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**EVOLUTION OF COMMUNICATION WITH
PARTIAL COMMON INTEREST**

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Evolution of Communication with Partial Common Interest*

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Abstract

This paper uses experiments to investigate the evolution of communication. We consider simple games of information transmission in which the interests of senders and receivers are imperfectly aligned. We show that under four canonical incentive conditions the no-communication hypothesis can be rejected with and without literal meanings. Communicative outcomes are less likely to evolve and, if they do, evolve more slowly without a commonly understood language. When we see communicative outcomes, they tend to satisfy a *partial common interest* condition. Equilibria are useful guideposts for analyzing outcomes but are not always obtained; e.g., with literal meanings we observe stable sucker behavior and adherence to focal meanings and, without literal meanings, combinations of actions that could not coexist under any equilibrium.

1 Introduction

This paper uses experiments to investigate the evolution of communication. It considers both the dynamic stability of pre-established meanings and the convergence toward meaningful messages from initially meaningless messages. This is done in an environment where imperfect incentive alignment between agents creates barriers to effective communication.

There is strong applied interest in communication with imperfect incentive alignment. In economics, Stein [1989] examines communication between the Federal Reserve Board and market traders. The Board wants to communicate part of its intentions but not all; otherwise, traders will take strategic positions that negate the policies of the Board. Similarly, in political science, Austen-Smith [1990] shows that preference diversity among legislators limits the scope for information transmission in debate. In accounting, Newman and Sansing [1993] analyze voluntary disclosures made by management to its firm's shareholders. The incumbent firm and stockholders have common interests and accurate information helps stockholders with consumption smoothing. However, the presence of a potential entrant, who observes the disclosure as well, creates an incentive to understate earnings in order to deter entry.

Such situations are commonly represented through sender-receiver games. In a sender-receiver game a privately informed sender sends a message to a receiver who then takes an action in response to the message. The payoffs of both players depend on the private information of the sender and the receiver's action, but not on the message sent.

Sender-receiver games tend to have a large number of equilibria and thus pose a serious equilibrium selection problem. The focus in the applied literature, which builds on the work by Crawford and Sobel [1982] (CS), is on the limits that incentives impose on communication. For this reason, this literature has concentrated on the most influential equilibria (Austen-Smith and Banks [1995]), i.e., the equilibria that induce the greatest number of different receiver actions. Under some regularity assumptions that are typically satisfied in the applied literature, these equilibria also *ex ante* Pareto-dominate the less influential equilibria. In every equilibrium of a CS game, if preferences are imperfectly aligned, subsets of the type set send a common message, which distinguishes them from other such sets; i.e., equilibria take the form of partition equilibria. Thus messages are only partially informative unlike in the work of Grossman [1981] and Milgrom [1981] where messages are assumed to be verifiable and turn out to be fully revealing in equilibrium. Without such verifiability, the most influential equilibria induce the finest partition of the type set and in that sense convey the most information.¹

There is strong intuition that in sender-receiver games with sufficiently

¹Note that informativeness of an equilibrium is necessary but not sufficient for it to be influential, because different posterior beliefs may induce identical best replies or because small variations in the posterior may not be sufficient to alter best replies.

closely aligned incentives at least some information will be revealed by the sender. However, this intuition is not captured by equilibrium refinements like strategic stability (Kohlberg and Mertens [1986]), which have strong implications in games with costly signaling.

There is a literature that addresses the problem of equilibrium selection in sender-receiver games that formulates refinements by appealing to the existence of a commonly understood language, Farrell [1993], Matthews, Okuno-Fujiwara and Postlewaite [1991], Rabin [1990]. Uninformative equilibria are eliminated by postulating that messages are interpreted consistent with their literal meaning unless this violates strategic aspects of the game. Unfortunately, in general none of the influential equilibria in CS games pass Farrell's test. This includes the favorite equilibria of the applied literature.

There are other limits to communication, which are not a direct result of the incentive conditions imposed by equilibrium. There is the issue, related to the refinement arguments, that often the most influential equilibria have properties that suggest they are unstable. Often in applied work, equilibria cannot be Pareto ranked. Finally, simple misunderstandings, where the intended meaning does not match the received meaning, are possible and also destabilizing. Under these circumstances, it is legitimate to ask whether the focus on influential or Pareto efficient equilibria is warranted.

We propose a stringent test. We consider both messages with and without literal meanings, and investigate whether and how meaningful communication evolves in games that satisfy a *partial common interest (PCI)* condition. *PCI* is a strong requirement used in both standard and evolutionary game theory (Rabin and Sobel [1996], Blume, Kim and Sobel [1993], and Blume [1996] [1997]) to predict meaningful communication despite imperfect incentive alignment. We relate the *PCI* condition to the CS model and investigate the proposed selection criteria of influentiality, Pareto efficiency and refinements in the spirit of Farrell.

The advantages of looking at meaningful messages are that (1) we obtain clean outcomes and (2) we get to observe degradation and recoding of meanings. Here the focus is on local stability of communicative outcomes.

The attraction of meaningless messages is that (1) we deal with a clearly delimited benchmark case, which permits us to consider variations of the message space in a systematic way, (2) we reduce focal point effects, which are not well understood, (3) we construct a reference point from which one can assess the contribution of a preexisting common language, (4) we make it easier for dynamic instability to affect informative outcomes, by removing the focal role of a commonly understood language, (5) we do not have to postulate the existence of unused messages and can instead rely on a theory that predicts that the dynamic process itself will generate the unused messages, which are necessary to destabilize uninformative outcomes, and (6) we can observe the mechanism by which uninformative equilibria become undone. Here the focus is on global convergence to communicative outcomes.

We show that under four canonical incentive conditions the no-communication

hypothesis can be rejected with and without literal meanings. There are non-trivial dynamics even when messages have literal meanings. Communicative outcomes are less likely to evolve, and, if they do, evolve more slowly without a commonly understood language. When we see communicative outcomes, they tend to satisfy a *partial common interest* condition. Equilibria are useful guideposts for analyzing outcomes but are not always obtained; e.g., we observe stable sucker behavior and adherence to focal meanings with literal meanings and, without literal meanings, combinations of actions that could not coexist under any equilibrium. Selection criteria that discriminate among equilibria on the grounds of influentiaity, ex ante efficiency or refinements do not capture the systematic deviations from equilibrium play that we do observe. In addition they may both under- and overpredict the extent of communication; e.g. we observe communication where refinements reject all equilibria, we observe a tendency toward partial pooling play where influentiaity would predict full separation, and for one of our incentive structures we observe one of two possible ex ante efficient equilibria in a given treatment, but not the other.

2 Theory and Hypotheses

This section describes CS games, proposes variations of CS games with experimentally salient incentives and discusses the selection criteria we wish to examine. We formulate our hypotheses to evaluate (1) the most-influential-equilibrium prediction, (2) the refinement prediction, (3) the most-efficient-equilibrium prediction and (4) the partial-common-interest prediction.

A sender-receiver game is a two-player game in which one player, the sender, has private information and the other, the receiver, takes an action. Before the receiver takes his action, the sender sends a message. Payoffs to both players depend solely on the sender's private information, his type, and on the receiver's action.

Crawford and Sobel analyze sender-receiver games with a continuum of types drawn from the unit interval in which the sender's and the receiver's preferences over actions are concave and in which the alignment of preferences can be expressed by a single parameter. As an example, they consider a model with quadratic preferences. The payoff to a sender of type t from action a is $-(a - (t + b))^2$, where $b > 0$, and the receiver's payoff equals $-(a - t)^2$. They show that in such games all equilibria are partition equilibria; i.e., the type set can be partitioned into a finite number of intervals such that types belonging to the same interval send a common message and receive the same action. The message of their paper is that costless communication can be effective and that the informativeness of such communication depends on the alignment of preferences, measured by the parameter b in the quadratic model. For every value of the alignment parameter b , there exists a number $N(b)$, such that there are partition equilibria with sizes (numbers of partition elements) $N = 1, \dots, N(b)$.

The maximal size, $N(b)$, is a nonincreasing function of b .

