Costly and discrete communication: An experimental investigation

Duffy, Sean and Hartwig, Tyson and Smith, John

Rutgers University-Camden

11 May 2011

Costly and Discrete Communication: An Experimental Investigation[*]

Sean Duffy[†] Tyson Hartwig[‡] and John Smith[§]

Rutgers University-Camden

May 11, 2011

Abstract

Language is an imperfect and coarse means of communicating information about a complex and nuanced world. We run an experimental investigation of a setting in which the messages available to the sender imperfectly describe the state of the world, however the sender can improve communication, at a cost, by increasing the complexity or elaborateness of the message. As is standard in the communication literature, the sender learns the state of the world then sends a message to the receiver. The receiver observes the message and provides a best guess about the state. The incentives of the players are aligned in the sense that both sender and receiver are paid an amount which is increasing in the accuracy of the receiver's guess. We find that the size of the language endogenously arises as a function of the costs of communication. Specifically, we find that higher communication costs are associated a smaller language. Although the equilibrium predictions do not perform well, this divergence occurs in a manner which is consistent with the experimental communication literature: overcommunication. For the receiver, there is a positive relationship between the payoffs relative to the equilibrium predictions and communication costs. This relationship is negative for the senders. We also find that the response times of both the senders and receivers are negatively, not positively, related to their payoffs.

JEL: C72, C91, D82

Keywords: information transmission, cheap talk, overcommunication, bounded rationality, experimental game theory

---

[*]The authors wish to thank Jack Worrall, and participants at the Economic Science Association Conference in Copehnagen, the 21st Stony Brook Game Theory Festival, and seminar participants at the University of Pittsburgh for helpful comments. This research was supported by Rutgers University Research Council Grants #202084 and #202171.

[†]Department of Psychology.

[‡]Department of Economics.

[§]Corresponding Author; Department of Economics, 311 North 5th Street, Camden NJ, 08102 USA; Email: smithj@camden.rutgers.edu; Phone: +1 856-225-6319; Fax: +1 856-225-6602.

1 Introduction

Words exhibit properties very different from those of real numbers. For instance, it is not the case that there exists a word with a meaning *between* any two words. However, words are used to construct statements which convey information about a complex and nuanced reality. One can use words to express more and more detailed and nuanced information, but only at a cost to the sender. It is our view that language is an imperfect and coarse means of communicating information about a complex and nuanced world. We run an experimental investigation of a setting in which the language available to the sender imperfectly describes the state of the world, however the sender can improve communication, at a cost, by increasing the complexity or elaborateness of the message.

Suppose, that your advisee has been invited to present at a conference. Your preferences and the preferences of your student are identical with regards to her performance at the conference: sound competent, receive helpful comments, etc. In order to facilitate this success, you wish to provide the student with information about how to best have a successful conference. However, there is not a single word to convey the full extent of your knowledge regarding how best to present, how best to prepare the slides, best to respond to potential questions, etc. You can increase the amount of information conveyed only by constructing additional statements. As a result, you are unlikely to communicate all of the information which is relevant. Further, the amount of information which you provide will be related to the costs which you bear in the construction of the statements.

Hertel and Smith (2011) adapt the uniform-quadratic version of Crawford and Sobel (1982) so that messages available to the sender are constrained to be costly and discrete. The authors employ an an out-of-equilibrium condition, whereby under this condition only the most informative class of equilibria remains. The paper makes the prediction that more costly signals will be conserved (sent on smaller regions of the state space) and that the size of the language used will arise in equilibrium. The present paper could be viewed as an experimental test of the setup and predictions of Hertel and Smith (2011).

In this experiment, the subjects are anonymously divided into pairs, one as a *sender* and one as a *receiver*. As is standard in the communication literature, the sender learns the state of the world then sends a message to the receiver. The receiver observes the message and selects an action which affects the payoffs of both players. The incentives of the players are aligned in the sense that both sender and receiver are paid an amount which is increasing in the accuracy of the receiver's action.

We make two notable departures from the literature. First, the set of messages imperfectly relate to the underlying state space. Second, in order to transmit a more elaborate message, a larger communication cost is incurred by the sender. Here the state space is an integer between -3 and 3. The sender can send a costless message, which we refer to as the empty message.[1] Additionally, the sender can compose a costly message consisting of two possible elements "High" and "Low." Given our state space, these message elements would seem to provide a natural ordering. The cost of a message is then a function of the number of elements in the message. Therefore, the empty message can be transmitted at a cost of 0; the messages "High" and "Low" can be transmitted at a cost of c; and the messages "High High," "High Low," "Low High" and "Low Low" can be transmitted at a cost of $2c$, where we vary c.

We find that the size of the language arises endogenously as a function of the costs of communication. Also, we find that the equilibrium predictions do not perform well. However, our experimental observations differ from the theoretical predictions in a manner consistent with other experimental communication papers: the senders are overcommunicating. We find that there is a negative relationship between the sender's payoffs relative to the equilibrium payoffs and the communication costs. However, we find a positive relationship between the receiver's payoffs relative to the equilibrium payoffs and the communication costs. We also find that the response time is negatively related to the payoffs relative to the equilibrium payoffs, for both senders and receivers.

[1] Throughout the paper we describe the costless message as *empty* rather than the condition of having not received a message. This is because, it might not be easy to distinguish between the sender having decided not to send a message and the sender having not yet sent a message. To rule out this confusion we describe the costless message as empty.

2 Related Literature

There is a literature which tests existing communication models in general and the Crawford and Sobel (1982) model in particular. Perhaps the first paper testing Crawford and Sobel was Dickhaut et. al. (1995) whereas more recent examples include Cai and Wang (2006), and Kawagoe and Takizawa (2009). Due to the limited ability of subjects to find complex equilibria in novel situations, testing communication equilibria typically uses simplified versions of the model. A natural way to accomplish this simplification is to specify the state space as a set of integers rather than the unit interval. For instance, Dickhaut et. al. specifies the state space as the integers between 1 and 4 and Cai and Wang specifies the state space as an integer between 1 and 9. We select a state space as the set of integers between -3 and 3 in order to render the signal elements of "High" and "Low" relatively meaningful. Further, we hoped that the empty message would be used to denote the set around the state 0. This would seem to aid in the coordination problem[2] between the sender and receiver. Also note that in Dickhaut et. al. (1995), Cai and Wang (2006), and Kawagoe and Takizawa (2009) there is a one-to-one relationship between the state and the set of feasible signals. By contrast, for sufficiently high communication costs (c), in out paper there is no such profitable relationship.

