage game with one-way communication. If this equilibrium occurs, announcements of 2, followed by the play of 2 by both players, avoid coordination failures.

Farrell [1987] proposes an equilibrium in which cheap talk matters in his analysis of the battle of the sexes game with *two-way communication*. We extend that logic to CCG with two-way communication. Farrell characterizes an equilibrium in which $\sigma^i(m_R,m_C)$ places all weight on m_i when $(m_R,m_C) \in \xi$, where ξ denotes the set of pure-strategy equilibria for the second stage of the game.[7] That is, if the players announce an equilibrium, they play it. For CCG announcements of (1,1) and (2,2) would translate into the play of the corresponding Nash equilibrium.

When the announcements do not constitute an equilibrium, Farrell assumes that play will evolve as if no announcements were made. That would occur in our model in the event that either player announces strategy 3 or when (1,2) or (2,1) is announced. Thus, $\sigma^i(m_R,m_C)$ is independent of (m_R,m_C) when $(m_R,m_C) \notin \xi$.

Associated with these $\sigma^i(\cdot)$ functions are implications for announcements in the first stage of the game. Since the observed experimental outcome of CCG without communication (see Cooper et al. [1990]) is the play of equilibrium (1,1), assume that disequilibrium announcements will lead to that same outcome. (As reported below, (1,1) is the observed outcome for SCG, so this assumption is reasonable for that game as well.) Thus, announcements of 2 dominate all other announcements in the first stage. As in the one-way communication game, this avoids all coordination failures since announcements of 2 by both players lead to the (2,2) equilibrium.

Thus, under either of these communication structures, one equilibrium for the game with communication is the announce-

7. For the game given in Figure I, $\xi = \{(1,1),(2,2)\}$.

ment of strategy 2 followed by its play. This equilibrium illustrates the value of preplay communication as a selection device.

It should be stressed, however, that there are a multitude of other equilibria in which communication matters. For example, one can simply permute the meaning of the announcements given in any of the equilibria above to arrive at other $\sigma^i(\cdot)$ functions that support the (2,2) equilibrium. Though we have concentrated on pure strategy equilibria, there will exist other equilibria in which the response to certain announcements are mixed strategies.[8]

III. Experimental Design

The design of this experiment was similar to that in Cooper et al. [1989, 1990]. The study was conducted using eighteen cohorts of players, each consisting of eleven different players, recruited from undergraduate classes (sophomore and above) and MBA classes at the University of Iowa. Players were seated at separate computer terminals and given a copy of the instructions. Since these instructions were also read aloud, we assume that the information contained in them is common knowledge. These instructions can be found in Cooper et al. [1989].[9]

Each player participated in a sequence of one-shot games against different anonymous opponents within his cohort. One was designated the row player, and the other the column player. All pairing of players was done through the computer using the same procedure as in Cooper et al. [1989, 1990]. A player knew neither the identity of the player with whom he was currently paired nor the history of decisions made by any of the other players in the cohort.

As in Cooper et al. [1989, 1990], we induced payoffs in terms of utility using the Roth and Malouf [1979] procedure. In the matrix games each player's payoff was given in points that determined the probability of the player winning a monetary prize. At the end of each game we conducted a lottery where "winning" players received \$1 and "losing" players received \$0. This procedure is

8. For example, in the two-way communication structure, announcements other than (2,2) could map into the mixed strategy of the second stage game.

9. There are only two differences in instructions between the games reported here and those in Cooper et al. [1989]. First, we replaced the 2×2 battle of the sexes game with the two coordination games considered in this paper. Second, here we do not allow players the option of silence as in Cooper et al. [1989].

designed so that all players will maximize the expected number of points in each game regardless of their attitudes toward risk.

Each cohort participated in two separate sessions.[10] In Session I all players participated in ten symmetric one-shot dominant strategy games. During Session I each player played one game against every other player. Since there were an odd number of players, one sat out each period. Thus, Session I consisted of eleven periods. Also, players alternated between being row and column players during the periods in which they were active participants. Session I was conducted to provide players with experience with experimental procedures, to see how well the dominant strategy equilibrium prediction performed, and to provide some information about the rationality of their opponents.

In Session II all players participated in twenty additional one-shot games that differed from the game played in Session I. Each played against every other player twice: once as a row player and once as a column player. As in Session I one player sat out in each period, and players alternated between being row and column players during the periods in which they were participating. Thus, Session II consisted of 22 periods.[11]

The Session II games were all versions of the coordination game using the payoffs illustrated in Figures I and II. However, we varied the type of communication between the players. In the *no communication* games players simultaneously chose actions that determined their payoffs. For the *one-way communication* games the row player sent the column player a message announcing what the row player "plans to play" in the second stage. After all messages were received, the players simultaneously chose actions. In the *two-way communication* games both of the players simultaneously sent messages to each other. The exchange of messages was then followed by the simultaneous choice of actions. In the games with preplay communication, subjects were told: "You are not required to choose the action you announced in the first stage." Three replications were conducted for each communication treat-

10. Each cohort completed the two sessions in one to one and half hours. Payments ranged from \$5 to \$21.

11. Our objective was to have the pairings satisfy two conditions: (i) players were to alternate being row and column players and (ii) each player was to play every other player twice (in Session II). The ordering of the players and consequently the pair assignments were randomized at the beginning of each session. Finally, since these two conditions can only be satisfied with an odd number of players, one player sat out each period. Having that player draw the lottery ticket may also serve the purpose of convincing players of the credibility of the lottery procedure.

ment for a total of nine replications for each of the two coordination games.[12]

IV. Results

In the Session I game with the dominant strategy, that strategy was played about 93 percent of the time over the eighteen cohorts. Thus, as reported in Cooper et al. [1989, 1990], the dominant strategy was almost always played.

In evaluating the Session II data for SCG and CCG, we tested for independence across periods, row and column players, and replications using announcements, actions in the no communication treatments, and actions conditional on announcements in the communication treatments. Unless otherwise stated, all data reported here are from the last eleven periods of each treatment pooled across row and column players.

A. Simple Coordination Game (SCG)

We conducted three replications for each of the three communication structures (no communication, one-way communication, and two-way communication) using the matrix given in Figure II. Our results are reported in Tables I–III for the last eleven periods of play by treatment.[13]

Table I provides information on announcements and actions taken in each of the three treatments and also presents the frequency of the possible action pairs by treatment. With no communication, coordination failures are observed: of the 330 total plays only 5 were of strategy 2. In contrast to the results reported in Cooper et al. [1990], these observations cannot be the conse-

12. One replication of CCG was previously reported as Game 3 in Cooper et al. [1990].

13. We used Fisher's exact test throughout this paper to test for the statistical significance of differences (see Kendall and Stuart [1979, pp. 584–86]). We tested for serial dependence in announcements, strategies played conditional on announcements and strategies played in the no communication treatment. These tests produced evidence of dependence using the data from all periods, but there was no evidence of dependence using the data from the last eleven periods of each replication. We failed to reject the hypothesis of no differences between row and column players, except for the obvious case of announcements in the one-way communication treatment. We also could not reject the hypothesis of no difference across replications in the two-way treatment. With one-way communication, however, one replication (replication 2) differed significantly from the other two in terms of announcements as well as strategies chosen given that the row player announced strategy 2. There were also significant differences in the strategies chosen given announcements of strategy 2 in the other two replications, but with a p-value of 0.047, this seems marginal. In what follows, we shall discuss these differences in replications in detail.

