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Abstract

Language is an imperfect and coarse means of communicating information about a complex and nuanced world. We report on an experiment designed to capture this feature of communication. 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. Here 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 emerges 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. We find that the sender's payoffs relative to equilibrium payoffs are decreasing in the cost of communication. We also find that the receiver's payoffs relative to equilibrium payoffs are increasing in the cost of communication. Finally, we find imperfections in coordination on the basis of the experimental labels.

JEL: C72, C91, D82

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

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1 Introduction

The properties of words are very different from the properties 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 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 report on an experiment designed to capture this feature of communication. In our experiment, the language available to the sender imperfectly describes the state of the world. By this, we mean that the sender cannot fully and costlessly communicate. However the sender can improve communication, at a cost, by increasing the complexity or elaborateness of the message.

By way of example, suppose that your advisee has been invited to present at a conference. Your preferences and the preferences of your advisee are identical with regards to her performance at the conference: to sound competent, to receive helpful comments, etc. In order to facilitate this success, you wish to provide her 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, how 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 relevant information. 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 (2012) provide a theoretical account of such communication by adapting the uniform-quadratic version of Crawford and Sobel (1982) so that messages available to the sender are constrained to be costly and discrete. Although there are many equilibria, the authors employ an out-of-equilibrium condition which identifies the equilibria with the largest possible number of transmitted messages, which we refer to as *most informative*. 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 emerge in equilibrium.

We design an experiment in order to investigate communication in the Hertel and Smith setting. The questions are then, how does the most informative equilibrium identified by Hertel and Smith (2012) perform in the laboratory, and, as predicted by Hertel and Smith (2012), does the size of the language emerge as a function of the communication costs.

In this experiment, the subjects are anonymously divided into pairs, one as a *sender* and one as a *receiver*. 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. In our experiment, messages imperfectly describe to the underlying state space. Specifically, due to the constraints of the message space, the sender is not able to fully and costlessly communicate. However, the sender is able to transmit more information by constructing an elaborate, but costly, message.

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." These message elements would seem to provide a natural ordering given our state space. 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 emerges endogenously as a function of the costs of communication. On the other hand, 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 over-communicating. Previous experimental communication papers have found that senders often

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

communicate more information than that which is in their best interest. In our setting, this would imply that the senders are not sufficiently affected by the communication costs. One way in which overcommunication could be detected would be the observation of a suboptimal relationship between changes in communication costs and changes in behavior. We find that the sender's payoffs relative to the equilibrium payoffs are decreasing in the cost of communication. However, we find that the receiver's payoffs relative to the equilibrium payoffs are increasing in the cost of communication. Finally, we find imperfections in coordination on the basis of the labels within our setting. In particular, we find that subjects are better able to coordinate on some states than others, despite that there does not exist an a priori reason to expect such differences.

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 the odd integers 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. 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) the set of costless messages is larger than the state space. By contrast, this is not the case in our paper.

Experimental studies of cheap talk communication find that the senders often overcommu-

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[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.

nicate.[3] Specifically, these studies find that in a cheap talk setting where senders and receives do not have aligned preferences, the senders often communicate more information than that which is in their best interest. Also, there is a literature which finds that subjects can have an aversion to lying.[4] Again, these findings can be interpreted as overcommunication by the senders. 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 obvious differences, we can apply the general principle of overcommunication to our setting. Are senders communicating more information than that which is in their best interest? In our experiment, senders can communicate an excessive amount of information by not sufficiently responding to the costs of communication. Although our environment is quite different from those found in the literature, we also find that the senders overcommunicate. In our setting, while the senders are sensitive to the costs of communication, they are not sufficiently sensitive. Given that we observe similar behavior in such different settings, we argue that overcommunication is a robust experimental phenomenon.

3 Equilibrium Predictions

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 message without an element (Empty message) costs $c(m) = 0$, a message with a single element costs $c(m) = c$, a message with two elements costs costs $c(m) = 2c$. 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, the payoff to the receiver is the nonnegative integer closest to:

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

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[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).

The payoff to the sender is the integer closest to:

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

Hertel and Smith (2012) characterize the equilibria.[5] The authors show that in any equilibrium, messages are sent on adjacent states and the empty message must be sent on at least one state. As mentioned previously, there are many equilibria in our setup. We now discuss the most informative equilibria.

For $c \in [0, 12.5]$ then any fully revealing equilibria will exist. In other words, each of the 7 messages are transmitted on one of the 7 states. Further, each permutation of messages and states can form an equilibrium. For $c \in (12.5, 25]$ then fully revealing equilibria will still exist, however it cannot be that messages on adjacent states have a difference in communication costs of $2c$. In each 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 the sender in each equilibria is $EU^S = EU^R - \frac{10}{7}c$.

For $c \in [25, 94]$, the messages "High" and "Low" are each sent on 2 adjacent states and the empty message is sent on 3 adjacent states. We also note that the messages with two elements are not used. 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 $EU^S = EU^R - \frac{4}{7}c$.

For $c \in [94, 100]$, the messages "High" and "Low" are each sent on the extreme states, 3 and -3. Here the messages with two elements are not used. 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 slightly lower

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[5] See Hertel and Smith (2012) 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.

payoff.