Studies of cheap talk communication have found that the senders often overcommunicate.[3] Relatedly there is a literature which finds that subjects can have an aversion to lying.[4] Again, this literature finds that senders overcommunicate. Note that our subjects never have an incentive to mislead the sender because the sender and receiver have identical preferences over the action of the receiver. Despite the fact that our experimental environment is quite different from the setting in these two literatures, we also find that the senders overcommunicate. Given that we observe similar behavior in such different settings, we argue that overcommunication is a robust phenomenon.

[2]Prior work finds that subjects can resolve similar coordination problems (Blume et. al., 1998, 2001; Blume and Gneezy, 2000; Kreps, 1990). However this is not the focus of our paper.

[3]For example, see Cai and Wang (2006) and Kawagoe and Takizawa (2009).

[4]For instance, Gneezy (2005), Hurkens and Kartik (2009), and Sanchez-Pages and Vorsatz (2007, 2009).

Economists have recently become interested in studying the response times of subjects.[5] Research has found that longer response times are associated with more strategic and less automatic reasoning. Consistent with this research, we find that longer response times are associated with a larger language used by the senders. However, we find that longer response times are also associated with lower per period payoffs for both senders and receivers.

3 Equilibrim Predictions

As mentioned previously, there are many equilibria in our model. We now discuss the most informative equilibria in our setting.[6] Recall that our state space is $s \in \{-3,\ -2,\ -1,\ 0,\ 1,\ 2,\ 3\}$. Our message space is $m \in \varnothing \cup (\cup_{i=1}^{2}\{High, Low\}^i)$. The communication costs $c(m)$ are a function of the number of elements transmitted. The receiver has an action space of $a \in \{-3, -2.5,\ -2,\ -1.5,\ -1, -0.5,\ 0,\ 0.5,\ 1,\ 1.5,\ 2,\ 2.5,\ 3\}$. Both the sender and receiver prefer the receiver to select the action as close to the state as possible. Specifically, in each period, the payoff to the receiver was the nonnegative integer closest to:

$$U_R = 100 - 25(a - s)^2. \tag{1}$$

In each period, the payoff to the sender was the integer closest to:

$$U_S = U_R - c(m). \tag{2}$$

For $c \in [0, 12.5]$, any fully revealing equilibria will exist. Specifically, each message is used and a single message is sent for each state. For $c \in [0, 25]$ then all fully revealing equilibria will exist, with the exception that adjacent states do not have a difference in communication cost of $2c$. In each of these fully revealing equilibria, the ex-ante payoffs are identical: the expected payoff for the receiver in each equilibria is $EU^R = 100$ and the expected payoff for

[5] For instance, Rubinstein (2007), Brañas-Garza and Miller (2008), Piovesan and Wengström (2009), Frank (2010), Matthey and Regner (2011), and Chabris et. al. (2008).

[6] See Hertel and Smith (2011) for further discussion of the modeling choices. For reasons which are specified in their paper, Hertel and Smith assume that each message has a unique cost of transmission. This would seem to be less natural in an experimental setting.

the sender in each equilibria is $EU^S = EU^R - \frac{10}{7}c$.

For $c \in [25, 94]$, the equilibria is such that the messages with two elements are not used. Messages "High" and "Low" are each sent on 2 adjacent states and the empty message is sent on 3 adjacent states. The expected payoff of the receiver is $EU^R = \frac{100}{7} + 2 \cdot \frac{75}{7} + 4 \cdot \frac{94}{7}$. The expected payoff for the sender is $EU^S = EU^R - \frac{4}{7}c$. It should be noted that the equilibrium predictions are identical within each of the intervals mentioned. Therefore, the predictions for equilibrium behavior are the same whether $c = 26$ or 93.

For $c \in [94, 100]$ then the equilibria is such that the messages with two elements are not used. Messages "High" and "Low" are each sent on the extreme states, 3 and -3. The empty message is sent on the remaining states. Given the empty message, the receiver is indifferent between selecting -0.5 and 0.5. The expected payoff to the receiver is $EU^R = 2 \cdot \frac{94}{7} + 2 \cdot \frac{44}{7} + 2 \cdot \frac{100}{7}$. The expected payoff to the sender is $EU^S = EU^R - \frac{2}{7}c$. Note that the receiver is indifferent between selecting -0.5 and 0.5 but not 0. If the sender is pooling on more than 3 states, the expected payoff of selecting -0.5 or 0.5 is $2 \cdot \frac{94}{7} + 2 \cdot \frac{44}{7} = \frac{286}{7}$ and the expected payoff of selecting 0 is $\frac{100}{7} + 2 \cdot \frac{75}{7} = \frac{250}{7}$. Therefore, selecting an integer action yields a lower payoff.

For $c > 100$ then the only equilibria is one in which the sender only sends the empty message for all states and the receiver has no additional information about the state and is therefore indifferent among selecting -1.5, 0.5, 0.5 and 1.5. The expected payoffs are then $EU^R = EU^S = 2 \cdot \frac{94}{7} + 2 \cdot \frac{44}{7}$.

4 Experimental Design

A total of 48 subjects participated in the experiment. The subjects were both undergraduate and graduate students at Rutgers University-Camden. The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). Sessions lasted from 90 to 120 minutes.

In each period, the sender was shown the state, which we referred to as the "secret number." The state s consisted of an integer between -3 and 3. In order to inform the receiver of its content, the sender was able to transmit a possibly costly message. The message "Empty message" cost $c(m) = 0$, the messages "High" and "Low" each cost $c(m) = c$, the messages "High High," "High Low," "Low High," and "Low Low," each cost $c(m) = 2c$, where $c \in \{10, 30, 50, 96\}$. Upon observing the message, the receiver selected a best guess about the state. The receiver's action a was selected from the action space of half integers between -3 and 3.