TABLE I
SCG

	Strategy 1		Strategy 2
Announcements			
No communication:	—		—
One-way:			
Rep. 1&3	19		91
Rep. 2	2		53
Total	21		144
Two-way:	0		330
Actions:			
No communication:	325		5
One-way:			
Rep. 1&3	88		132
Rep. 2	15		95
Total	103		227
Two-way:	15		315
	Action pair (1,1)	(2,2)	(1,2), (2,1)
Treatment:			
No communication:	160	0	5
One-way:			
Rep. 1&3	25	47	38
Rep. 2	1	41	13
Total	26	88	51
Two-way:	0	150	15

quence of failed attempts at cooperation. Instead, we would argue, following Harsanyi and Selten [1988], that play of strategy 1 is a consequence of strategic uncertainty over the play of an opponent. That is, unless one believes that the likelihood an opponent will play strategy 2 is 8/10 or more, play of strategy 1 is optimal.

TABLE II
SCG
MAPPING OF ANNOUNCEMENTS TO ACTIONS
ONE-WAY COMMUNICATION

Announcement	Actions- Row, Column				
Row	1,1	2,2	1,2	2,1	Total
1	20	1	0	0	21
2	6	87	22	29	144
Total	26	88	22	29	165

TABLE III
SCG
MAPPING OF ANNOUNCEMENTS TO ACTIONS
TWO-WAY COMMUNICATION

Announcements Row, Col	Actions- Row, Column 1,1	2,2	1,2	2,1	Total
1,1	0	0	0	0	0
2,2	0	150	7	8	165
1,2	0	0	0	0	0
2,1	0	0	0	0	0
Total	0	150	7	8	165

Loosely speaking, a player must be convinced that his opponent will play 2 before it is best to do so.

The role of communication then is to provide a basis for the strong beliefs needed to overcome coordination failures. As indicated in Table I, these coordination problems are completely resolved by two-way communication: of the 330 plays, 315 of them are of strategy 2. In terms of announcements, strategy 2 was announced all 330 times. This is a dramatic improvement over the results without preplay communication and accords with the theoretical predictions of the Section II model.

Surprisingly, the results with one-way communication are different from either of the other two treatments. There are significantly more plays of strategy 2 in this treatment relative to no communication and significantly more plays of strategy 1 relative to the two-way treatment.

As indicated by Table I, the difference in the actions chosen in the communication treatments cannot solely be attributed to differences in announcements. In particular, 12.7 percent of the announcements were strategy 1 in one-way communication, and 0 percent in two-way. While this difference is statistically significant, it is not enough to account for the observed differences in play; strategy 2 was played 95 percent of the time in two-way communication but only 69 percent of the time in one-way communication. Instead, as we discuss below, these differences can be traced to how column players responded to the row player's announced intention to take action 2 when there was one-way communication.

In summary, we draw three conclusions from Table I.

FACT 1. In the game without communication play of the (1,1) equilibrium is observed.

FACT 2. One-way communication increases the frequency of the (2,2) equilibrium, but a significant number of coordination failures were observed.

FACT 3. Two-way communication resolves coordination failures: strategy 2 is played almost all of the time.

The detailed results for the last eleven periods of play for the one-way communication treatment are presented in Table II. Note first that strategy 2 was announced 144 times or about 87 percent of the time.

As for the mapping between announcements and actions, 20 of the 21 times the row player announced 1, the (1,1) equilibrium was observed. Of the 144 times strategy 2 was announced in the last eleven periods, the (2,2) equilibrium was observed only 60 percent of the time, far less than predicted by the theory. In 28 instances the row player took action 1 after announcing action 2, while in 35 instances the column player chose to play action 1 after hearing the row player announce action 2. Coordination failures appear to be the consequence of receivers not best responding to announcements and, recognizing this, senders not following through on their announcements.

This can be seen directly by examining the first five periods of play in replications 1 and 3. On 39 occasions the row player announced his intention to take action 2. In eleven of these instances the column player chose action 1, while the row player deviated from his announcement only two times. In the ensuing periods the row players began to deviate from their announcement of action 2 with the same likelihood as the column players.

Additionally, the ability to achieve the (2,2) outcome in this game seems very sensitive to a small number of players choosing action 1, after saying or hearing an announcement of 2. Replication 2 illustrates this. In the first fourteen periods of play, there is only one instance where a row player announced action 2 and chose action 1 and the column player always took action 2 upon hearing an announcement of 2. In period 15 a column player chose action 1 after hearing an announcement of 2. This row player announced 2 but chose action 1 in two subsequent games and also later chose action 2 after hearing an announcement of 2. This player's choice of action 1 led a third player to begin choosing action 1 after they were paired. This provides an example of the potential instability of a (2,2) equilibrium, as a small perturbation away from the equilibrium can lead to further defections from announced actions.

FACT 4. Strategy 2 was announced 87 percent of the time in one-way communication, but this announcement was followed by play at the (2,2) equilibrium only 60 percent of the time. When strategy 1 was announced, the (1,1) equilibrium was observed.

As seen in Table III, two-way communication was much more successful in overcoming the coordination failures observed in the game without preplay communication. As indicated in this table, strategy 1 was never announced in the last eleven periods of play and was announced only 2.2 percent of the time in the overall game. Of these 165 observations in only fifteen cases did play not occur at (2,2): seven times the row player played 1, and eight times the column player played 1.

FACT 5. In two-way communication, strategy 2 was announced all the time, and the (2,2) equilibrium was observed 94 percent of the time.

B. Cooperative Coordination Game (CCG)

Table IV presents statistics on the frequency of play across the treatments, with particular attention to the combinations of strategies that constitute equilibria for CCG.[14] For the last eleven periods of play, the only rejection of independence in this game occurs in the frequency of announcements across the two-way communication treatment.[15] For that reason, the data for two-way communication are presented by replication.

From this table note first, as reported in Cooper et al. [1990], that coordination failures occur in CCG without preplay communication. That is, the (2,2) equilibrium occurs in only five of the 165 observations, while the (1,1) equilibrium is observed 103 times. In terms of the effects of preplay communication on the frequency of play of the (2,2) equilibrium, we find that

FACT 6. Equilibrium (2,2) was not always observed in one-way and two-way communication.