The equilibria of size $N(b)$ receive the most attention in the literature. This is sometimes justified by pointing out that being most influential confers saliency or by appealing to the *ex ante* efficiency of these equilibria. Unfortunately, refinements in the spirit of Farrell reject influential equilibria when they exist.

A direct experimental examination of CS games, while intriguing, runs into three principal difficulties: (1) It is difficult to experimentally implement continuous type, message and action spaces, (2) the incentives of marginal types (near partition boundaries) are not salient, and (3) it is impossible to disentangle the roles of influentiality, efficiency, and refinements. For these reasons, we derive our canonical incentive structures from a generalization of the quadratic example in which the preference alignment parameter is a function of the type, $b(t)$. Furthermore, we discretize the type space by representing classes of types by a single type whose incentives reflect those of a typical member in that class.

Our objective is to examine equilibrium selection criteria for sender-receiver games with partition equilibria of different sizes, with and without literal meanings of messages. Two of these criteria are commonly used in the applied literature. Influentiality selects those equilibria that induce the maximal number of distinct receiver actions. The efficiency criterion selects the *ex ante* efficient equilibria. Although the applied works informally appeal to a commonly understood language, the two criteria are silent about the role such a language might play.

Refinements in the spirit of Farrell [1993] select equilibria that are robust to credible statements in a commonly understood language. Given a reference equilibrium, a statement "I belong to the set of types S " is deemed credible if (1) types in S would want to make that statement conditional on it being believed and (2) only types in S would want to make that statement under that condition. Equilibria that pass the refinement test need not always exist; for example, there may be only a pooling equilibrium, a set S may be able to credibly identify itself relative to that equilibrium but types in the complement S^c of S would prefer to misrepresent themselves as members of S rather than be identified. This may undermine the credibility of the self-identification of the set S and initiate a dynamic process that subverts the original meaning of the message "I belong to the set of types S ."²

Partial common interest (PCI) is an alternative way of expressing incentive alignment between senders and receivers. The central idea is that one may be able to partition the type set in such a way that the sender is willing to credibly reveal information consistent with that partition but not necessarily more. PCI is particularly well suited for making predictions in environments where

²This is analogous to the so called Stiglitz Critique of equilibrium refinements (see Cho and Kreps [1987]). Farrell [1993] has proposed a dynamic interpretation of this phenomenon. Rabin and Sobel [1996] examine a solution concept that takes a refinement argument *à la* Farrell as a starting point but through a quasi-dynamic process avoids the existence problems resulting from the subversion of meanings.

meanings evolve, either because no *a priori* meanings are given, or because, as above, given meanings degrade over time. Intuitively, receivers always prefer a finer partition and if subsets of sender types prefer to be revealed as such, we expect there to be dynamic forces to bring about that revelation. The PCI condition tries to ensure that this process is a one-way street. Once separated, types from different partition elements never have an incentive to be pooled again. The dynamic arguments to which PCI is related require message spaces to be sufficiently large. Therefore, in all of our implementations we chose the message space to be larger than the type space. This ensures that none of the equilibria are strict and, for the games considered, is sufficient to render the PCI prediction valid.

We adopt the following more formal version of PCI.³ For a partition $\mathcal{I}$ of the type set, denote the partition element containing type t by $I(t)$, and let $BR(I(t))$ be the set of best replies to beliefs supported on the set of types $I(t)$. A sender-receiver game satisfies PCI with respect to the partition $\mathcal{I}$ if (1) each type t strictly prefers all actions in $BR(I(t))$ to all actions outside of this set, and (2) $BR(I(t)) \cap BR(I(t')) = \emptyset \quad \forall I(t) \neq I(t')$.

Condition (1) ensures that information revelation that is only consistent with the coarser partition is unstable. Conditions (1) and (2) together ensure that once information is revealed consistent with the finer partition, no less informative outcome can recur. Note that PCI, thus formulated, does not make any reference to equilibria.

PCI permits us to predict communication without reference to equilibrium play. This is one reason for considering PCI as a conservative predictive tool; PCI does not commit itself to equilibrium. The other reason for viewing PCI as a conservative criterion is that it imposes strong conditions on the game's incentive structure. In the literature (Blume, Kim and Sobel [1993], Rabin and Sobel [1996], and Blume [1996] [1997]) PCI plays the role of a strong sufficient condition for effective communication to arise. If we want to strengthen the predictive content of PCI, we can in addition require a prediction to be an equilibrium.

Our four selection criteria, although not nested, differ in strength. For example, PCI does not rule out efficient equilibria. PCI equilibria always exist whereas refinements may reject all equilibria. Overall, PCI makes the most conservative predictions in the games we examine, the *ex ante* efficiency predictions are slightly stronger, influentiality is stronger yet. Refinements cannot be ranked with influentiality; e.g., in two of our games the predictions differ. However, refinement criteria appear to be quite strong, given that they may eliminate all equilibria.

³This definition is in the same spirit but generally stronger, and simpler than the definitions in the literature. Blume and Diekmann [1997] use this formulation of PCI to characterize stochastically stable states of an explicit dynamic process by which players learn to communicate in sender-receiver games. The PCI definitions in the literature, Blume, Kim, and Sobel [1993], Rabin and Sobel [1996], Blume [1996] make the same predictions in our games.

We focus on the simplest possible games that permit us to consider partial information revelation. This requires there to be at least three types (classes of types). To limit the large number of possible incentive structures that can arise even with only three types, we require that (1) one sender type (type t_3) prefers to be fully identified and (2) the other two types, t_1 and t_2 , prefer to be identified as a partition element, $\{t_1, t_2\}$ but not necessarily as individual types. Qualitatively, within the $\{t_1, t_2\}$ element, three cases can arise: (1) both types prefer to be fully identified, (2) none of the types prefer to be identified, and (3) only one of the types prefers to be identified. In the third case we also distinguish between two subcases, one where a separating equilibrium exists, and one where no such equilibrium exists. This gives us four canonical incentive structures to examine.

Our first game (Game 1) is one where incentives are perfectly aligned. The diagram on the left graphs the alignment parameter as a function of type. Preferences being perfectly aligned is expressed via $b(t) = 0$ for all t . The typical types t_1 , t_2 , and t_3 can be thought of as the midpoints of the three intervals $(0, 1/3)$, $(1/3, 2/3)$, and $(1/3, 1)$. The payoff matrix on the right is the three-type representation of perfect incentive alignment.⁴ Types are equally likely, the entries in each cell indicate sender-receiver payoff pairs and for each type, t_i , there is exactly one action, a_i , that maximizes both the sender's and the receiver's payoff.

Figure 1 - Game 1

In a pooling equilibrium all types of the sender send a common message and the receiver's response does not depend on the message. In this game there are also

⁴ a_i is the most preferred action for type t_{4-i} , i.e. the action that maximizes $-(a - t_i)^2$. The payoff from each type's most preferred action is positive, which can be achieved by adding a positive constant to the corresponding CS payoffs. The payoffs from other actions must be strictly lower; in the interest of saliency we set them equal to zero, instead of deriving them from the quadratic utility function. The construction of the finite representations for the other games is similar, stressing salient characteristics, instead of numerical detail.

the other element $\{t_3\}$ is $\{a_3\}$. Clearly, the two sets of actions are disjoint, as required by condition (2). Type t_3 receives his maximum payoff from action a_3 and thus prefers none of the other actions, as required by condition (1). The lowest payoff for both type t_1 and t_2 from actions in $\{a_1, a_2, a_4\}$ is 100, whereas their highest payoff from any other action is 0, again as required by condition (1). Finally, one can check that PCI is satisfied for no other, in particular no finer, partition. For the finest partition, this follows from the fact that a_2 is the unique best reply to t_2 , while this type prefers action a_4 in violation of condition (1). In summary, the sender is willing to reveal information consistent with the partition $\{\{t_1, t_2\}, \{t_3\}\}$, but not necessarily more. And if the sender reveals his type to belong to an element I , we expect the receiver to respond with an action in $BR(I)$. This will be our PCI prediction for Game 2; the predictions for Games 3 and 4 can be derived in an almost identical manner.