The per period payoff to the receiver was the nonnegative integer closest to $100-25(a-s)^2$. The per period payoff to the sender was the integer closest to the receiver's payoffs minus $c(m)$. In order to aid in the comprehension of their payoffs, the subjects were given a table indicating the payoffs associated with each state and action selected by the receiver.[7] The subjects were given a \$5 show up fee and \$1 for every 300 points accumulated.[8]

Sender and receiver were matched and played the game for 15 periods where c was held fixed. After the 15 periods, each subject was rematched with a different opponent, each switched role as sender and receiver, and played with a new value of c. Each trial consisted of 4 rounds of 15 periods. The subjects were made aware of these matching procedures. We ran two treatments which consisted of 8 subjects and two treatments of 16 subjects. Therefore, we have a total of 1440 data points for both senders and receivers.

A few comments on our methodology are in order. Since we expected overcommunication, even though only the senders incurred the communication costs, we designed the experiment to reduce the social preferences of the sender towards the receiver. First, we emphasized the differences in the payoffs by displaying the per period payoff of both subjects. Second, we emphasized the anonymous matching whereby after each round of 15 periods, the players would be rematched with a new partner. This was done in order to discourage any implicit reciprocal play.

[7] See the appendix for this table.

[8] The total amount earned in the experiment ranged from \$6.29 to \$20.54, with an average of \$15.62.

Additionally, many experimental communication papers rematch the subjects after each period. However, we decided not to rematch, as there is a reasonably difficult coordination problem, which would be aggravated by rematching after every period. Finally, note that we constrain the receiver's payoffs to be nonnegative. This experimental feature was designed to make the payoffs easier to understand, and to avoid very negative payoffs for the receiver.

5 Results

In each of the four rounds, the subjects exhibited learning across periods 1-15. Across all periods, the relationship between the sender's payoffs and the period in which it was obtained is very significant ($p = 0.01$). However, within periods 5-15, the relationship is not significant ($p = 0.7$). Therefore, within each round, we exclude from consideration the data obtained in periods 1-4.[9]

We first ask whether the size of the language arises endogenously as a function of the cost of communication. In other words, are expensive signals conserved when communication is costly? To address this question we run logistic regressions with three different measures of the size of the language. In the first logistic regression, the dependent variable is a dummy indicating whether the message was empty. We assign a value of 1 in the event that the message was empty, and a 0 otherwise. We refer to this regression as "Empty." In the second specification, the dependent variable is a dummy indicating whether the message was either empty or either "High" or "Low." We refer to this regression as "Empty or One." In contrast to the two binary logistic regressions above, in the third specification, we run an ordered multinomial logistic regression. In this specification, the dependent variable is the number of elements in the message. In other words, we assign a value of 0 for the empty message, a value of 1 for the messages "High" or "Low" and 2 otherwise. We refer to this regression as "Number of Elements." In each of the regressions below, we include controls for the state because it is not obvious, given a particular communication cost, that a message

[9] We do not explore whether there was learning across rounds, because each subject experienced only one of the following two sequences of communication costs: $10 - 50 - 30 - 96$ and $96 - 30 - 50 - 10$.

would be appropriate for all states. Further, for all regressions below, we account for the subject specific fixed effects. Note that in the output below, we do not list the estimations of intercepts and that each regression has $n = 1056$. We list the results below in Table.1.

	Empty	Empty or One	Number of Elements
Communication Costs	0.0401***	0.0140**	−0.0195***
	(0.00743)	(0.00553)	(0.00405)
-2 log L	412.8	812.1	1365.2
LR χ^2	796.3***	548.3***	924.3***

Table 1: Results of logistic regressions where *** indicates significance at $p < 0.01$ and ** indicates significance at $p < 0.05$. Each regression accounts for the subject specific fixed effects and state dummy variables.

In each of our three specifications, we find evidence that the size of the language is affected by the communication costs. In other words, we find that more expensive signals are conserved when communication becomes costly. In the first specification, we see that higher communication costs are associated with a greater likelihood of sending the empty message. We see the analogous result in the second specification: there is a relationship between communication costs and the transmission of the messages "Empty", "High" or "Low." Finally, in the third specification we see that higher communication costs are associated with the transmission of lower cost messages. In short, the results summarized in Table 1 suggest that the size of the language used arises endogenously as a function of the cost of communication.

As a robustness check, we perform the analogous analysis, but include the average payoffs entering the period, within the current match. Again note that we do not list the estimates of the intercepts and that $n = 1056$ for each regression. We list the results of these regressions below in Table 2.

	Empty	Empty or One	Number of Elements
Communication Costs	0.0467***	0.0147**	−0.0223***
	(0.00806)	(0.00594)	(0.00421)
Average Payoffs	−0.00868**	−0.00422**	0.00498***
	(0.00352)	(0.00181)	(0.00160)
Costs-Average Payoffs Interaction	0.000127**	0.000048	−0.000069**
	(0.000059)	(0.000039)	(0.000030)
-2 log L	406.4	806.0	1355.4
LR χ^2	802.7***	554.3***	934.1***

Table 2: Results of logistic regressions where *** indicates significance at $p < 0.01$ and ** indicates significance at $p < 0.05$. Each regression accounts for the subject specific fixed effects and a dummy for each state.

We first note that the qualitative findings from Table 1 also hold here in Table 2: the senders are conserving higher cost messages when communication is costly. The new insight which emerges is that we observe that lower average payoffs are associated with transmission of the empty message. We see the analogous result for the "Empty or One" regression. We also note that lower average payoffs are associated with sending a less costly message. We also note that there is evidence that the average profit and the communication costs are interacting. Specifically, we find that higher communication costs are associated with a greater sensitivity of the relationship between average payoffs and the likelihood of sending an empty or a less costly message.

The results of the regressions summarized in Table 2 suggest that senders are jointly considering the communication costs and the average payoffs obtained in the match when deciding on the size of the language. In particular, it seems that the senders are weighing whether the costs of the messages are less than their benefits. This determination is based on both the direct cost incurred by sending the message and the proficiency of the receiver in selecting the appropriate action.

Up to this point, we have found that communication costs shrink the size of the language used and previous success within the match increases the size of the language. It is natural to ask about the relationship between the strategic considerations of the senders and the size of the language. To address this, we examine the response time of the subjects. Again, we perform the analogous analysis as in Table 2, however we also include the time remaining when the subject sends the message.