14. In Table IV (1&3) means either (1,3) or (3,1). This table and Table VII also includes an "egoist" treatment that will be explained and analyzed at the end of this section.

15. Again, using the tests described in footnote 13, we found evidence of serial dependence using the data from all periods, but there was no evidence of dependence using the data from the last eleven periods of each replication. We again fail to reject the hypothesis of no differences between row and column players, except for the obvious case of announcements in the one-way communication treatment. We also could not reject the hypothesis of no difference across replications except for announcements in the two-way treatment.

TABLE IV
CCG
FREQUENCY OF EQUILIBRIUM PLAY

	N	(1,1)	(2,2)	(1&3)	(3,3)
Treatment					
None	165	103 (62.4%)	5 (3.0%)	6 (3.6%)	
One-way	165	25 (15.2%)	111 (67.3%)	12 (7.3%)	3 (1.8%)
Two-way					
rep 1	55	35 (63.6%)	3 (5.5%)	7 (12.7%)	1 (1.8%)
rep 2	55	19 (34.5%)	6 (10.9%)	12 (21.8%)	1 (1.8%)
rep 3	55	6 (10.9%)	39 (70.9%)		
"Egoist"	55	4 (7.2%)	44 (80.0%)	2 (3.6%)	

In fact, there were frequent plays of (1,1), (3,1) (1,3), and (3,3) in both treatments.

The frequency of (2,2) play differed significantly across the replications in two-way communication. Replication 3 had the most plays of (2,2) followed by replication 2 and then replication 1.

The table is also useful for comparing the two communication treatments against the baseline of no communication. Compared with no communication, the frequency of (2,2) play is significantly higher in the one-way communication treatment. As for the two-way communication, in replication 1, the frequency of play of the (2,2) equilibrium does not differ from that observed in the game without communication. For replications 2 and 3 the frequency is significantly higher. Comparing one-way and two-way communication, the play of (2,2) is significantly less in replication 1 and 2 and no different in replication 3.

The data on announcements and the mapping from announcements to actions for the one-way treatment are reported in Table V. Announcements as well as players' responses to announcements can be determined from that table.

FACT 7. In the one-way treatment strategy 2 is not always announced.

As indicated in the table, the frequency of announcements of strategies 1, 2, and 3 were 7 percent, 72 percent, and 21 percent,

TABLE V
CCG
MAPPING OF ANNOUNCEMENTS TO ACTIONS
ONE-WAY COMMUNICATION

Announcement	Actions- Row, Column									
Row	2,2	3,3	1,1	1,3	3,1	2,3	3,2	1,2	2,1	Total
1		1	8		1			2		12
2	111								7	118
3		2	17	6	5		1	3	1	35
Total	111	3	25	6	6		1	5	8	165

respectively. One player in replication 1 always announced strategy 1 (five times) and accounted for about half of the announcements of 1. Three players, one in each replication, accounted for fourteen (40 percent) of the strategy 3 announcements.

As for the mapping between announcements and actions, when strategy 2 is announced by the row player, (2,2) is played 94 percent of the time. Announcements of 1 lead to the play of (1,1) 75 percent of the time. That is,

FACT 8. Announcements of 1 and 2 are generally followed by play of (1,1) and (2,2), respectively.

However, 21 percent of the announcements are strategy 3, and 86 percent of these announcements are followed by the play of (1,1), (1,3), (3,1), and (3,3).

We present the mappings of announcements to actions for the two-way communication treatment in Table VI.

FACT 9. Over one half of the announcements in the two-way communication treatment are different from 2.

In particular, 25 percent of the announcements are strategy 1, and 33 percent of the announcements are strategy 3.

FACT 10. Announcements of (2,2) are generally followed by the play of (2,2).

The results for (2,2) announcements are quite strong: of the 39 announcements of (2,2), play of this equilibrium is observed 38 times. Further, of the ten announcements of (1,1), this equilibrium is observed six times.

For the announcements of (3,3), (1,3), and (3,1), 93 percent were followed by the play of (1,1), (1,3), and (3,1). Play following

TABLE VI
CCG
MAPPING OF ANNOUNCEMENTS TO ACTIONS
TWO-WAY COMMUNICATION

Announcements Row, Col	Actions- Row, Column									
	1,1	1,2	1,3	2,1	2,2	2,3	3,1	3,2	3,3	Total
2,2		1			38					39
3,3	11	1	2	1			3		1	19
1,1	6		1	1			2			10
1,3	19	2	1				1			23
3,1	11		1				2			14
2,3	6	2		5		1	3	2		19
3,2	2	2	1	5	5	1			1	17
1,2	3	2	1	1	1		1			9
2,1	2	1		8	4					15
Total	60	11	7	21	48	2	12	2	2	165

these announcements did not differ from the play in the no communication treatment. However, the play following announcements of (1,2), (2,1), (3,2), and (2,3) did differ significantly from play without communication.

For the two-way treatment our analysis also indicated that

TABLE VII
CCG
MAPPING OF ANNOUNCEMENTS TO ACTIONS
EGOIST

Announcements Row, Col	Actions- Row, Column									
	1,1	1,2	1,3	2,1	2,2	2,3	3,1	3,2	3,3	Total
2,2	1				29					30
3,3	3		1				1			5
1,1										
1,3										
3,1										
2,3				2	5					7
3,2		1		1	5					7
1,2				1	3					4
2,1					2					2
Total	4	1	1	4	44		1			55

both announcements and unconditional actions differed across replications. For this reason, Table VIII shows the announcements, actions, and certain action pairs by replication.

FACT 11. There are significantly more (fewer) announcements and plays of strategy 2 (1 and 3) in replication 3 than in replications 1 and 2.

From Table VIII note that strategy 3 was announced 44 times in replication 1 and 50 times in replication 2 but only 17 times in replication 3. In contrast, strategy 2 was announced 87 times in replication 3 but only 17 times in replication 1 and 34 times in replication 2. There are corresponding differences in play: strategy 2 is played 88 times in replication 3 but only 15 times in replication 1 and 29 times in replication 2.

V. MODEL EVALUATION

The model presented in Section II suggested that allowing preplay communication would overcome coordination problems so that the (2,2) equilibrium would be observed for both SCG and CCG. Further, that model had predictions about the mapping from announcements to actions. This section evaluates those predictions given the results reported above.

TABLE VIII
CCG
TWO-WAY COMMUNICATION
ANNOUNCEMENTS, ACTIONS, AND ACTION PAIRS

	Replications			
	1	2	3	"Egoist"
Announcements:				
1	49	26	6	6
2	17	34	87	80
3	44	50	17	24
Actions:				
1	86	66	19	15
2	15	29	88	93
3	9	15	3	2
Action pairs:				
(2,2)	3	6	39	44
(1,1)	35	19	6	4
(3,3), (1&3)	8	13	0	2

A. Simple Coordination Game (SCG)

The results, summarized in Facts 2 and 3, for the SCG seem qualitatively consistent with the predictions of the model of preplay communication. The results for two-way communication are quite strong: as predicted, strategy 2 is announced by both players, and it is generally played by both.