In our next game, Game 3, the misalignment of preferences between senders and receivers becomes more severe. Game 3 is a finite representation of an incentive structure where low types, $[0, 1/3]$, prefer to overstate their true types, and types in the interval $(1/3, 2/3]$ like to understate their true types. In Game 3, while a fully separating equilibrium does still exist, both types t_1 and t_2 prefer being pooled to being correctly identified.⁵

Figure 3 - Game 3

Refinements rule out full separation and pooling in this game. Informativity selects complete separation. Efficiency and PCI are consistent with both complete separation and partial separation, where types t_1 and t_2 send common messages, and type t_3 is identified.

⁵Melumad and Shibano [1991] use incentive structures like these to argue that there will not necessarily be "ex ante unanimity regarding the installation of communication-based organizational structures."

The incentive structure motivating our final game, Game 4, incorporates even stronger misalignment of preferences. Types in the interval $[0, 2/3]$ prefer to understate their true type, as in Game 2, but so strongly that there is no equilibrium in which subintervals of $[0, 2/3]$ send different messages. In Game 4 no fully separating equilibrium exists because rather than being correctly identified, type t_2 would prefer to be misidentified as type t_1 . There are pooling equilibria, and partial pooling equilibria in which types t_1 and t_2 send a common message.

Figure 4 - Game 4

In this game refinements rule out all equilibria because in both pooling and partial pooling equilibria type t_1 can credibly self-identify himself and thus destroy such equilibria. Influentiality, efficiency and PCI all select partial separation.

The theory concerning these games, as sketched out above, makes predictions about whether there will be communication, whether communicative outcomes satisfy a PCI condition, whether communicative outcomes are supported by equilibria and whether these equilibria need to be ex ante efficient, most influential or have to satisfy a refinement criterion. Accordingly, we formulate the following null-hypotheses for all of our games:

- H1 Communication hypothesis: For games which have a unique pooling action (Games 2-4), the most frequent action is the pooling action. For Game 1, the distribution of actions is independent of type.
- H2 PCI hypothesis: The frequency of PCI-outcomes does not exceed the frequency from a uniform distribution.
- H3 Equilibrium hypotheses:

- H3a Pooling hypothesis: The frequency of pooling outcomes does not exceed the uniform distribution frequency.
- H3b Partial pooling hypothesis: The frequency of partial pooling outcomes does not exceed the uniform distribution frequency.
- H3c Separation hypothesis: The frequency of separating outcomes does not exceed the uniform distribution frequency.
- H3d Ex ante efficiency hypothesis: The frequency of ex ante efficient equilibrium outcomes does not exceed the uniform distribution frequency.
- H3e Influentiality hypothesis: The frequency of most influential equilibrium outcomes does not exceed the uniform distribution frequency.
- H3f Refinement hypothesis: The frequency of equilibrium outcomes consistent with Farrell's neologism proofness test does not exceed the uniform distribution frequency. Caveat: The neologism proofness refinement does not always make a prediction.

3 Design

The experiments were conducted using a series of population cohorts. A cohort consisted of twelve participants: six senders and six receivers. All participants were recruited from undergraduate (sophomore and above) and graduate classes at the University of Iowa. None of the participants had previously taken part in or otherwise gained experience with this series of experiments. Upon arrival, players were seated at separate computer terminals and given a copy of the instructions for the experiment.⁶ Since these instructions were read aloud, we assume that the information contained in them was common knowledge.

Each cohort played two sender-receiver games. First, all cohorts played 20 periods of Game 1 in Session I; subsequently, in Session II each cohort played 40 periods of one of the Games 2-4. We induced risk neutrality using the Roth-Malouf procedure, Roth and Malouf [1979] and Berg et al. [1986].

Each player was randomly designated a sender or receiver at the beginning of an experiment and remained so for all periods of the experiment. Each period of each sender-receiver game had the following structure. First, senders and receivers were paired using a random matching procedure. Second, types were independently and identically drawn for each sender; each type was equally likely. Senders were then informed of their respective types. In the message stage of the game, senders sent a message to the receivers with which they were paired. In the action stage, each receiver chose an action after receiving their respective sender's message. Each sender-receiver pair then learned the sender's type, message sent, action taken and points earned in the period. Finally, all players received information about the senders; in particular, they viewed a

⁶Instructions are available from the authors upon request.

summary of the sender types drawn and the messages sent by the respective sender types for the current and all previous periods.

We chose the structure of Game 1 to provide players with experience in experimental procedures and to ensure that players understood the structure of a sender-receiver game, the message space, and the population history. As will be evident in section 4, subjects found the tasks presented by Games 2-4 quite difficult, even with the experience gained in Game 1. The task would be excessively difficult if participants lacked the opportunity to play Game 1 first. Specifically, Blume, DeJong, Kim and Sprinkle [1997] compare play in relatively simpler games than Games 2-4 with and without a similar first session. They find that the outcomes of the second session games are similar across treatments; however, play converges to these outcomes slowly and less completely when players do not participate in the first session.

The message space for Game 1 corresponded to the first four letters of the alphabet; thus, the size of the message space is the smallest size that exceeds the cardinality of the type space. Note also that in order to evaluate the role of focal point effects for *a priori* coordination, payoffs of the separating outcomes for types t_1 and t_3 are on the off-diagonal; i.e., for type t_1 (t_3) payoffs are positive if action a_3 (a_1) is taken. This does not affect the fundamental incentive structure of the game but makes it more difficult to coordinate on *a priori* grounds. It is still possible to indicate the *second* type, t_2 , by the *second* letter of the alphabet, B , in order to induce the *second* action, a_2 . For the first letter of the alphabet, on the other hand, there are two conflicting natural associations, one with the first type, the other with the first action (similarly for the third and fourth letter). As detailed in the results and analysis section, this gives rise to interesting coordination issues in Game 1.

For the literal meaning treatments, Games 2, 3 and 4 were run for three replications using the message space $M = \{1, 2, 3, 4, 5\}$, such that messages corresponded to the five actions of the receivers. For the meaningless message treatments we ran the same games, using the message space $M = \{\%, \sim, *, \#\}$.⁷ In addition, we endowed participants with different representations and orderings of the message space. For example, a message represented as $*$ for one set of participants was represented as $\%$ for another set of participants. We informed participants that such representations were used and were stable throughout the experiment; however, participants were not informed of the specific mappings assigned. This purpose of using this procedure was to destroy all conceivable focal points that participants might have used for *a priori* coordination on messages.

As in Session I, in Session II participants received the same aggregate information about the population: the distribution of sender types drawn and

⁷For the literal meaning treatments, the choice of the message space meets two objectives: (1) Its size exceeds the cardinality of the type space, and (2) meanings are easily understood - as instructions to take a particular action. For the meaningless message treatments, the size of the message space is the minimum size that exceeds the number of sender types.

the messages sent by the respective sender types. For the meaningless-message treatments, this information was displayed in terms of each participant's representation and ordering of the message space. The information was provided for the current and all previous periods of the session.

Before each game, we read the instructions aloud to each cohort, and participants individually filled out questionnaires confirming their knowledge and understanding of the instructions. We then went over the questionnaire orally and answered questions. Each replication lasted from two and one-half to three and one-quarter hours, during which participants earned between fifteen and fifty-four dollars in cash.

4 Results and Analysis

4.1 Game 1

We introduce Game 1 into our experiments primarily to familiarize participants with sender-receiver games and the learning environment, with the intent of making the learning task manageable in games with complex incentive structures. However, Game 1 is of considerable interest in its own right. It demonstrates what can be learned and how fast when the incentive structure is simple and it validates our concern about focal points.