	Empty		Empty or One		Number of Elements	
Comm. Costs	0.0732***	0.0776***	0.0294***	0.0315***	−0.0386***	−0.0388***
	(0.0204)	(0.0220)	(0.0111)	(0.0113)	(0.00967)	(0.00955)
Average Payoffs	−0.00959***	−0.0144*	−0.00349*	0.00055	0.00451***	0.00199
	(0.00367)	(0.00741)	(0.00184)	(0.0041)	(0.00163)	(0.00353)
Costs-AP Int.	0.000141**	0.000138**	0.000037	0.000033	−0.00007**	−0.00007**
	(0.000061)	(0.00006)	(0.00004)	(0.00004)	(0.000031)	(0.000031)
Time Remaining	0.139**	0.162**	0.0851***	0.0821***	−0.0937***	−0.0887***
	(0.0578)	(0.0686)	(0.0272)	(0.0262)	(0.0254)	(0.0255)
Costs-Time Int.	−0.00106	−0.0012	−0.00072	−0.00085*	0.00069*	0.000711*
	(0.000804)	(0.0009)	(0.00046)	(0.00048)	(0.00040)	(0.000391)
Profit-Time Int.	–	0.00022	–	−0.00020	–	0.00011
		(0.00029)		(0.00017)		(0.00014)
-2 log L	396.2	395.6	569.0	790.1	1334.1	1333.5
LR χ^2	813.0***	813.5***	791.3***	570.3***	955.3***	955.9***

Table 3: Results of logistic regressions where *** indicates significance at $p < 0.01$, ** indicates significance at $p < 0.05$, and * indicates significance at $p < 0.1$. Each regression accounts for the subject specific fixed effects and a dummy for each state.

Again the basic results the results summarized in Tables 1 and 2, hold when we account for the response time. Again, we find that higher communication costs are associated with a smaller language. Additionally, we find evidence that average payoffs are associated with a larger language. However, Table 3 reveals some additional results regarding response times. First, note that a larger time remaining is associated with a smaller language. In each of the 6 specifications in Table 3, we see that a faster response is associated with a conservation of costly messages, according to each of our three measures. This suggests that the subjects who expend a greater time thinking about their action, and hence could be described as acting more strategically, employ a larger language than do the subjects who do not spend such time deliberation about their action.

One might conjecture that there will be an interaction between the communication cost and the response time. This relationship could arise as a result of the relative simplicity of the equilibrium when there are large communication costs. It might also be conjectured that there will be an interaction between the average payoffs and response time. This could be due to the fact that lower average payoffs might make the decision easier, and hence there would be a greater sensitivity to response time. Howerver, we do not find evidence in support of either of these conjectures. In particular we find only very weak evidence in support of an interaction between the communication cost and the response time. We also do not find evidence in support of an interaction between the average profit and the response time.

We now turn our attention to the overall performance of the subjects, as measured by their payoffs. This allows us to ask, "How are the subjects performing relative to the equilibrium predictions?" We first note that the equilibrium predictions do not perform particularly well. Within each communication cost treatment, there is a significant difference between the sender's payoffs and the equilibrium prediction. In all but the highest cost treatment, there is a significant difference between the receiver's payoffs and the equilibrium prediction. This data is presented in Table 4.

	Sender		Receiver	
	Equilibrium	Actual	Equilibrium	Actual
$c = 10$	85.71	67.13***	100.00	81.03***
$c = 30$	72.29	47.16***	89.43	84.09***
$c = 50$	60.86	29.60***	89.43	76.00***
$c = 96$	40.57	-6.14***	68.00	69.86

Table 4: Equilibrium predictions of payoffs and actual mean payoffs for senders and receivers according communication costs. Results of one-sample t-tests each with 263 degrees of freedom, where *** indicates significance of a one-sided test at $p < 0.01$.

Recall that the receiver's payoffs correspond to the accuracy of the receiver's action and the sender's payoffs correspond to this accuracy minus the cost of the message sent. A glance at Table 1 suggests that as communication costs increase, the actions are becoming more accurate yet the senders are doing worse relative to the equilibrium predictions. This suggests that the senders are overcommunicating. In particular, Table 4 suggests that the sender's payoffs vary too much with communication costs and the receiver's payoffs do not vary enough. We perform the following analysis in order to test this speculation.

In regressions $(S1) - (S4)$ of Table 5, the dependent variable is the sender's actual payoffs minus the sender's equilibrium payoffs. In regressions $(R1) - (R4)$ of Table 6, the dependent variable is the receiver's actual payoffs minus the receiver's equilibrium payoffs. In regressions ($S1$) and ($R1$), we employ no additional controls. In regressions ($S2$) and ($R2$), we account for the subject specific fixed effects. In regressions ($S3$) and ($R3$), we account for the information known by the subject at the time of the decision. In the case of the receiver ($R3$), this is the message observed, and in the case of the sender ($S3$), this is the state observed. Finally, in regressions ($S4$) and ($R4$) we account for the subject specific fixed effects and the information known by the subject at the time of the decision. Each regression has $n = 1056$.

	($S1$)	($S2$)	($S3$)	($S4$)
Intercept	-15.2^{***}	-11.5	-27.9^{***}	-22.6^{**}
	(2.81)	(10.2)	(4.59)	(9.75)
Communication Costs	-0.327^{***}	-0.335^{***}	-0.320^{***}	-0.321^{***}
	(0.0497)	(0.0819)	(0.0455)	(0.0726)
Subject Fixed Effects	No	Yes	No	Yes
State Dummy	No	No	Yes	Yes
R^2	0.04	0.23	0.21	0.40

Table 5: Results of regressions where the dependent variable is the sender's actual payoffs minus sender's equilibrium payoffs, and *** indicates significance at $p < 0.01$ and ** indicates significance at $p < 0.05$.