Though the results for one-way communication are not so strong, one-way communication clearly improves over the baseline in terms of the frequency of (2,2) outcomes. Further, consistent with the theory, when strategy 1 is announced, it is generally played by both players. However, in contrast to the theoretical model, when strategy 2 is announced, the outcome is not always (2,2), (see Fact 4).

One interpretation of the data which we cannot reject is that players are in the following equilibrium: play is at (1,1) following the announcement of 1 and at the mixed strategy equilibrium following the announcement of 2.[16] In the mixed strategy equilibrium of SCG, players choose 2 with probability 0.8 and obtain the same expected payoff as in the (1,1) equilibrium.

This equilibrium seems quite implausible, however, and instead we would conjecture that one-way communication is simply insufficient to convince the sender to take the risk that the receiver will play 2. Knowing this, the receiver may in fact play 1 as well. The tenuous nature of the (2,2) equilibrium with one-way communication was described in the previous section. This doubt about the action of a receiver is overcome by the two-way communication design since both players receive information about the likely play of their opponents. The fact that two-way communication overcomes risk dominance lends support to the prediction of Harsanyi and Selten [1988, pp. 89–90] that ". . . with preplay communication they may come to the conclusion that they can trust each other to choose [the payoff-dominant Nash Equilibrium]." While Harsanyi and Selten were not specific with regard to the communication structure, our results indicate that two-way communication is needed to support the Pareto-dominant Nash equilibrium.

B. Cooperative Coordination Game (CCG)

The results for CCG are not nearly as strong relative to the theory. The conflict between the model and the theory arises

16. We are grateful to a referee for pointing this out.

mainly in the nature of the announcements and not in the actions of the players given announcements.

For the one-way communication treatment, relative to the baseline of no communication, allowing a single player to make an announcement dramatically increases the frequency of play of the Pareto-dominant equilibrium. However, from Fact 6 we know that coordination problems were not completely resolved by one-way communication. Note from Facts 7 and 8 that the observed plays other than (2,2) were the consequence of messages other than 2, in particular announcements of 3. Thus, qualitatively the model's predictions are upheld though the results are not as strong as the theory suggests.

For two-way communication, as indicated by Fact 6, the (2,2) outcome was not observed in all replications. From Fact 9 this was mainly a consequence of messages other than (2,2), since from Fact 10 we know that announcements of (2,2) generally led to play of (2,2). Again, these messages generally included strategy 3.

The model can also be evaluated from the mapping between announcements and actions reported in Tables V and VI. Facts 8 and 10 provide strong support for the assertion that equilibrium announcements lead to equilibrium plays.

Overall, we find that coordination problems persist despite the introduction of cheap talk. The model does have the virtue of explaining part of the mapping between announcements and actions, particularly announcement of 2 (2,2) in the game with one-way (two-way) communication. The fact that the (2,2) outcome is not universally observed is the consequence of players making announcements other than strategy 2 in both communication treatments; announcements that often included strategy 3.

VI. Altruism: Theory and Evidence

The data from CCG are inconsistent with the predictions of the theoretical model in two important ways: (i) there are numerous announcements and plays of strategy 3 in the one-way communication treatment and (ii) the results for two-way communication are replication specific, particularly with regard to announcement and play of strategy 3. These anomalies point to the important role of strategy 3 in CCG. Since this is a dominated strategy, from the perspective of self-interested players, it is puzzling that it plays such an important role in CCG. However, there is now an abundance of evidence in experimental economics on the importance of cooperative play, particularly in prisoner's and social dilemma games.[17] Further, in Cooper et al. [1990] we found that play of the cooperative, dominated strategy in our coordination games was quite prevalent and that variations in payoffs from an opponent's play of that strategy influenced selection of a Nash equilibrium.

The point of this section is to evaluate the role of strategy 3 in CCG. We consider a model which allows for altruism and evaluate the possibility that the failure of preplay communication to lead to the (2,2) equilibrium in CCG is a consequence of cooperative play.[18] The cooperative strategy in CCG creates a tension between attempts at cooperation and reaching the Pareto-superior Nash equilibrium.

A. Theory

One leading explanation of cooperative play is that players believe they are involved in a finitely repeated game of incomplete information where there is some probability their opponent is a tit-for-tat player. Then, even if the game is played by purely self-interested players, there is an equilibrium where cooperation occurs for some periods (see Kreps, Milgrom, Roberts, and Wilson [1982]). That theory has no power in our experiment since players are involved in a series of one-shot games against anonymous opponents.

This then leads us to consider another explanation of observed cooperative play: the possibility that not all players are self-interested. We follow Palfrey and Rosenthal [1985, 1988a] and model altruism through an additional payoff a player receives from playing the cooperative strategy. We chose this model of altruism because it has some empirical support as discussed by Palfrey and Rosenthal. In addition, other, equally parsimonious, models of altruism were either clearly inconsistent with our data or led to

17. See, for example, Dawes [1980], Dawes and Thaler [1988], Isaac and Walker [1988], Palfrey and Rosenthal [1985, 1988], and Roth [1988] for a discussion of some of this evidence.

18. Once we introduce altruists, the terms, coordination failure, and Pareto-dominant equilibrium, need to be carefully defined. We shall refer to play of (1,1) as a coordination failure since it is the outcome of the interaction of two egoists who would be better off at the (2,2) equilibrium. We shall continue to term the (2,2) equilibrium, the Pareto-dominant equilibrium, which is appropriate *if* the interaction is between two egoists. As discussed later, there are new equilibria, (3,1) ((1,3)) if the row player is an altruist (egoist) and the column player an egoist (altruist) and (3,3) if both players are altruists.

predictions that were equivalent to those from our model.[19] It should be stressed that our goal here is modest: to suggest an alternative to the model of egoists that might account for some of the anomalies in our data.

Consider again the game presented in Figure I. The payoffs for egoists are given in the cells of the matrix. As in Palfrey and Rosenthal [1985, 1988a] suppose that a cooperative player receives, in addition to the payoffs in the cells of Figure I, a "warm glow" of δ from playing the cooperative strategy 3.[20] We assume that all players know that there are some cooperative individuals in the cohort with $550 \geq \delta \geq 400$ but that preferences are private information. Call players with $550 \geq \delta \geq 400$ altruists and those with $\delta = 0$ egoists, and let ρ denote the proportion of altruists in the population. These bounds on δ arise from the condition that strategy 3 be neither dominant nor dominated for altruists.[21] We assume that ρ is common knowledge.