Table 1									
Session I: Game 1									
Type-Action Associations - Final Five Periods									
Type	t ₁			t ₂			t ₃		
Action	a ₁	a ₂	a ₃	a ₁	a ₂	a ₃	a ₁	a ₂	a ₃
Rep 1	0	0	6	0	14	0	10	0	0
Rep 2	8	0	3	3	8	0	5	1	2
Rep 3	5	0	8	0	10	0	4	0	3
Rep 4	0	1	5	0	14	0	10	0	0
Rep 5	2	0	6	0	11	0	8	1	2
Rep 6	0	2	7	0	9	3	6	2	1
Rep 7	1	0	8	0	9	0	12	0	0
Rep 8	0	1	9	0	11	0	8	1	0
Rep 9	0	0	11	0	8	0	11	0	0
Rep 10	0	0	10	0	12	0	8	0	0
Rep 11	2	0	10	0	5	0	12	0	1
Rep 12	1	0	10	0	7	2	7	0	3
Rep 13	2	0	7	0	7	0	12	0	2
Rep 14	0	0	8	0	9	1	8	1	3
Rep 15	0	0	12	0	10	0	6	0	2
Rep 16	0	0	8	1	9	1	10	1	0
Rep 17	0	0	9	0	14	0	7	0	0
Rep 18	1	0	13	0	11	0	4	0	1
Total	22	4	150	4	178	7	148	7	20

The essential properties of the Session I outcomes are summarized in Table 1. Table 1 reports which actions were taken conditional on sender type, aggregated

over the final five periods of each replication of Game 1 (Session I). Thus, from the line starting with "Rep 4" we learn that in the final five periods of the fourth replication of Game 1, type t_3 was drawn 10 times and received (his favorite) action a_1 each time, type t_2 received his favorite action 14 times, and type t_1 5 out of 6 times. For almost every replication of Game 1, the outcome is very close to separating behavior; in three out of fifteen replications play over the final five periods is fully consistent with a separating equilibrium. A proportion of 88% (s.d.=.12) of type-actions pairs in the last five periods are consistent with a separating equilibrium. In the final period alone this coordination proportion is 84% (s.d.=.18), compared to a coordination proportion of 49% (s.d.=.19) in the initial period.

Under the null hypothesis of independence of types and actions, the distribution of the proportion of type-action pairs consistent with separation is centered at 33%. Using a t -test, with the final-period results in each replication serving as independent observations, we can reject the null hypothesis of independence at $p < .01$ ($t = 18.85$, 17 d.f.). Interestingly, we can also reject the null hypothesis of independence using the first period results $p < .01$ ($t = 4.70$, 17 d.f.). As explained in more detail below, this is likely evidence of a focal point effect. There is a relatively large proportion of (t_2, a_2) pairs in the initial period because a large number of senders and receivers from the beginning linked message "B" to type t_2 .

In addition to outcomes, it is interesting to see which messages were used and which types they indicated. The type-message associations, aggregated over the final five periods, are reported in Table 2.

Type	t_1				t_2				t_3			
Message	A	B	C	D	A	B	C	D	A	B	C	D
Rep 1	6	0	0	0	0	14	0	0	0	0	10	0
Rep 2	8	0	3	0	0	8	3	0	3	0	3	2
Rep 3	10	0	3	0	0	10	0	0	3	0	3	1
Rep 4	5	1	0	0	0	14	0	0	0	0	10	0
Rep 5	8	0	0	0	0	11	0	0	3	0	8	0
Rep 6	8	1	0	0	3	8	0	1	0	0	8	1
Rep 7	1	0	8	0	0	9	0	0	12	0	0	0
Rep 8	0	0	9	1	0	11	0	0	9	0	0	0
Rep 9	11	0	0	0	0	8	0	0	0	0	11	0
Rep 10	0	0	10	0	0	12	0	0	8	0	0	0
Rep 11	1	0	11	0	0	5	0	0	12	0	1	0
Rep 12	1	0	10	0	0	9	0	0	8	0	2	0
Rep 13	0	0	9	0	0	7	0	0	13	0	1	0
Rep 14	8	0	0	0	0	9	0	1	2	0	7	3
Rep 15	10	0	0	2	0	10	0	0	2	0	6	0
Rep 16	8	0	0	0	0	11	0	0	0	0	11	0
Rep 17	9	0	0	0	0	14	0	0	0	0	7	0
Rep 18	2	0	12	0	0	11	0	0	5	0	0	0
Total	96	2	75	3	3	181	3	2	80	0	88	7

Table 2 shows that message "D" played virtually no role in the last five rounds. Indeed, of the total (across all time periods, replications, and players) of 2,160 messages sent only 74 were message "D." This is approximately 3.5%; in the final five periods this percentage drops to 2.2%.

Senders used the first three messages of the alphabet to signal the three possible types. This is one manifestation of focal point effects. The other is that message B was used to indicate type t_2 in all 15 replications. This again is a natural focal point, considering that it associates the *second* letter of the alphabet with the *second* type for whom both senders and receivers prefer the *second* action. This focal point effect is blunted for the other two types, because for example, the optimal action for the third type t_3 is the first action a_1 , and senders and receivers cannot *a priori* coordinate on whether messages should signal types or actions. Indeed we observe that message A is sometimes sent by type t_1 and sometimes by type t_3 . Formally, the hypothesis that in the final outcome the type-messages pairs (t_1, A) and (t_1, C) are equally likely cannot be rejected in a two-tailed binomial test ($p > .48$).

The data also suggest that initial precedents for type-message associations predict terminal type-message associations. This is obvious for message "B." In addition, in 15 out of 18 replications, if the initial (first five periods) proportion of (t_1, A) and (t_3, C) pairs exceeded (was less than) the initial proportion of (t_1, C) and (t_3, A) pairs then the same relation held in the last period.

Figure 5 examines the time paths that led to these outcomes. In each type-action cell, (t_i, a_i) , we measure the frequency of action a_i conditional on the true type being t_i , as a five-period moving average over the duration of the treatment, averaged over replications. Note that convergence to the final separating outcome takes time. This is interesting because rational players in most instances could use play in the first period as a precedent that would allow them to perfectly coordinate in the second period and all subsequent periods.

4.2 Games with Literal Meanings

The difficulty of the learning task depends both on the nature of the message space (messages with or without literal meanings) and on the incentive structure (simple or complex). With our Session I games we examine one of the four possible combinations, namely a simple incentive structure in conjunction with (largely) meaningless messages, and get definite final outcomes. It stands to reason that outcomes would be equally determinate with a simple incentive structure and literal meanings. Therefore we proceed by considering literal meanings combined with more complex incentive structures.

We have considered three treatments, Game 2, 3, and 4 with three replications for each treatment. The outcomes, i.e. the type-action associations over the final five periods, are reported in Table 3.

Table 3 Literal Meanings - Senders and Receivers Type-Action Associations - Final Five Periods																
Type	t_1					t_2					t_3					
Action	a_1	a_2	a_3	a_4	a_5	a_1	a_2	a_3	a_4	a_5	a_1	a_2	a_3	a_4	a_5	
Game 2																
Rep 1	10	0	0	0	0	0	8	0	4	0	0	0	8	0	0	
Rep 2	12	0	0	0	0	0	9	0	2	0	0	0	7	0	0	
Rep 3	7	0	0	0	0	0	6	0	5	0	0	0	12	0	0	
Total	29	0	0	0	0	0	23	0	11	0	0	0	27	0	0	
Game 3																
Rep 1	1	4	0	7	0	0	3	0	6	0	0	0	9	0	0	
Rep 2	4	2	1	3	0	0	7	1	4	0	0	0	8	0	0	
Rep 3	1	1	0	5	0	0	2	0	11	0	0	0	10	0	0	
Total	6	7	1	15	0	0	12	1	21	0	0	0	27	0	0	
Game 4																
Rep 1	5	0	0	0	0	8	8	0	2	0	0	0	7	0	0	
Rep 2	13	0	0	0	0	3	4	0	2	0	1	0	7	0	0	
Rep 3	5	1	0	0	0	5	4	0	4	0	0	0	11	0	0	
Total	23	1	0	0	0	16	16	0	8	0	1	0	25	0	0	

In the three replications of Game 2 terminal play is consistent with PCI and close to a fully separating outcome. Specifically, 100% of the type-action pairs in the last five periods are consistent with PCI, and 88% (s.d.=.05) are consistent with a separating equilibrium. Note however that in each replication type t_2 receives action a_4 with positive probability. This action would be optimal against a message sent by both types t_1 and t_2 but not in response to a message that identifies type t_2 . We will see below, in the analysis of messages, that type t_2 sends overwhelmingly "requested" their favorite action a_4 . Some of the receivers then displayed "sucker behavior" by taking action a_4 , as requested, rather than making the inference that only type t_2 was making that request.