	($R1$)	($R2$)	($R3$)	($R4$)
Intercept	-18.4^{***}	-40.2^{***}	0.374	-17.5^{**}
	(1.88)	(7.90)	(3.97)	(8.61)
Communication Costs	0.203^{***}	0.388^{***}	0.212^{***}	0.351^{***}
	(0.0333)	(0.0553)	(0.0342)	(0.0546)
Subject Fixed Effects	No	Yes	No	Yes
Message Dummy	No	No	Yes	Yes
R^2	0.03	0.21	0.086	0.26

Table 6: Results of regressions where the dependent variable is the receiver's actual payoffs minus receiver's equilibrium payoffs, and *** indicates significance at $p < 0.01$ and ** indicates significance at $p < 0.05$.

First, note that in Table 5, every specification involving communication costs has a negative and significant estimate. This suggests that as communication costs increase, the senders do worse relative to the equilibrium predictions. We note the opposite effect for the receivers. Table 6 shows that the estimates of the coefficient for communication costs are positive and significant. Therefore, as the communication costs increase, the receivers do better relative to the equilibrium predictions.

At this point it is natural to ask about the relationship between the strategic considerations of the subjects and their payoffs. Again, we use response times to address this issue. In the regression below we include the time remaining when the decision is made and the interaction between the communication costs and the time remaining. Each regression has $n = 1056$.

	$(S1)$	$(S2)$	$(S3)$	$(S4)$
Intercept	-41.7^{***}	-33.9^{***}	-49.2^{***}	-37.9^{***}
	(8.71)	(13.0)	(9.15)	(12.5)
Communication Costs	-0.721^{***}	-0.660^{***}	-0.697^{***}	-0.580^{***}
	(0.155)	(0.170)	(0.142)	(0.152)
Time Remaining	1.15^{***}	1.02^{***}	0.848^{***}	0.641^{*}
	(0.367)	(0.377)	(0.341)	(0.342)
Cost-Time Interaction	0.0176^{***}	0.0153^{**}	0.0169^{***}	0.0122^{**}
	(0.00657)	(0.00677)	(0.00603)	(0.00607)
Subject Fixed Effects	No	Yes	No	Yes
State Dummy	No	No	Yes	Yes
R^2	0.10	0.27	0.25	0.42

Table 7: Results of regressions where the dependent variable is the sender's actual payoffs minus sender's equilibrium payoffs, and *** indicates significance at $p < 0.01$, ** indicates significance at $p < 0.05$, and * indicates significance at $p < 0.1$.

	$(R1)$	$(R2)$	$(R3)$	$(R4)$
Intercept	-36.2^{***}	-56.3^{***}	-16.6^{**}	-30.5^{***}
	(6.30)	(10.2)	(7.68)	(11.1)
Communication Costs	0.0734	0.329^{***}	0.0920	0.290^{**}
	(0.111)	(0.124)	(0.111)	(0.124)
Time Remaining	0.783^{***}	0.731^{**}	0.599^{**}	0.499^{*}
	(0.272)	(0.285)	(0.278)	(0.292)
Cost-Time Interaction	0.00619	0.00314	0.00609	0.00357
	(0.00488)	(0.00519)	(0.00483)	(0.00512)
Subject Fixed Effects	No	Yes	No	Yes
Message Dummy	No	No	Yes	Yes
R^2	0.07	0.23	0.11	0.27

Table 8: Results of regressions where the dependent variable is the receiver's actual payoffs minus receiver's equilibrium payoffs, and *** indicates significance at $p < 0.01$, ** indicates significance at $p < 0.05$, and * indicates significance at $p < 0.1$.

Much of the main results of Tables 5 and 6, also hold here in Tables 7 and 8. In particular, in all 4 specifications in Table 7, we see that communication costs are negatively related to the sender's payoffs relative to equilibrium payoffs. Also, there is some evidence that the communication costs are positively related to the receiver's payoffs relative to equilibrium payoffs.

Also note the results of Tables 7 and 8 involving the time it took the subject to make the choice. Perhaps surprisingly, in each of the 8 specifications there was a positive relationship between the time remaining and the payoffs relative to equilibrium payoffs. In other words, subjects who made their decision more quickly, did better than subjects who reflected further on their choice.

We mention two other features of the results presented in Tables 7 and 8. First, the senders exhibit an interaction between communication costs and the time remaining. Specifically, there is evidence that, given higher communication costs, there is a stronger relationship between the time remaining and payoffs relative to equilibrium payoffs. This result seems to suggest that spending time thinking about the message is markedly unhelpful when communication costs are large. In contrast, there is no evidence of the analogous interaction for the receivers. In particular, there is no significant interaction between the communication costs and the time remaining. So it seems that the unhelpfulness of additional time thinking about the problem does not vary with the cost of communication.

The results summarized in Tables 5 and 7 provide evidence that the senders are overcommunicating. In other words, the senders are not sufficiently conserving expensive words and as a result, there is a negative relationship between communication costs and sender payoffs relative to equilibrium payoffs. Further, the results summarized in Tables 6 and 8 provide evidence of a positive relationship between communication costs and receiver payoffs relative to equilibrium payoffs. In other words, the overcommunication seems to be benefiting the receiver.

The questions are then, "How robust is the finding that senders are overcommunicating?"

and "Is the positive relationship between communication costs and receiver payoffs caused by the receivers making better decisions or are they merely benefiting from the overcommunication of the senders?"

To answer these questions we run a series of discrete choice multinomial logits. Designed for use in the analysis of experiments, McKelvey and Palfrey (1998) developed the Agent Quantal Response Equilibrium (AQRE). This nonequilibrium concept assumes that subjects will not perfectly play the equilibrium strategies and a free parameter is a measure of the errors committed by the subjects. Several researchers have estimated the AQRE parameter in order to measure the proximity of the observed play to that predicted by equilibrium.[10]

However, in our setting, there is a great deal of computational complexity, which is not present in the previous studies. In other words, we are not eager to solve a 140 parameter fixed point problem.[11] As a result, we estimate the multinomial choice logits as follows. For the sender we estimate λ_c^S, where $p_m(s;c)$ is the probability of transmitting message m' given state s and communication cost c:

$$p_{m'}(s;c) = \frac{e^{\lambda_c^S \cdot \overline{u_{m'}}(s;c)}}{\sum_{m \in M} e^{\lambda_c^S \cdot \overline{u_m}(s;c)}}. \tag{3}$$

In expression (3), the term $\overline{u_{m'}}(s;c)$ is the observed expected payoffs for the sender by sending message m when the state is s are communication costs are c. We calculate $\overline{u_{m'}}(s;c)$ by noting the observed relationship between the actions of the receiver upon observing message m. For the receiver, we estimate λ_c^R, were $q_{a'}(m;c)$ is the probability of selecting action a' given message m and communication cost c:

$$q_{a'}(m;c) = \frac{e^{\lambda_c^R \cdot \overline{u_{a'}}(m;c)}}{\sum_{a \in A} e^{\lambda_c^R \cdot \overline{u_a}(m;c)}}. \tag{4}$$

In expression (4), the term $\overline{u_a}(m;c)$ is the observed expected payoffs for the receiver by

[10] For intance, see Cason and and Reynolds (2005), Guarnaschelli et. al. (2000), Goeree and Holt (2002), and Baye and Morgan (2004).