19. As in Cooper et al. [1990], we also considered a model in which altruists' preferences were given by the minimum of the payoffs in a cell. Surprisingly, there were only pooling equilibria for that specification of altruism. In contrast to the warm-glow model described below, the proportion of altruists had to be relatively high in order to induce them to announce and play strategy 3. This condition was inconsistent with that needed to provide the correct incentives to egoists. Hence, the role of announcing strategy 3 as a signal of preferences could not arise in that model. The resulting pooling equilibrium would be rejected by our data. As in Cooper et al. [1989], we also considered a model in which the true payoff for some players was the sum of the payoffs in each cell of the matrix given in Figure I. This turns out to be equivalent to the warm-glow model for the parameters used here. A referee suggested to us a model of "reciprocal altruism" in which an altruist obtains an extra payoff from cooperation iff his opponent cooperates as well. This model has the same best-response pattern as the "min-model" mentioned above. This model did have separating equilibria if the extra payoff for altruists exceeded 1,187. This model shares with the model discussed in the paper an inability to explain announcements of 3 followed by plays of 1 in the one-way communication treatment.

20. See also Bergstrom, Blume, and Varian [1986] for a further discussion of warm-glow altruism. For altruists, view the payoffs in the modified Figure I that includes δ for playing strategy 3 as the actual utility levels for the individual players, and thus ignore the translation from points into dollars. In terms of our experiment we think of cooperative players as obtaining utility from playing 3 in addition to the points earned from the choice of this strategy. That is, suppose that the utility function for a cooperative player is $q[u(1) - u(0)] + u(0) + \psi C$, where $C = 1$ if the cooperative strategy is chosen and 0 otherwise. Here q is the number of points earned in the play of the game divided by 1,000 and ψ is the value of cooperating. One can then think of the δ associated with the play of the cooperative strategy as the "point equivalence" of this utility from cooperation.

21. Here we simplify matters by assuming that there are two types of agents: altruists with $550 \geq \delta \geq 400$ and egoists with $\delta = 0$. If $\delta \in (0,400)$, then 3 is still a dominated strategy, and this leads to behavior that is observationally equivalent to $\delta = 0$. If $\delta \geq 550$, then 3 is a dominant strategy. If altruists had $\delta \geq 550$, then the theoretical results reported in the Appendix would be altered in that (1) Proposition 1 would not hold as there would be no (2,2) equilibrium and (2) the value 4/13 in Propositions 3–6 would be replaced by 1/6. As we find no evidence of players always playing strategy 3, we restrict attention to $\delta < 550$. A less parsimonious model would specify a distribution of δ across players.

When $\rho > 0$, this is a game of incomplete information, as players do not know the preferences of their opponents. Preplay communication serves to signal types as well as influence the selection of an equilibrium.[22] To the extent that these two effects of communication conflict, cheap talk communication might not be as effective as in a game between egoists.

Appendix A contains an explicit model of this game of incomplete information. Here we summarize those results and use them to evaluate our data.

B. One-way Communication

For *one-way communication,* if $\rho > 4/13$, all players will announce 3 with the egoists playing 1 and the altruists choosing 3. Thus, cheap talk will provide no information. If $\rho \leq 4/13$, there exists a totally revealing equilibrium in which the egoists announce 2 and play it, while the altruists announce 3 and play it. In response to hearing 3, the egoists play 1, and the altruists play 3. Upon hearing 2, both egoists and altruists select strategy 2. Self-interested players choose not to announce 3 because the risk they will meet another egoist, and hence earn 350 from the (1,1) outcome, is too high when $\rho \leq 4/13$. Outcomes of (2,2), (3,3), (3,1), and (1,3) are consistent with this equilibrium. As Table V indicates that not all announcements were of strategy 3, we focus on this fully revealing equilibrium.

From Table IV 76.4 percent (126/165) of the observed outcomes coincide with those predicted by this model while only 111 are explained by a model with all egoists. However, of these fifteen additional observations, only seven are consistent with the theory in terms of the mapping from announcements to actions.

Furthermore, the model with all egoists predicted that the announcements of 3 (21 percent of the announcements) should lead to the (1,1) equilibrium. Instead, as noted earlier, 22.8 percent of those announcements were followed by the play of strategy 3. This play is consistent with a model with cooperative players, since altruists will play strategy 3 upon either saying or hearing strategy 3.

Still, there are 39 plays that are not predicted by the model; 25 of these are (1,1) which represents a coordination failure between egoists (since strategy 1 is a dominated strategy for altruists).

22. Ben-Porath and Dekel [1989] raise a similar point in their discussion of forward induction.

Table V illustrates the source of these plays of (1,1). Of the 35 announcements of strategy 3, seventeen of them led to play of (1,1). This is inconsistent with the predictions of a fully revealing equilibrium since altruists are the only players saying 3 and they should proceed to play it.

The model provides a means of estimating ρ from our data. Two estimates of the value of ρ are given in Table IX. For the one-way treatment the first estimate, ρ_1 is obtained from the frequency of the announcements of 2. The model in the Appendix gives the probability that a random player announces 2 as $(1\text{-}\rho)$. Based on the observed frequency of announcements of 2, we can then estimate ρ_1. The second estimate ρ_2 is calculated by taking the frequency of announcements of strategy 3 that are followed by the play of strategy 3 and dividing by the total possible announcements. In equilibrium these estimates should be the same. They differ because the play, in particular that following disequilibrium announcements, did not satisfy the predictions of the model. Still, we see that both estimates exceed zero, indicating the presence of altruists and both fall below the critical cutoff of 4/13.

C. Two-Way Communication

For *two-way communication,* the Appendix demonstrates that, if $\rho \leq 4/13$, a partially revealing equilibrium can be constructed in which altruists always announce strategy 3 while the egoists randomize between announcements of 2 and 3. Egoists who announce 3 and then play 1 are trying to profit by being matched with an altruist who always plays 3 when his opponent announces 3. Egoists who announce 2 play 2 regardless of the announcement of their opponent. So announcements of (3,2) or (2,3) lead to the play of (2,2). When ρ is low, the egoists will perceive a cost of announcing 3 and playing 1: there is a high probability that two egoists saying 3 will be matched and both play 1 leading to a payoff

TABLE IX
CCG
ESTIMATE OF ρ

	One-way	Two-way by replication 1	2	3	Egoist
ρ_1	0.29	0.26	0.21	0.05	0.09
ρ_2	0.09				
ρ_3		0.33	0.29	0.15	0.14

of only 350. Thus, egoists will mix between announcing 2 and 3. Therefore, the model predicts that two-way communication may not yield the (2,2) outcome since the interaction between altruists and egoists can lead to considerable play of strategies 1 and 3.[23]

When the proportion of altruists is high enough, $\rho > 4/13$, a partially revealing equilibrium will not exist because the chance of being matched with another egoist and thus earning 350 from the play of (1,1) is sufficiently low that all egoists announce 3 and play 1. Here there is a pooling equilibrium in which all types announce strategy 3. As in the one-way communication treatment, we see no evidence of this announcement pattern and thus focus on the $\rho \leq 4/13$ case.