In the three replications of Game 3, the outcome is consistent with PCI and about two thirds of the observations are compatible with a partial pooling equilibrium. Specifically, 98% (s.d.=.04) of the type-action pairs in the last five periods are consistent with PCI, 70% (s.d.=.19) with a partial pooling equilibrium, and 50% (s.d.=.12) with a separating equilibrium.

In all three Game 4 replications the outcome is consistent with PCI but not with any of the Nash equilibria of the game. Specifically, 99% (s.d.=.02) of the type-action pairs in the last five periods are consistent with PCI, but only 37% with a partial pooling equilibrium, and none with a pooling equilibrium. Interestingly, although there is no separating equilibrium in this game, 70% (s.d.=.07) of the type-action pairs in the last five periods are consistent with the fully separating outcome. Note in particular that type t_1 almost always receives his preferred action a_1 , despite the fact that there does not exist a Nash equilibrium in which action a_1 is taken with positive probability.

For Games 2-4, under the null-hypothesis, the distribution of type-action pairs is centered at 47% for PCI, and 20% for separation, partial pooling and

pooling.⁸ Using a *t*-test, with the final period results in each replication serving as independent observations, we can reject the null-hypothesis of independence in favor of PCI for Games 2-4 (largest $p < .01$). In addition, for Game 2 we can reject the null-hypothesis of independence in favor of separation at $p < .01$ ($t = 23.29$, 2 d.f.); for Game 3 we can reject the null-hypothesis of independence in favor of partial pooling at $p < .03$ ($t = 4.64$, 2 d.f.) and in favor of separation at $p < .03$ ($t = 4.45$, 2 d.f.); for Game 4 we can reject the null-hypothesis of independence in favor of separation at $p < .01$ ($t = 11.85$, 2 d.f.). Beyond this, no other outcomes were significant at $p \leq .05$.

Interestingly, Nash equilibrium is problematic in all three treatments. In the Game 2 treatment it is undermined by stable sucker behavior, in the Game 3 treatment because type t_1 and t_2 senders receive both separating and partial pooling actions, and in the Game 4 treatment because type t_1 manages to obtain his favorite (nonequilibrium) action and because type t_2 is either identified or mistaken for type t_1 (neither of which is part of any equilibrium).

For Game 4 we observe an interesting shift from initial to terminal play as seen from a comparison of the terminal play data in Table 3 and the initial play data in Table 4 below.

Type	t_1					t_2					t_3				
Action	a_1	a_2	a_3	a_4	a_5	a_1	a_2	a_3	a_4	a_5	a_1	a_2	a_3	a_4	a_5
Game 4															
Rep 1	12	1	0	1	1	1	4	0	4	0	0	0	5	1	0
Rep 2	14	0	0	0	0	2	3	0	1	0	1	0	9	0	0
Rep 3	11	0	0	0	0	0	3	0	5	1	1	0	9	0	0
Total	37	1	0	1	1	3	10	0	10	1	2	0	23	0	0

The fact that stands out is that initially hardly any t_2 types receive action a_1 whereas in the end there is a considerable proportion of such type-action pairs. One interpretation is that initially most senders send messages that if believed would maximize their payoffs. Receivers who may initially be credulous and take the corresponding actions, eventually learn to identify types at which point it becomes advantageous for t_2 types to mimic t_1 types. Terminal play shows that some of the senders understand the incentives and mimic t_1 types. The next logical step in this sequence would be for receivers to resort to the partial pooling action a_4 against the message "1," which is now common for types t_1 and t_2 . Note that this step is not taken and therefore nonequilibrium play appears fairly stable.

The messages that were sent by the various types over the last five periods are reported in Table 5.

⁸Compare Table 11 below.

Table 5 Literal Meanings - Senders Type-Message Associations - Final Five Periods															
Type	t_1					t_2					t_3				
Message	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Game 2															
Rep 1	10	0	0	0	0	0	0	0	12	0	0	0	8	0	0
Rep 2	12	0	0	0	0	0	0	0	11	0	0	0	7	0	0
Rep 3	7	0	0	0	0	0	2	0	9	0	0	0	12	0	0
Total	29	0	0	0	0	0	2	0	32	0	0	0	27	0	0
Game 3															
Rep 1	1	0	0	11	0	0	1	0	8	0	0	0	9	0	0
Rep 2	4	0	1	5	0	0	5	1	6	0	0	0	8	0	0
Rep 3	0	0	0	7	0	0	0	0	13	0	0	0	10	0	0
Total	5	0	1	23	0	0	6	1	27	0	0	0	27	0	0
Game 4															
Rep 1	5	0	0	0	0	8	1	0	7	2	0	0	7	0	0
Rep 2	13	0	0	0	0	4	0	0	5	0	0	0	8	0	0
Rep 3	6	0	0	0	0	9	0	0	4	0	0	0	11	0	0
Total	24	0	0	0	0	21	1	0	16	2	0	0	26	0	0

Table 5 shows that in all three replications of Game 2, the types sent those messages that, had the receivers interpreted them as recommended actions and followed the recommendation, would guarantee the highest sender payoff. The handful of exceptions can be interpreted as truthful revelations of type. Essentially the same can be said about the Game 3 replications, except that in one replication there is a significant percentage of messages whose literal meaning is a request for a separating action, even though the types involved would prefer not to be identified. Moreover, the senders in Game 3 exhibited partial pooling behavior. Specifically, 86% of the type-message pairs in Game 3 are consistent with partial pooling, while only 42% are consistent with separation. In the Game 4 replications again most types send messages that effectively ask for their favorite replies. Remarkable is that for type t_1 the requested action a_1 is not part of any equilibrium; nevertheless the message "1" is sent by all type t_1 's in the last five periods of all replications and is almost always successful. The second remarkable fact is that in all three replications over the final five periods we find a significant percentage of type t_2 's sending message "1," thus mimicking the behavior of type t_1 's. Note that type t_2 prefers being misidentified as type t_1 rather than being identified as type t_2 . The other message frequently sent by type t_2 's is "4," a request for their favorite reply. Receivers sometimes follow the request but more often they correctly identify who sends that message and reply with a_2 instead of a_4 (see Table 7, below).

The attempt of type t_2 's to mimic type t_1 's that we found for the terminal play is not present in initial play, as shown in Table 6.

Table 6 Literal Meanings - Senders Type-Message Associations - Initial Five Periods															
Type	t_1					t_2					t_3				
Message	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Game 4															
Rep 1	15	0	0	0	0	0	4	0	5	0	0	0	6	0	0
Rep 2	14	0	0	0	0	1	3	0	2	0	0	0	10	0	0
Rep 3	11	0	0	0	0	0	1	0	8	0	1	0	9	0	0
Total	40	0	0	0	0	1	8	0	15	0	1	0	25	0	0

Apparently, it takes time for receivers to correctly link the message "4" to type t_2 , and then for type t_2 senders to discover that they are better off mimicking t_1 than being identified

For the most part receivers did not blindly follow instructions but instead correctly identified the types who would most benefit from the instructions being followed, and responded accordingly. This can be seen from Table 7, which reports the actions taken by receivers after the various messages.