[11] The sender has 49 pure strategies (7 states x 7 messages) , and the reciever has 91 pure strategies (7 messages x 13 actions).

selecting action a, when the message is m and communication costs are c. We calculate $\overline{u_a}(m;c)$ by noting the observed relationship between the message transmitted by the sender upon observing state s.

As with the AQRE parameter, a higher estimate of our parameter implies that subjects are making decisions closer to the optimal decision. However there are several important differences between our estimates and the estimates of the AQRE parameter. Note that, unlike AQRE analyses, we are not estimating a fixed point problem. As such, we estimate different parameters for the sender and receiver. Further, we estimate our parameters by using the observed frequency of the strategies of the complementary players. The estimate the sender's parameter is based on the observed frequency of the receiver's strategy, and the estimate the receiver's parameter is based on the observed frequency of the sender's strategy.

In the table below, we present a summary of our estimates.

	Sender	Receiver
$c = 10$	0.03418	0.0609
	(0.00224)	(0.00456)
$c = 30$	0.02745	0.0665
	(0.00173)	(0.00500)
$c = 50$	0.02621	0.0520
	(0.00169)	(0.00364)
$c = 96$	0.01443	0.0455
	(0.0008975)	(0.00345)

Table 9: Maximum likelihood estimates of multinomial logistic choice parameter in expressions (3) and (4), with standard errors in parentheses. The estimate within each cell is based on 264 observations.

Table 9 presents evidence that the both the senders and receivers are making worse decisions as the communication costs increase, however this seems to be more acute for the sender. This sender estimates in Table 9 corroborate the evidence found in Tables 5 and 7, namely that the senders are making worse decisions as communication becomes costly. On the other hand, the receiver estimates in Table 9 suggest that the positive relationship between receiver payoffs and communication costs is not caused by better decision making, but rather the receivers are benefiting from the overcommunication of the senders.

6 Conclusions

We run an experiment where the messages available to the sender imperfectly describe the state of the world, however the sender can improve communication, at a cost, by increasing the complexity or elaborateness of the message. The incentives of the players are aligned in that both sender and receiver are paid an amount which is increasing in the accuracy of the receiver's action. Although the equilibrium predictions of Hertel and Smith (2011) do not perform well, our experimental results do corroborate some of the qualitative predictions. In particular, we find that the size of the language arises endogenously as a function of the cost of communication.

Further, the differences between our observations and the equilibrium predictions are consistent with other experimental communication papers: the senders overcommunicate. As a result of this overcommunication, there is a negative relationship between the cost of communication and the sender's payoffs relative to the equilibrium predictions. The receivers benefit from this overcommunication, as we observe a positive relationship between the cost of communication and the receiver's payoffs relative to the equilibrium predictions.

Consistent with the response time literature, we find that the response time is related to the size of the language used by the sender. However, we also find that the response time of both the sender and receiver are negatively related to payoffs. In other words, we find that less, and not more, time deliberating about the decision leads to better outcomes. How do we interpret the response time results? It is possible that there exists unobserved heterogeneity among the subjects and this drives the results. Specifically, it is possible that subjects who respond in a shorter period of time are more proficient in the game. To some extent the data supports this view, because the response time results are weaker when we account for the subject specific fixed effects.[12] However, when we account for the subject specific fixed effects, the relationship still persists.

[12] To our knowledge, Piovesan and Wengström (2009) is the only other paper which analyzes response times and conducts a fixed effects analysis.

Although there are significant differences between the equilibrium predictions and our observations, we are encouraged by our results. As mentioned, these differences are largely due to the overcommunication of the senders. Since observing overcommunication in experimental settings is common, we do not find this divergence to be problematic. Further, the main insights from Hertel and Smith (2011) are observed in our experimental setting: the size of the language employed is determined by the cost of communication. As a result, it would seem to be profitable to think more about theoretical and experimental issues related to costly and discrete communication.

7 References

Baye, Michael R. and Morgan, John (2004): "Price Dispersion in the Lab and on the Internet: Theory and Evidence," *RAND Journal of Economics*, 35(3), 449–466.

Blume, Andreas, DeJong, Douglas, Kim, Yong-Gwan and Sprinkle, Geoffrey (1998): "Experimental evidence on the evolution of meaning of messages in sender-receiver games," *American Economic Review*, 88: 1323–1340.

Blume, Andreas, DeJong, Douglas, Kim, Yong-Gwan and Sprinkle, Geoffrey (2001): "Evolution of communication with partial common interest," *Games and Economic Behavior*, 37: 79–120.

Blume, Andreas and Gneezy, Uri (2000): "An Experimental Investigation of Optimal Learning in Coordination Games," *Journal of Economic Theory*, 90: 161-172.

Brañas-Garza, Pablo and Miller, Luis (2008): "Instinctive Response in the Ultimatum Game," working paper Universidad de Grenada and Oxford University.

Cai, Hongbin and Wang, Joseph Tao-Yi (2006): "Overcommunication in strategic information transmission games," *Games and Economic Behavior*, 56: 7–36.

Cason, Timothy N. and Reynolds, Stanley S. (2005): "Bounded rationality in laboratory bargaining with asymmetric information," *Economic Theory*, 25: 553–574

Chabris, Christopher F., Laibson, David , Morris, Carrie L., Schuldt, Jonathon P., Taubinsky, Dmitry (2008): "Measuring Intertemporal Preferences Using Response Times," NBER Working Paper 14353.