The observed play of (1,1), (2,2), (3,1), (1,3), and (3,3) reported in Table IV coincides with the predicted outcomes of this model. In fact, the new model accounts for 81 additional observations (49 percent) that are not predicted by the egoist model. However, only 22 of these additional observations follow from announcements of (3,3), (3,2), and (2,3) as predicted by the model with altruists. Many of the observed (1,1), (1,3), and (3,1) outcomes were preceded by announcement pairs in which at least one player announced strategy 1. In fact, if we interpret the announcements 1 and 3 as identical, then 49 additional observations are consistent with the predicted mapping between announcements and actions.

Further, from Table VIII note that there are numerous announcements of both strategies 2 and 3 as predicted by the theory. Since (2,2) announcements lead to (2,2) (recall Fact 8), the data are consistent with that feature of the model. Moreover, the observed play of (1,3), (3,1), and (3,3) stemming from announcements of (3,3) is consistent with our theory. The fact that 17/19 of the plays following announcements of (3,3) were combinations of strategies 1 and 3 is also explained by the model of altruism.

The explanation for Fact 11, the differences across replications in announcements and actions, can be attributed to differences in the proportion of altruists across cohorts. When ρ is high, the theory predicts more announcements of 3, both because there are more altruists and because there are more egoists pretending to be altruists.[24]

As was the case for one-way communication, we can estimate

23. The model also predicts that as ρ increases, the frequency of strategy 3 announced by egoists increases.

24. The model has an interesting feature that even a small value of ρ can create a considerable amount of announcements of 3 and plays of 1. As discussed by Haltiwanger and Waldman [1986], in games with strategic complementarities such as coordination games, altruists will have a large effect on the equilibrium outcome.

the value of ρ for this treatment by replication. The first estimate of ρ in Table IX, ρ_1, is again obtained from the frequency of the announcements of 2. According to the model, the probability that a randomly selected player will announce 2 is $1 - (13/4)\rho$. The second estimate ρ_3 comes from the observed play of strategy 1.[25] Except for ρ_3 in replication 1 these estimates of ρ fall below 4/13, the theoretical cutoff for the partially revealing equilibrium. Note though that these estimates all exceed zero, providing some support for the argument that not all players were self-interested. In replication 3 the low value of ρ implies more announcements and plays of 2 relative to the other replications in which the estimated value of ρ is higher. Overall, we would attribute the inability of cheap talk to lead to the (2,2) outcome, desired between egoists, to the presence of altruists in the cohorts in replications 1 and 2.

In our view, this model is a useful extension of that presented in Section II since it allows us to explain a greater proportion of the observed announcements and plays in our game. Since adding altruism gives us extra degrees of freedom to explain the results, we sought some independent evidence that altruism was important in the observed coordination failures with preplay communication. This evidence, reported next, is obtained by controlling, as much as possible, for altruism within a cohort.

D. Controlling for Altruism

To further evaluate the role of altruism in our results, we recruited players who had participated in a bargaining experiment reported in Forsythe, Horowitz, Savin, and Sefton [1988]. In that experiment two players were anonymously matched for a single period to play a dictator game. One (the dictator) was given either \$5 or \$10 and the option of giving \$$X$ to the other player. Once the dictator decided on X, the participants were paid off, and the experiment ended. In the \$5 (\$10) game Forsythe et al. find that only 36 percent (21 percent) of the players set $X = 0$ and 22 percent (21 percent) gave their opponents \$2.50 (\$5) or more.

We recruited eleven players from this experiment who chose $X = 0$ and termed these players "egoists." The egoists participated in a two-way communication replication identical to that described

25. From the model in the Appendix the probability of observing the play of 1 is $(1 - \rho)\pi[\rho + (1 - \rho)\pi]$, where ρ is the proportion of altruists in the population and π is the probability that an egoist announces 3, which equals $9\rho/((1 - \rho)4)$. Note that the play of 1 can arise when an egoist saying 3 meets an altruist or another egoist saying 3.

above with one exception. At the start of the treatment the egoists were informed that the players in the experiment were chosen because they had not given anything away in the earlier experiment.[26]

The theory predicts that for low values of ρ, as in the egoist treatment, the outcome (2,2) should be observed most of the time and supported by announcements of strategy 2. Looking at Tables IV and VII, the egoist treatment seems to be close to this prediction. The (2,2) outcome was observed 80 percent of the time in this treatment. Strategy 2 was announced 55 percent of the time, and (2,2) announcements were followed by play of (2,2). Announcements and plays did not differ significantly between the egoist treatment and replication 3. In both, the (2,2) outcome was observed more than in the one-way treatment and the other two-way communication replications.[27]

VII. Conclusions

In previous work we have found that coordination failures can occur in coordination games. The point of this paper was to determine whether allowing preplay communication would overcome these problems.

Our results indicate that the lack of communication between individuals is not the source of the coordination problems reported in Cooper et al. [1990] for coordination games such as CCG. Allowing preplay communication does not uniformly lead to the play of the Pareto-dominant Nash equilibrium, nor is equilibrium

26. At the start of the egoist treatment, the following was read aloud: "Each of you previously participated in an experiment within the last year in which you were given a sum of money (either \$5 or \$10) and had the opportunity to give an amount of this to a person in another room. You each chose to keep the entire amount for yourself."

27. We also recruited eleven "altruists"; i.e., players who gave away at least 40 percent of their initial endowment in the dictator games. Overall, the altruist treatment was not significantly different from replication 2. Except for announcements, the treatment did not differ from replication 1 in the last five periods. See Lutzker [1960] for an attempt at separating egoists and altruists in a prisoner's dilemma game.

We only report details of the egoist treatment since our control of altruists was imperfect. In terms of our model of altruism, players recruited for the egoist experiment presumably had δ's which were zero or very low so that they were likely to view strategy 3 in the coordination game as dominated. However, the value of δ relative to 400 is more difficult to determine from the fact that they gave away money in the dictator game. Further, while players may act altruistically in a dictator game because of its asymmetric structure, they may not display the same preferences in other, perhaps more symmetric environments. As a consequence, we would argue that our control over payoffs in the altruist treatment was less successful than in the egoist treatment.

play always observed. Instead, one observes play of both the cooperative strategy and the strategy supporting the Pareto-inferior Nash equilibrium. This is inconsistent with the predictions of a model which assumes that egoists will use preplay communication to select the preferred Nash equilibrium.