Table 7 Literal Meanings - Receivers Message-Action Associations - Final Five Periods																
Message	1				2		3			4				5		
Action	a_1	a_2	a_4	a_5	a_2	a_4	a_1	a_3	a_4	a_1	a_2	a_4	a_5	a_2		
Game 2																
Rep 1	10	0	0	0	0	0	0	8	0	0	8	4	0	0		
Rep 2	12	0	0	0	0	0	0	7	0	0	9	2	0	0		
Rep 3	7	0	0	0	2	0	0	12	0	0	4	5	0	0		
Total	29	0	0	0	2	0	0	27	0	0	21	11	0	0		
Game 3																
Rep 1	1	0	0	0	1	0	0	9	0	0	6	13	0	0		
Rep 2	4	0	0	0	4	1	0	10	0	0	5	6	0	0		
Rep 3	0	0	0	0	0	0	0	10	0	1	3	16	0	0		
Total	5	0	0	0	5	1	0	29	0	1	14	25	0	0		
Game 4																
Rep 1	13	0	0	0	0	1	0	7	0	0	6	1	0	2		
Rep 2	16	1	0	0	0	0	1	7	0	0	3	2	0	0		
Rep 3	10	3	2	0	0	0	0	11	0	0	2	2	0	0		
Total	39	4	2	0	0	1	1	15	0	0	11	5	0	2		

Table 7 shows how the deviations from fully separating play in Game 2, from partial pooling equilibrium play in Game 3 and from equilibrium in Game 4 arise. In Game 2 it is receivers who follow instructions (a_4 after "4") without realizing the incentive implications. In that sense receivers prove gullible. It is interesting that even with session I and considerable experience with Game 2 itself, this sucker behavior does not vanish.⁹ For Game 3, the observations

⁹Sucker behavior in cheap-talk games has also been reported in Forsythe, Lundholm and Rietz [1995]. An alternative explanation for what we interpret as sucker behavior is that a certain fraction of players have preferences for altruism as discussed for example in Andreoni and Miller [1997], and Andreoni, Brown and Vesterlund [1997]. From that perspective, one can view the receiver's choice of an action, consistent on type t_2 having been revealed, much

that deviate from partial pooling behavior are not as easily explained; they arise out of action a_2 being taken in response to the partial pooling message 4, and from a tendency toward separation in the second replication of Game 3. For the Game 4 treatments we see that message "1" mostly induced action a_1 , the favorite reply of type t_1 . Message "4" was either taken at face value, inducing action a_4 , or, more frequently, correctly interpreted as coming from type t_2 , in which case action a_2 was taken. Here again it is interesting to point out the difference between terminal play and initial play, as reported in Table 8.

Table 8 Literal Meanings - Receivers Message-Action Associations - Initial Five Periods															
Message	1				2		3			4					5
Action	a_1	a_2	a_3	a_4	a_1	a_2	a_1	a_2	a_3	a_4	a_1	a_2	a_3	a_4	a_5
Game 4															
Rep 1	12	1	1	1	4	0	0	5	1	1	0	4	0	0	0
Rep 2	15	0	0	0	3	0	1	9	0	1	0	1	0	0	0
Rep 3	12	0	0	0	0	1	0	9	0	0	2	5	1	0	0

As seen from a comparison of Tables 7 and 8 receivers become less gullible with experience. Message "4" is more likely to induce action a_2 during the final five periods than during the initial 5 periods of Game 4.

Despite the fact that literal meanings are available, learning takes place in all three treatments. However, this learning benefits the group in only the Game 2 and the Game 3 treatments where, on average, from the first five to the last five periods, payoffs increase for both senders and receivers. As Table 9 reveals, in Game 4 payoffs *fall* in all three replications for both senders and receivers.

like a dictator game: The receiver can exploit the information and choose a large share for himself or instead forgo the benefit from using the information. One interpretation of our data is that there is a certain percentage of altruistic receivers. While we feel that this is a potentially fruitful way to look at the data, this approach would have to explain why, as noted below, payoffs decline over time, why there is a large percentage of inefficient type-action pairs (t_2, a_1), why in the final periods there is a higher incidence of mimicry, and why we do not observe the same phenomena with meaningless messages. Compare for example the data on Game 2 in Table 10, where action a_4 is never taken in two replications and not tied to a particular type in the other; or, the Game 4 data in Table 10, where a_4 is just as often associated with type t_1 as with t_2 .

Table 6 Literal Meanings - Evolution of Payoffs				
Players	Senders		Receivers	
Periods	First Five	Last Five	First Five	Last Five
Game 2				
Rep 1	483	546	667	760
Rep 2	506	560	713	780
Rep 3	523	530	776	750
Average	504	545	718	763
Game 3				
Rep 1	423	420	610	577
Rep 2	340	367	540	630
Rep 3	373	467	577	617
Average	378	418	575	608
Game 4				
Rep 1	513	390	663	593
Rep 2	570	540	716	683
Rep 3	537	450	710	620
Average	540	460	697	632

The decrease in payoffs in the Game 4 treatment can be explained by players moving from naive truth-telling and gullibility to a more sophisticated response to the incentives, which rule out a truth-telling equilibrium. Note that in the process the *a priori* meanings of messages deteriorate: Receivers learn not to believe certain implied statements and senders undermine the meaning of messages through mimicry.

The time paths leading to these outcomes are shown in Figure 6, aggregated over all three replications of Game 2, in Figure 7 for Game 3, and in Figure 8 for Game 4. The feature that stands out in all three treatments is that while behavior is consistent with PCI, there is persistent non-equilibrium play. Across all 40 periods, type t_2 receives both actions a_2 and a_4 with positive probability in Game 2, types t_1 and t_2 receive actions a_1 , a_2 and a_4 with positive probability in Game 3, and type t_1 receives action a_1 nearly all the time in Game 4.

4.3 Games with Meaningless Messages

From an evolutionary perspective, the most interesting environment is one where incentive structures are complex and messages are *a priori* meaningless. Then, learning must occur for communication to come about and the learning process must overcome whatever divergence of interest there is between senders and receivers.

We consider three treatments (parallel to the previous section), Game 2, Game 3, and Game 4 all of which utilized the same Session I games, with three types and four messages.¹⁰ The outcomes, i.e. the type-action associations over the final five periods, are reported in Table 10.

¹⁰Data for two variations of Game 2, Game 2A, which was run with a two-message session I, and Game 2B, which was run with a three-message session I can be obtained upon request from the authors. The results are broadly consistent with the results reported here.

Table 10 Meaningless Messages - Senders and Receivers Type-Action Associations - Final Five Periods															
Type	t_1					t_2					t_3				
Action	a_1	a_2	a_3	a_4	a_5	a_1	a_2	a_3	a_4	a_5	a_1	a_2	a_3	a_4	a_5
Game 2															
Rep 1	14	0	1	0	0	1	5	0	0	0	0	0	9	0	0
Rep 2	11	2	0	0	0	0	11	0	0	0	0	0	5	0	1
Rep 3	1	1	1	1	3	1	4	1	1	6	0	1	5	1	3
Total	26	3	2	1	3	2	20	1	1	6	0	1	19	1	4
Game 3															
Rep 1	1	0	1	3	1	1	5	2	3	3	0	1	8	1	0
Rep 2	0	0	3	4	6	0	0	1	1	5	1	0	1	2	6
Rep 3	8	1	1	1	0	0	4	0	2	0	0	0	13	0	0
Total	9	1	4	8	7	1	9	3	6	8	1	1	22	3	6
Game 4															
Rep 1	3	2	0	3	2	4	7	0	2	0	0	0	7	0	0
Rep 2	4	0	0	3	7	1	3	2	1	1	0	4	1	0	3
Rep 3	7	0	1	0	1	0	2	2	2	3	0	0	9	0	3
Total	14	2	1	6	10	5	12	4	5	4	0	4	17	0	6

The first thing to note about these outcomes is that we can reject the hypothesis H1 that the pooling action is the most frequent action. Aggregated over replications and treatments, the frequency of the pooling action in the last five periods is less than 20%. While there are two replications (Game 2 Rep 3 and Game 3 Rep 2) in which the frequency of the pooling action is high, it never comes close to 100% as would be required for a pooling outcome.

A casual inspection of the data suggests that in addition to the pooling hypothesis being rejected, communication occurs over the final five periods. For example, two of the Game 2 and one of the Game 3 replications are close to full separation, and type t_3 appears to be well identified in at least two replications in each of the three treatments.

In our meaningless message treatments outcomes are noisier than in the literal meaning treatments. For that reason we adopt the following approach toward better identifying communication outcomes: First we form classes of type-action pairs that are consistent with different forms of communication; second we calculate the frequency with which type-actions pairs fall into each class; finally we ask whether this frequency could have been generated by a uniform distribution over all type-action pairs.

The following tables serve to report frequencies of partial common interest play (PCI), separating play (S), partial pooling equilibrium play (PPE), pooling equilibrium play (PE), the frequency of PCI play within the non-pooling play (PCI\PE), and the frequency of partial pooling equilibrium play within the non-pooling play (PPE\PE).