Crawford, Vincent and Haller, Hans (1990): "Learning How to Cooperate: Optimal Play in Repeated Coordination Games," *Econometrica*, 58: 581-596.

Crawford, Vincent and Sobel, Joel (1982): "Strategic Information Transmission," *Econometrica*, 50(6): 1431-1451.

Dickhaut, John, McCabe, Kevin and Mukherji, Arijit (1995): "An experimental study of strategic information transmission," *Economic Theory*, 6, 389-403.

Fischbacher, Urs (2007): "z-Tree: Zurich Toolbox for Ready-made Economic Experiments," *Experimental Economics*, 10(2), 171-178.

Frank, Björn (2010): "The effects of enforced reflection in three simple experiments," working paper University of Marburg.

Goeree, Jacob K. and Holt, Charles A. (2002): "Quantal Response Equilibrium and Overbidding in Private-Value Auctions," *Journal of Economic Theory*, 104: 247–272.

Gneezy, Uri (2005): "Deception: The Role of Consequences," *American Economic Review*, 95(1), 384-394.

Guarnaschelli, Serena, McKelvey, Richard D. and Palfrey, Thomas R. (2000): "An Experimental Study of Jury Decision Rules," *American Political Science Review*, 94(2): 407–423.

Hertel, Jo and Smith, John (2011): “Not So Cheap Talk: Costly and Discrete Communication,” working paper Rutgers University-Camden.

Hurkens, Sjaak and Kartik, Navin (2009): "Would I Lie to You? On Social Preferences and Lying Aversion," *Experimental Economics*, 12: 180-192.

Kawagoe Toshiji and Takizawa, Hirokazu (2009): “Equilibrium refinement vs. level-k analysis: An experimental study of cheap-talk games with private information,” *Games and Economic Behavior*, 66: 238–255.

Kreps, David (1990): "A Course in Microeconomic Theory," Princeton University Press, Princeton NJ, pages 414-415.

Matthey, Astrid and Regner, Tobias (2011): "Do I Really Want to Know? A Cognitive Dissonance-Based Explanation of Other-Regarding Behavior," *Games*, 2: 114–135.

McKelvey, Richard D. and Palfrey, Thomas R. (1998): "Quantal Response Equilibria for Extensive Form Games," *Experimental Economics*, 1: 9–41.

Piovesan, Marco and Wengström, Erik (2009): "Fast or Fair? A Study of Response Times," *Economics Letters*, 105, 193-196.

Rubinstein, Ariel (2007): "Instinctive and Cognitive Reasoning: A Study of Response Times," *Economic Journal*, 117, 1243-1259.

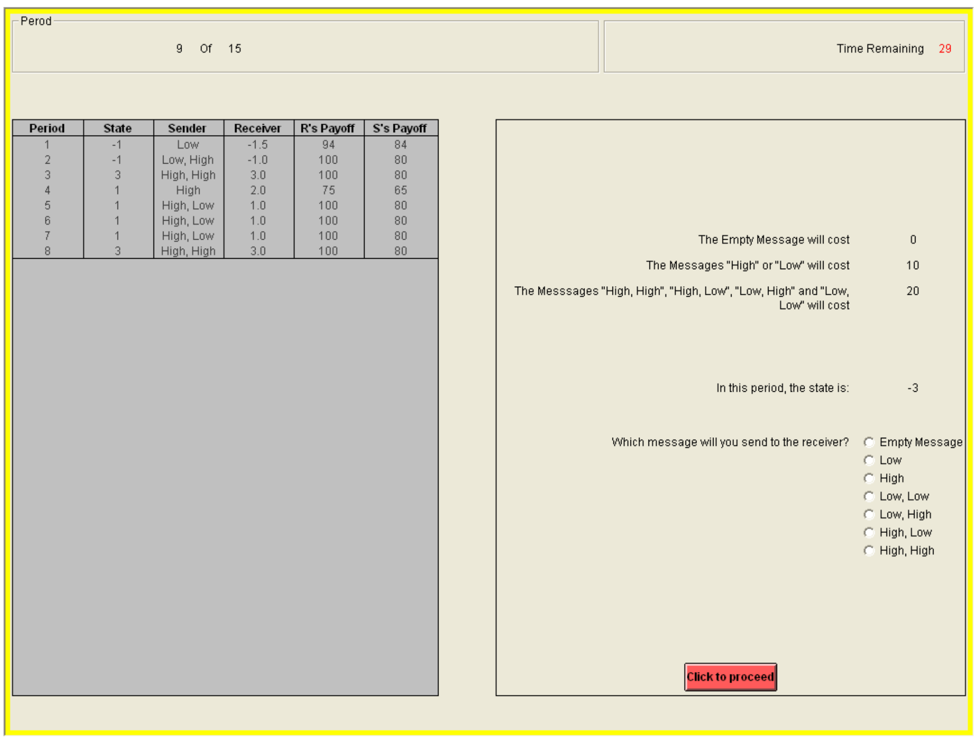
Sanchez-Pages, Santiago and Vorsatz, Marc (2007): "An Experimental Study of Truth-Telling in a Sender-Receiver Game," *Games and Economic Behavior*, 61, 86-112.

Sanchez-Pages, Santiago and Vorsatz, Marc (2009): "Enjoy the Silence: An Experiment on Truth-Telling," *Experimental Economics*, 12: 220-241.