To understand our observations for the coordination game with a cooperative strategy, we then considered an alternative model that allowed for the presence of some altruistic players in a given cohort. While the model accounted for only a few additional observations in the one-way communication treatment, for two-way communication the model with altruists explained a significantly greater number of the observed outcomes and also provided insights into the differences in outcomes across cohorts of players. Controlling for altruism enhanced the ability of preplay communication to resolve coordination problems.

For SCG the predictions of the theory are qualitatively supported. This is certainly the case for two-way communication when the (2,2) equilibrium is observed almost all of the time.

Two areas for future work emerge from this research. First, it is interesting to contrast the results from SCG with those reported in Cooper et al. [1989] for the battle of the sexes games. By definition there is no conflict in the simple coordination game, while conflicting interests are at the heart of the battle of the sexes games. Relative to this, note that one-way communication completely resolved coordination problems in the battle of the sexes game, while two-way communication was the better institution in SCG. In contrast to CCG the coordination problems in SCG were a consequence of the riskiness of the strategy supporting the Pareto-dominant equilibrium so that two-way communication was necessary to resolve strategic uncertainty. This suggests a general theme that may be worth pursuing: one-way communication is preferred in games of conflict, while two-way communication is needed to resolve coordination problems in games, such as SCG, in which strategic uncertainty leads to coordination failures.

Second, our work suggests, once again, the need for further theoretical and experimental consideration of cooperative play. There has been a considerable amount of cooperative play observed elsewhere in experimental games. Of this the work on finitely repeated prisoner's dilemma games has received the most attention and has been explained by reputation effects, such as those emphasized by Kreps et al. [1982]. Since the history-dependent strategies required to support cooperation are not feasible in our setting, we were forced to adopt a model with some altruists to explain our results. This leads naturally to a question of the relative importance of reputation effects and altruism in the games in which cooperative play has been observed.

APPENDIX

Here we formally consider equilibria of our games in which a proportion ρ of the players are altruists and the remainder are egoists. The payoffs for the egoists are given in Figure I while altruists receive an extra "warm glow" payoff of δ from playing strategy 3, where $550 \geq \delta \geq 400$. We assume that the proportion ρ is common knowledge but that players' preferences are not observable.

No Communication

For the game without communication there will exist a number of equilibria. Here we discuss two that are of special interest.

PROPOSITION 1. For all values of ρ there exists an equilibrium in which all players play 2.

Proof of Proposition 1. This is clearly an equilibrium since 2 is a best response to 2 for both egoists and altruists.

Q.E.D.

PROPOSITION 2. For all values of ρ there will exist an equilibrium in which egoists play 1 and altruists play 3.

Proof of Proposition 2. The expected payoff to an egoist from playing 1, $\rho 1{,}000 + (1 - \rho)350$, exceeds the payoff of $(1 - \rho)250$ from playing 2. For the altruists the expected payoff from playing 3 is $\rho 600 + \delta$ which is greater than the payoff from playing 2, $(1 - \rho)250$ as $\delta \geq 400$ by assumption. These are the only alternatives we need to check since strategy 1 is a dominated strategy for altruists and strategy 3 is a dominated strategy for egoists.

Q.E.D.

In addition to these pure strategy equilibria, there will also exist mixed strategy equilibria in the game without communication. For example, if $\rho < 1/6$, there will exist an equilibrium in which all the altruists play 3 and the egoists mix between 1 and 2.

When ρ exceeds 1/6, the return to playing 1 is sufficiently high that all egoists will play that strategy.

One-Way Communication

PROPOSITION 3. If $\rho > 4/13$, there is a nonrevealing equilibrium in which all players announce 3, egoists play 1, and altruists play 3. All other announcements lead to the play of 2.

Proof of Proposition 3. For the egoists the strategy of saying 3 and playing 1 yields $\rho 1{,}000 + (1 - \rho)350$. If they deviate and announce either 1 or 2, they will receive 550. When $\rho > 4/13$, $\rho 1{,}000 + (1 - \rho)350 > 550$. Egoists who hear 3 best respond by playing 1. This is a best response to an altruist's play of 3 and the play of 1 by another egoist.

For altruists an announcement of 3 yields $\delta + \rho 600$ in equilibrium which exceeds the 550 obtained by an alternative announcement. Altruists respond to the announcement of a 3 by playing 3 since this is the best response to either the play of 3 *or* the play of 1.

Q.E.D.

PROPOSITION 4. If $\rho \leq 4/13$, there will exist a totally revealing equilibrium in which altruists announce 3 and egoists announce 2. Egoists play 2 (1) in response to hearing 2 (3). Altruists play 2 (3) in response to hearing 2 (3).

Proof of Proposition 4. The proof given above indicates that when $\rho \leq 4/13$, egoists will prefer to announce 2 and play 2 rather than announcing 3 and playing 1. Egoists will respond to the announcement of 3 by playing 1 since, in equilibrium, the altruists announce and play 3. Further, the egoist will respond to the announcement of 2 by playing 2 since, in equilibrium, the announcer of 2 is playing 2.

For altruists, announcing 3 dominates announcing 2 by the argument given in the proof of Proposition 3. The altruist best responds to the announcement of 3 by playing 3 in response to the conjecture that the announcement of 3 was by another altruist. The altruist responds to the announcement of 2 by playing 2 since the egoist plans to play 2 after announcing it.

Q.E.D.

Two-Way Communication

Here we modify the notation introduced in Section II. Let $\sigma^i(m_R,m_C)$ be the mixed strategy of agent of type $i = A,E$ when the announcement is (m_R,m_C). The jth element in the vector $\sigma^i(m_R,m_C)$ is the probability that action j is chosen. Here we view the row player as the agent whose strategy we are describing. The notation $i = A$ refers to an altruist and $i = E$ refers to an egoist.

PROPOSITION 5. If $\rho \geq 4/13$, there will exist a nonrevealing equilibrium in which all players announce strategy 3. Further, $\sigma^A(3,3) = (0,0,1)$, $\sigma^E(3,3) = (1,0,0)$, and $\sigma^i(m_R,m_C) = (0,1,0)$ for $(m_R,m_C) \neq (3,3)$ for $i = A,E$.

Proof of Proposition 5. For egoists the returns to announcing 3 are $\rho 1{,}000 + (1 - \rho)350$, and this exceeds 550, the gains from announcing anything else, as long as $\rho \geq 4/13$. Egoists best respond to an announcement of (3,3) by playing 1 since this is their best response to the play of either 3 or 1.

The return for an altruist from saying 3 is $\rho 600 + \delta$ which exceeds 550 if $\rho \geq 4/13$. Altruists respond to hearing (3,3) by playing 3 since this is their best response to the play of either 3 or 1.

The play of (2,2) by both types of players following any other announcement is a Nash equilibrium for the continuation game since both types of players respond to the play of 2 by selecting strategy 2.