Outcome frequencies are obtained according to Table 11 and reported in Table 12. Recall that an outcome for a sender-receiver game is a joint probability distribution over types and action. For example the probability distribution associated with a PCI outcome assigns positive probability to a cell in Table 11

if and only if that cell contains a PCI-label (is a "PCI-cell"). To obtain the frequency of PCI play for the final 5 periods we divide the number of observations in PCI-cells by 30, the total number of observations over the last five periods. To obtain the frequency of PCI\PE play we divide the number of observations in PCI-cells by the total number of observations that do not belong to a PE-cell. The frequencies of the other outcomes are constructed analogously.

Table 11 Outcome Measures used in Table 12					
	a_1	a_2	a_3	a_4	a_5
t_1	S, PCI	PCI	*	PPE, PCI	PE
t_2	PCI	S, PCI	*	PPE, PCI	PE
t_3	*	*	S, PPE, PCI	*	PE

Table 12 reports the outcome frequencies for each of the nine replications. In reading this table it is useful to compare the reported frequencies with the frequencies that would obtain if the data had been generated by a uniform distributions (20% for S, PPE and PE, 47% for PCI, 58% for PCI\PE, 25% for PPE\PE). For example, the observed PCI frequency exceeds the benchmark frequency in six out of nine replications, the PCI\PE frequency exceeds the benchmark frequency in eight out of nine cases. Therefore, there is only one replication in which PCI has no explanatory power. Note however that for this replication the PPE\PE frequency (.46) exceeds the benchmark frequency (.25), suggesting that some communication does indeed occur, even in this replication.

Table 12 Meaningless Messages - Senders and Receivers Outcome Frequencies - Final Five Periods						
Outcome	PCI	S	PPE	PE	PCI\PE	PPE\PE
Game 2						
Rep 1	.97	.93	.30	.0	.97	.30
Rep 2	.97	.90	.17	.03	1	.17
Rep 3	.47	.33	.23	.40	.78	.39
Average	.80	.72	.23	.14	.92	.29
p-value	.09	.06	.23	.65	.02	.32
Game 3						
Rep 1	.70	.47	.47	.13	.81	.54
Rep 2	.20	.03	.20	.57	.46	.46
Rep 3	.97	.83	.53	.0	.97	.53
Average	.62	.44	.40	.23	.75	.51
p-value	.29	.20	.09	.43	.19	.01
Game 4						
Rep 1	.93	.47	.4	.07	1	.43
Rep 2	.43	.27	.17	.37	.68	.27
Rep 3	.67	.60	.37	.23	.87	.47
Average	.68	.45	.31	.22	.85	.39
p-value	.14	.07	.13	.41	.05	.08

Table 12 also reports the p-values for a simple t-test (2 d.f.) of the null-hypothesis that the data were generated by a uniform distribution (noise)

against the alternative that the frequency of the outcomes across the three replications within each treatment exceeds the uniform distribution frequency. Note, for example, that for Game 2 we can (marginally) reject the noise hypothesis in favor of PCI, S and PCI\PE. For Game 3, we can marginally reject the noise hypothesis in favor of PPE. And for Game 4, we can marginally reject the noise hypothesis in favor of PCI\PE.

In principle, senders may separate, partially separate, etc. without receivers responding appropriately. This suggests that the outcome data, as reported in Table 12, understate the extent of communication; a wrong message (in terms of current population play) may be correctly interpreted or a message that is correctly interpreted (given the current state of population play) may have been sent by the wrong type. To partially address this, we report sender play in Table 13. The data in Table 13 confirm our earlier observation that there appears to be a significant amount of communication in all three treatments. Types can frequently be identified by their message. As expected, the sender data (Table 13) by themselves are "cleaner" than the outcome data (Table 12). For example in each treatment, there are two replications in which type t_3 sends only one of the four possible messages.

Interestingly, in each replication of the Game 4 treatment, there exists a message identifying type t_1 well enough for action a_1 to be the unique best reply, even though such an identification is not part of any equilibrium. Note that this phenomenon is consistent with what we found in the corresponding treatment with literal meanings.

Table 13 Meaningless Messages - Senders Type-Message Associations - Final Five Periods												
Type	t_1				t_2				t_3			
Message	A	B	C	D	A	B	C	D	A	B	C	D
Game 2												
Rep 1	0	0	15	0	6	0	0	0	0	0	0	9
Rep 2	0	2	11	0	0	3	0	8	6	0	0	0
Rep 3	3	2	1	1	7	3	1	2	1	6	2	1
Game 3												
Rep 1	1	0	3	2	4	1	0	9	0	10	0	0
Rep 2	0	3	3	7	1	1	3	2	2	1	0	7
Rep 3	1	9	0	1	0	0	5	1	13	0	0	0
Game 4												
Rep 1	0	1	1	8	0	4	5	4	7	0	0	0
Rep 2	2	0	8	4	0	5	2	1	2	5	0	1
Rep 3	1	0	7	1	1	2	0	6	12	0	0	0

The meaningless message - complex incentive treatments demonstrate that with sufficient time players can learn to communicate even under adverse conditions. However, the learning process is both slower and less complete than with either simple incentives or meaningful messages. This is confirmed by Figures 9-11, which graph the evolution of outcomes as a function of time, aggregated over replications. Figure 9 reports the data for the three replications of Game

2, Figure 10 for Game 3, and Figure 11 for Game 4. In each type-action cell (t_i, a_i) we graph the observations of that type type-action pair as a percentage of observations of type t_i , over five period intervals, as a rolling average from period 1 to period 40.

Interestingly, while the meaningless message data (Fig. 9-11) are noisier than the literal meaning data (Fig. 6-8), they display some of the same tendencies, toward separation in Game 2, toward identification of type t_3 in all three treatments, and toward identification over a significant length of time for type t_1 in Game 4.

4.4 Evaluation of Hypotheses

We assess the validity of our hypotheses in a four-cell reference frame in which the nature of the message space, literal vs. meaningless, interacts with the structure of incentives, simple vs. complex.

The most unambiguous results are obtained with simple incentives and meaningless messages, i.e. in our Session I games. We can reject the hypotheses that communication does not matter, i.e. that actions are independent of types (H1), that PCI does not matter (H2), and that (separating) equilibrium play does not matter (H3c). The outcomes observed are consistent with *ex ante* efficiency, influentiality and pass the neologism proofness test; i.e. H3d-f can all be rejected. We did not examine the simple incentive - literal meaning cell because it seems reasonable to expect that the result would be the same.

Fairly clean results arise also when we combine complex incentives with literal meanings. We can reject H1, the hypothesis that there will be no communication, i.e. that the pooling action is the most frequent action, for every replication of every treatment. We can also reject H2, the hypothesis that PCI is irrelevant, for each one of the replications. Equilibrium play is more problematic because in each case there is a systematic deviation from equilibrium. We find that in Game 2 all types are fully identified by their message and that most of the time receivers respond accordingly. Therefore we can reject the hypothesis that separating equilibrium play does not matter (H3c). However in all three replications of Game 2, there are some receivers who appear credulous and take the partial pooling response after type t_2 's message, a departure from separating equilibrium. For Game 3 we can also reject the hypothesis that equilibrium play does not matter (H3b-H3f). However, with so many hypotheses to reject, we suffer from an embarrassment of riches; while the only outcome that is close to an equilibrium is a partial pooling outcome, the evidence is not decisive (H3b and H3c), and the same can be said for the selection criteria of efficiency (H3d), influentiality (H3e), and refinements (H3f). In Game 4 we find that type t_1 is fully identified in all three replications, and indeed we can reject the hypothesis that separating outcomes do not matter (H3c). Note however that this game does not have a separating equilibrium. Thus, we see a robust departure from equilibrium play. Because of the nonexistence of a neologism-

proof equilibrium we cannot reject hypothesis H3f. However, it is interesting to note that the departure from equilibrium play is in the direction suggested by the refinement literature; according to the refinement literature, in any equilibrium of this game type t_1 would be able to identify himself through a credible neologism. Overall, for games with literal meanings we find that both equilibrium predictions and criteria that attempt to select among equilibria (efficiency, influentiality, refinements) are problematic.