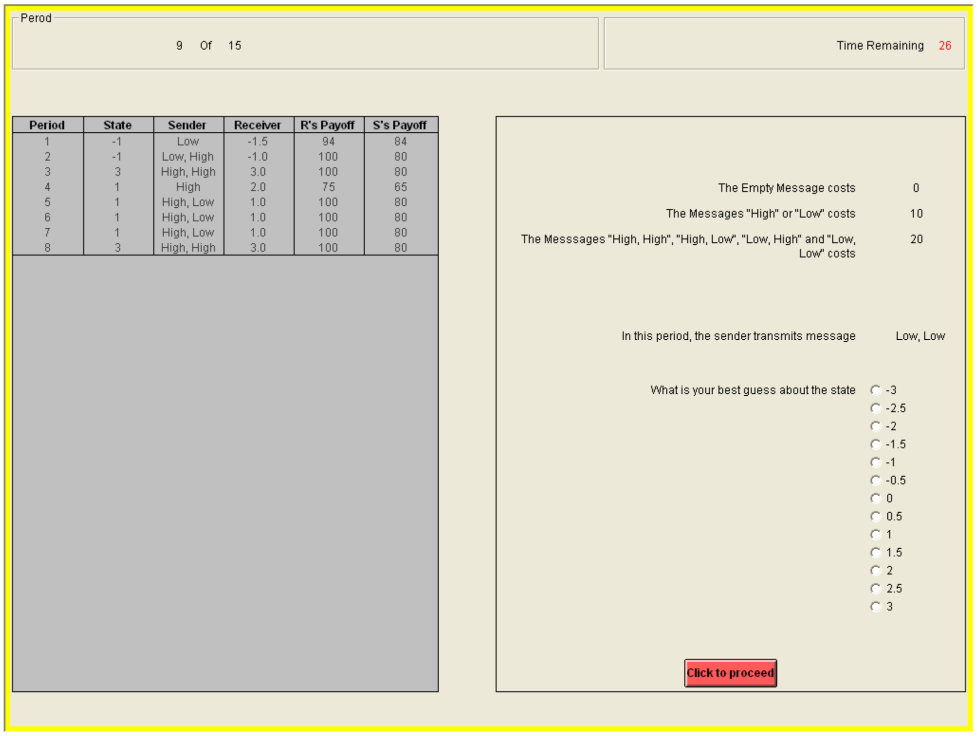
8 Appendix

Although the payoffs were specified by equations (1) and (2), the subjects were also presented with the following table.

State \ Action	-3	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3
-3	100	94	74	44	0	0	0	0	0	0	0	0	0
-2	75	94	100	94	74	44	0	0	0	0	0	0	0
-1	0	44	75	94	100	94	74	44	0	0	0	0	0
0	0	0	0	44	75	94	100	94	74	44	0	0	0
1	0	0	0	0	0	44	75	94	100	94	74	44	0
2	0	0	0	0	0	0	0	44	75	94	100	94	75
3	0	0	0	0	0	0	0	0	0	44	75	94	100



Sender's Screen



Receiver's Screen

8.1 Outcomes

Messages sent by the senders given the state observed and communication costs

$c = 10$		Messages						
		Empty	High	Low	Low Low	Low High	High Low	High High
	−3	1	1	1	31	3	2	0
	−2	1	1	21	4	19	1	0
States	−1	0	0	16	0	14	3	0
	0	34	0	1	0	1	0	0
	1	0	4	14	0	7	18	0
	2	1	19	0	1	2	9	3
	3	0	9	0	0	0	0	22

$c = 30$		Messages						
		Empty	High	Low	Low Low	Low High	High Low	High High
	−3	0	1	5	26	0	1	0
	−2	0	0	27	5	5	3	0
States	−1	6	1	10	0	11	2	0
	0	27	4	1	0	2	2	0
	1	16	7	4	0	6	10	1
	2	2	29	0	0	1	11	0
	3	0	12	0	0	0	0	26

$c = 50$		Messages						
		Empty	High	Low	Low Low	Low High	High Low	High High
	−3	2	0	23	14	0	0	2
	−2	1	1	32	0	3	0	0
States	−1	16	0	16	1	7	0	0
	0	36	0	2	1	0	0	0
	1	18	4	8	1	1	4	0
	2	3	29	0	0	2	9	0
	3	0	15	1	0	0	0	12

$c = 96$		Messages						
		Empty	High	Low	Low Low	Low High	High Low	High High
	−3	4	2	20	18	1	1	0
	−2	8	0	12	1	2	2	0
States	−1	20	0	13	2	5	0	0
	0	35	0	0	0	0	0	0
	1	25	4	3	0	0	5	0
	2	13	27	0	1	0	1	0
	3	5	18	0	0	0	0	16

Action selected by the receivers given the message and communication costs

$c = 10$		Action												
		-3	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3
	Empty	0	0	0	0	0	0	36	1	0	0	0	0	0
	High	0	0	0	0	0	0	0	0	1	2	22	7	2
	Low	3	2	19	11	6	3	1	1	6	1	0	0	0
Messages	Low Low	30	2	0	0	2	0	0	1	1	0	0	0	0
	Low High	3	3	14	4	10	1	1	0	6	3	0	1	0
	High Low	0	0	3	0	2	0	0	0	15	7	6	0	0
	High High	0	0	0	0	0	0	0	0	0	0	0	4	21

$c = 30$		Action												
		-3	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3
	Empty	0	0	0	0	0	2	49	0	0	0	0	0	0
	High	0	0	0	0	0	0	1	0	3	8	22	17	3
	Low	2	6	20	9	6	0	1	0	2	0	1	0	0
Messages	Low Low	28	0	1	0	0	0	1	0	1	0	0	0	0
	Low High	0	0	4	1	11	1	1	0	5	0	2	0	0
	High Low	0	0	4	1	2	0	2	0	9	4	7	0	0
	High High	0	0	0	0	0	0	0	0	0	1	0	0	26

$c = 50$		Action												
		-3	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3
	Empty	0	1	2	0	1	2	59	5	4	1	1	0	0
	High	1	0	1	0	0	0	0	0	6	3	15	15	8
	Low	6	12	16	18	20	2	2	0	3	3	0	0	0
Messages	Low Low	14	1	0	0	2	0	0	0	0	0	0	0	0
	Low High	0	0	2	0	6	0	0	2	2	1	0	0	0
	High Low	0	0	0	0	0	1	0	0	2	2	7	1	0
	High High	1	1	0	0	0	0	0	0	0	0	0	0	12

$c = 96$		Action												
		-3	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3
	Empty	3	4	1	7	4	4	58	8	8	6	4	1	2
	High	0	1	1	0	0	0	1	1	3	2	17	9	16
	Low	11	6	12	3	8	1	0	0	5	0	0	2	0
Messages	Low Low	18	1	0	0	1	0	0	1	0	0	0	0	1
	Low High	0	0	1	0	6	0	0	1	0	0	0	0	0
	High Low	0	0	0	0	2	0	0	0	5	1	1	0	0
	High High	0	0	0	0	0	0	0	0	0	0	0	1	15