Q.E.D.

PROPOSITION 6. If $\rho < 4/13$, there exists a sequential Nash equilibrium in which all altruists announce 3, a proportion π of the egoists announce 3, and the remainder of the egoists announce 2. Further, $\sigma^A(3,3) = (0,0,1)$, $\sigma^A(3,2) = (0,1,0)$, while $\sigma^E(3,3) = (1,0,0)$ and $\sigma^E(2,2) = \sigma^E(2,3) = (0,1,0)$. All other pairs of announcements lead to the play of (2,2) regardless of the players types.

Proof of Proposition 6. For the egoists to be indifferent with respect to the announcement of 2 and 3, it must be the case that

$$550 = \rho 1{,}000 + (1 - \rho)(\pi 350 + (1 - \pi)550). \qquad \text{(A1)}$$

The left side of this equality is the certain return to announcing 2. If the egoist announces 3 and plays 1, then with probability ρ the egoist meets an altruist and so earns 1,000; with probability

$(1 - \rho)\pi$ two egoists are matched, and each earn 350; while with probability $(1 - \rho)(1 - \pi)$ the egoist is matched with another egoist who says 2, and so both play 2. Note that here we use the fact that if an egoist says and hears 3, he will play 1. This is rational since the egoists best response to the play of either 1 or 3 is strategy 1. Note too that in the equilibrium, the egoist is assumed to play 2 in response to any other message. This is a consequence of the fact that playing 2 is a best response to the play of 2 by another player. For (A1) to be met with $\pi \leq 1$, it is necessary and sufficient that $\rho \leq 4/13$. From (A1), $\pi = \rho 9/((1 - \rho)4)$.

For the altruists the condition that announcing 3 be at least as good as announcing 2 is

$$\text{(A2)} \qquad \rho(600 + \delta) + (1 - \rho)(\pi\delta + (1 - \pi)550) \geq 550.$$

The right side is the return to announcing 3. With probability ρ the altruist is matched with another altruist, and both earn $600 + \delta$. With probability $(1 - \rho)\pi$ the altruist is matched with an egoist who says 3. In this case, the altruist plays 3 and earns δ. Finally, with probability $(1 - \rho)(1 - \pi)$ the altruist says 3 and hears 2, so that both players play 2 and the altruist earns 550. Thus, the actions assigned to the altruist for the various combinations of announcements are best responses. Using (A1), (A2) is met as long as $\delta > 400$ which has been assumed.

Q.E.D.

Department of Economics, Boston University
Department of Accounting, University of Iowa
Department of Economics, University of Iowa
Department of Economics, Carleton University, Canada

References

Ben-Porath, Elhanan, and Edward Dekel, "Coordination and the Potential for Self-Sacrifice," mimeo, revised, May 1989.
Bergstrom, Theodore, Lawrence Blume, and Hal Varian, "On the Private Provision of Public Goods," *Journal of Public Economics*, XXIX (1986), 25–50.
Bryant, John, "A Simple Rational Expectations Keynes-Type Model," *Quarterly Journal of Economics*, XCVII (1983), 525–29.
Cooper, Russell, Doug DeJong, Robert Forsythe, and Thomas Ross, "Communication in the Battle of the Sexes Game," *Rand Journal of Economics*, XX (1989), 568–87.
Cooper, Russell, Doug DeJong, Robert Forsythe, and Thomas Ross, "Selection Criteria in Coordination Games: Some Experimental Results," *American Economic Review*, LXXX (1990), 218–33.
Cooper, Russell, and Andrew John, "Coordinating Coordination Failures in Keynesian Models," *Quarterly Journal of Economics*, CIII (1988), 441–63.
Dawes, Robyn M., "Social Dilemmas," *Annual Review of Psychology*, XXXI (1980), 169–93.

——, and Richard H. Thaler, "Anomalies: Cooperation," *Journal of Economic Perspectives,* II (1988), 187–97.
Diamond, Peter, "Aggregate Demand Management in Search Equilibrium," *Journal of Political Economy,* XCI (1982), 881–94.
Farrell, Joseph, "Communication and Nash Equilibrium," working paper, GTE Laboratories, 1985.
——, "Cheap Talk, Coordination, and Entry," *Rand Journal of Economics,* XVIII (1987), 34–39.
Forsythe, Robert, Joel Horowitz, N. Eugene Savin, and Martin Sefton, "Replicability, Fairness and Pay in Experiments with Simple Bargaining Games," University of Iowa Working Paper 88-30, 1988.
Haltiwanger, John, and Michael Waldman, "The Role of Altruism in Economic Interaction," mimeo, UCLA, June 1986.
Harsanyi, John, and Reinhard Selten, *A General Theory of Equilibrium Selection in Games* (Cambridge, MA: MIT Press, 1988).
Isaac, Mark, and Mark Walker, "Communication and Free Riding Behavior: The Voluntary Contribution Mechanism," mimeo, University of Arizona, 1986.
——, and ——, "Group Size Effects in Public Goods Provision: The Voluntary Contribution Mechanism," *Quarterly Journal of Economics,* CIII (1988), 179–200.
Kendall, Maurice, and Alan Stuart, *The Advanced Theory of Statistics, Vol. 2* (New York, NY: Macmillan, 1979).
Kreps, David, Paul Milgrom, John Roberts, and Robert Wilson, "Rational Cooperation in the Finitely Repeated Prisoner's Dilemma," *Journal of Economic Theory,* XVII (1982), 245–52.
Lutzker, Daniel, "Internationalism as a Predictor of Cooperative Behavior," *Journal of Conflict Resolution,* IV (1960), 193–97.
Myerson, Roger, "Credible Negotiation Statements and Coherent Plans," Discussion Paper No. 691, Center for Mathematical Studies in Economics and Management Science, Northwestern University, 1987.
Palfrey, Thomas, and Howard Rosenthal, "Altruism and Participation in Social Dilemmas," Carnegie Mellon University, Working Paper #35-84-85, 1985.
——, and ——, "Private Incentives and Social Dilemmas: the Effect of Incomplete Information and Altruism," *Journal of Public Economics,* XXXV (1988a), 309–32.
——, and ——, "Testing for Effects of Cheap Talk in a Public Goods Game with Private Information," mimeo 1988b, *Games and Economic Behavior,* forthcoming.
Roth, Alvin E., "Laboratory Experimentation in Economics: A Methodological Overview," *Economic Journal,* XCVIII (1988), 974–1031.
——, and Michael W. K. Malouf, "Game-Theoretic Models and the Role of Bargaining," *Psychological Review,* LXXXVI (1979), 574–94.
Van Huyck, John, Raymond Battalio, and Richard Beil, "Tacit Coordination Games, Strategic Uncertainty and Coordination Failure," *American Economic Review,* LXXX (1990), 234–48.