Even for the combination of complex incentives and meaningless messages there is enough structure in outcomes to suggest that communication does occur; and where it does occur it is consistent with PCI. We can reject the no-communication hypothesis (H1). For the Game 2 data we can also (marginally) reject the hypothesis that separating equilibrium is irrelevant (H3c), implying, in this game, a rejection of the hypotheses H3d-H3f that efficiency, influentiality and refinements do not matter. If we ignore pooling actions, we can also reject the hypothesis that PCI is irrelevant (H2). For Game 3 we can (marginally) reject the hypothesis that partial pooling equilibrium play is irrelevant for explaining the data (H3b); as a consequence we can also reject the hypothesis that efficiency does not matter (H3d). The evidence on influentiality (H3e), and refinements (H3f) is mixed because there is one replication with strong separating tendencies; separation would favor influentiality whereas only the partial pooling equilibrium is neologism proof. Note that in this game the partial pooling equilibrium outcome is one of the two equilibrium outcomes that are consistent with the PCI condition. Thus, for this game, while the nonequilibrium version of PCI has not much explanatory power, an equilibrium version of hypothesis (H2) that PCI is irrelevant can be rejected. For Game 4 we can marginally reject the hypothesis that separating outcomes do not matter (H3c); however, this game has no separating equilibrium. Indeed, we cannot reject the hypotheses of irrelevance of pooling equilibria (H3a) and partial pooling equilibria (H3b). On the other hand, we find that the portion of type-action pairs that does not involve a pooling action can be explained in terms of PCI (intuitively, where receivers troubled themselves with decoding messages, they found them informative). Overall, PCI appears to have some explanatory power for all three meaningless message treatments; to obtain this explanatory power we sometimes have to focus on nonpooling actions (Game 4) or combine the PCI prediction with an equilibrium prediction (Game 2).

5 Conclusion

There is strong intuition that at least some of the efficiency gains from sharing private information will be realized if communication is costless. This intuition has been used to motivate the investigation of efficient communication in applied work and has been given formal expression both in the cheap-talk refinement literature and in the evolutionary literature.

Our experimental study demonstrates that with sufficient incentive alignment there are indeed forces favoring effective communication. We find that these forces are likely to be decisive if either incentives are closely aligned and simple or if participants have access to messages with pre-established meanings. Participants make use of focal points for *a priori* coordination on meanings, both when meanings are given explicitly and when they suggest themselves. Sometimes, when the provided meanings take the form of instructions, receivers appear credulous by simply following instructions rather than taking into account the sender's incentives. Even if incentives are only imperfectly aligned and meanings have to emerge endogenously, we observe effective communication in most cases. As might be expected, with both imperfect incentive alignment and meaningless messages, learning takes more time and is less complete.

While there is evidence for effective communication, the focus of the applied literature on selecting equilibria receives less support. Equilibria sometimes help in understanding the data. However, for moderately complicated incentives there is no guarantee that equilibrium will be attained after a moderate length of time. There is even less evidence that we can guarantee a particular equilibrium selection criterion to be satisfied. Selection criteria that discriminate among equilibria on the grounds of influentality, ex ante efficiency or refinements do not capture the systematic deviations from equilibrium play that we do observe. In addition they may both under- and overpredict the extent of communication; e.g. we observe communication where refinements reject all equilibria, we observe a tendency toward partial pooling play where influentality would predict full separation, and for one of our incentive structures (Game 3) we observe one of two possible ex ante efficient equilibria in a given treatment, but not the other. Multiple equilibria, lack of convergence to equilibrium, and systematic deviations from equilibrium play (like adherence to focal points and stable sucker behavior) all appear possible. This makes less demanding predictive tools useful.

The partial common interest condition, which appears both in the cheap-talk refinement literature and the evolutionary literature, does a fairly good job of organizing our data. Both in the simple incentive - meaningless message case and with literal meanings, all our final outcomes are consistent with PCI. With meaningless messages and only partial incentive alignment PCI explains two thirds of our data in six out of nine replications and explains three-fourths of the non-pooling data in two out of the remaining three replications. Across all our replications, there is only one in which PCI has no explanatory power.

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FIGURE 5 (Game 1): For the eighteen replications of Game 1 (see Figure 1 for a description of Game 1) this figure presents the time paths that led to the outcomes presented in Table 1. Specifically, for each replication of Game 1 we first measure, over five-period intervals, the frequency of play (i.e., the number of a_i, t_i pairs) in each of the nine cells of Game 1. Next, we divide each of these frequencies by the respective frequency of t_i 's over these five-period intervals to measure, for each sender type, the proportion of play of each action. Finally, for purposes of parsimony and given the similarity of the outcomes over replications, these proportions are averaged across replications.

FIGURE 6 (Game 2 with Literal Meanings): For the three replications of Game 2 (see Figure 2 for a description of Game 2) with literal meanings, this figure presents the time paths that led to the outcomes presented in Table 3. Specifically, for each replication of Game 2 with literal meanings, we first measure, over five-period intervals, the frequency of play (i.e., the number of a_i, t_i pairs) in each of the fifteen cells of Game 2. Next, we divide each of these frequencies by the respective frequency of t_i 's over these five-period intervals to measure, for each sender type, the proportion of play of each action. Finally, for purposes of parsimony and given the general similarity of the outcomes over replications, these proportions are averaged across replications.

FIGURE 7 (Game 3 with Literal Meanings): For the three replications of Game 3 (see Figure 3 for a description of Game 3) with literal meanings, this figure presents the time paths that led to the outcomes presented in Table 3. Specifically, for each replication of Game 3 with literal meanings, we first measure, over five-period intervals, the frequency of play (i.e., the number of a, t pairs) in each of the fifteen cells of Game 3. Next, we divide each of these frequencies by the respective frequency of t 's over these five-period intervals to measure, for each sender type, the proportion of play of each action. Finally, for purposes of parsimony and given the general similarity of the outcomes over replications, these proportions are averaged across replications.

FIGURE 8 (Game 4 with Literal Meanings): For the three replications of Game 4 (see Figure 4 for a description of Game 4) with literal meanings, this figure presents the time paths that led to the outcomes presented in Table 3. Specifically, for each replication of Game 4 with literal meanings, we first measure, over five-period intervals, the frequency of play (i.e., the # of a_i, t_i pairs) in each of the fifteen cells of Game 4. Next, we divide each of these frequencies by the respective frequency of t_i 's over these five-period intervals to measure, for each sender type, the proportion of play of each action. Finally, for purposes of parsimony and given the general similarity of the outcomes over replications, these proportions are averaged across replications.

FIGURE 9 (Game 2 with Meaningless Messages): For the three replications of Game 2 (see Figure 2 for a description of Game 2) with meaningless messages, this figure presents the time paths that led to the outcomes presented in Table 10. Specifically, for each replication of Game 2 with meaningless messages, we first measure, over five-period intervals, the frequency of play (i.e., the # of a_i, t_i pairs) in each of the fifteen cells of Game 2. Next, we divide each of these frequencies by the respective frequency of t_i 's over these five-period intervals to measure, for each sender type, the proportion of play of each action. Finally, for purposes of parsimony and given the rough similarity of the outcomes over replications, these proportions are averaged across replications.

FIGURE 10 (Game 3 with Meaningless Messages): For the three replications of Game 3 (see Figure 3 for a description of Game 3) with meaningless messages, this figure presents the time paths that led to the outcomes presented in Table 10. Specifically, for each replication of Game 3 with meaningless messages, we first measure, over five-period intervals, the frequency of play (i.e., the # of a_i, t_i pairs) in each of the fifteen cells of Game 3. Next, we divide each of these frequencies by the respective frequency of t_i 's over these five-period intervals to measure, for each sender type, the proportion of play of each action. Finally, for purposes of parsimony and given the rough similarity of the outcomes over replications, these proportions are averaged across replications.

FIGURE 11 (Game 4 with Meaningless Messages): For the three replications of Game 4 (see Figure 4 for a description of Game 4) with meaningless messages, this figure presents the time paths that led to the outcomes presented in Table 10. Specifically, for each replication of Game 4 with meaningless messages, we first measure, over five-period intervals, the frequency of play (i.e., the number of a_i, t_i pairs) in each of the fifteen cells of Game 4. Next, we divide each of these frequencies by the respective frequency of t_i 's over these five-period intervals to measure, for each sender type, the proportion of play of each action. Finally, for purposes of parsimony and given the rough similarity of the outcomes over replications, these proportions are averaged across replications.

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