For $c > 100$, the only equilibria is one in which the sender exclusively sends the empty message for all states. 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 undergraduate or 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" costs $c(m) = 0$, 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 receiver's payoffs minus $c(m)$. The sender and receiver were each given 30 seconds in which to make a decision. In order to facilitate their understanding of the setting, the subjects were given a table indicating the payoffs associated with each state and action selected by the receiver.[6] The subjects were given a $5 show up fee and $1 for every 300 points accumulated.[7]

Sender and receiver were matched and played the game for 15 periods where c was held fixed. A complete history within each match was available to both sender and receiver. See Appendix A for the screen shot of both the sender and the receiver. After the 15 periods,

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[6] This table is provided in Appendix A.

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

each subject was rematched with a different opponent, each switched their role (sender or receiver), and played with a new value of c. Each session consisted of 4 rounds of 15 periods. The subjects were made aware of these matching procedures. Each subject experienced only one of two sequences of communication costs. One sequence was ordered 10-50-30-96 and the other was ordered 96-30-50-10. We ran two sessions which consisted of 8 subjects and two sessions of 16 subjects. Therefore, we have a total of 1440 data points for both senders and receivers.

A few comments on our experimental design 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, the payoffs of both sender and receiver were displayed to both players in each period. In this way, the sender might act less generously if the receiver and sender outcomes are sufficiently inequitable. 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.

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. For these reasons, despite our fixed matching protocol, we also do not expect repeated game effects to be present. However, we expect the fixed matching to yield better coordination outcomes.

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 negative payoffs for the receiver. Although this would affect the babbling equilibrium, we did not expect that we would observe this behavior in the laboratory. We also note that only a small fraction of outcomes would be affected by the choice to constrain the receiver's payoffs to be greater than or equal to 0. Only 14.75% (59 of 384) of actions in periods 1-4 and 8.36% (92 of 1056) in periods 5-15 would have produced a negative receiver payoff, had we not censored the receiver's payoffs at 0.

There are interesting questions related to the differences in the meaning of the messages within a match and whether these change across matches.[8] However, our experimental setup is not designed to investigate these issues. First, within each match, a particular state only occurs a few times. Further, each subject only plays the game with a particular communication cost during a single round. As a result, our experimental setup does not facilitate the investigation of these interesting questions.

Finally, we selected the communication costs in order observe behavior possibly ranging from full communication to virtually no communication. For a number of reasons we selected both $c = 30$ and 50, despite that their equilibrium predictions are identical. First, we did not want only a single value between the highest and lowest communication costs. Second, although the equilibrium predictions are identical, it was not clear that behavior would be identical. Additionally, we wanted to use 4 values of communication costs, in order to balance the experiment such that each subject played as sender with two communication costs and as receiver with two communication costs.

5 Results

5.1 Overview of Data

First, we investigate whether the order of the sequences of communication costs affect the earnings of the sender. We perform a regression with sender payoffs as the dependent variable. To account for the fact that not every match observes the same sequence of states, the independent variables include the cost of communication, a dummy indicating one of the two sequence orders, the communication cost-order interaction, and dummy variables accounting for the state.[9] We find that neither the order dummy ($p = 0.81$) nor the communication cost-order interaction ($p = 0.54$) are significant. As a result, we do not find evidence that the order of the communication costs affect the behavior of the senders.

We also investigate whether there is learning across the 15 periods within each round.

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[8] For instance, Weber and Camerer (2003).

[9] These results are available from the corresponding author upon request.

Across all rounds, the relationship between the sender's payoffs and the period in which it was obtained is significant ($p = 0.01$).[10] However, within periods 5-15, the relationship is not significant ($p = 0.7$). Therefore, for the bulk of the analysis, within each round we exclude from consideration the data obtained in periods 1-4.

Finally, we provide a summary of the raw data in Appendix B. In particular, there we provide the distribution of the sender's messages for each state and each of the four possible communication costs. We also provide the distribution of receiver's actions for each of the messages and each of the four possible communication costs.

5.2 Size of the Language Used

We 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? The raw data provided in Appendix B suggest that expensive signals are conserved. However, to address whether this impression is correct, we run logistic regressions with three different measures of the size of the language. In the first specification, the dependent variable is a dummy indicating whether the message had one or two elements. We assign a value of 1 in the event that the message had either one or two elements, and 0 otherwise. We refer to this regression as "One or Two." In the second specification, the dependent variable is a dummy indicating whether the message had two elements. We refer to this regression as "Two." 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 would be appropriate for all states. We accomplish this by including dummy variables indicating the state. Further, for all regressions

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[10] Here, as we do in the following sentence, we report the p-value of the period coefficient in an OLS regression with the sender's payoffs as the dependent variable and the period as the independent variable.

below, we account for the subject-specific fixed-effects. Note that in the regressions below, the communication costs enter linearly rather than as a categorical variable. Communication costs enter linearly into the sender's payoffs and therefore this would seem to be the most natural specification. We summarize the analysis below in Table 1.

Table 1-Size of Language and Communication Costs

	One or Two	Two	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^{**}

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 and has 1056 observations from 24 senders in 4 rounds of 11 periods. We do not list the estimations of intercepts.

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 lower likelihood of sending a message with one or two elements. We see the analogous result in the second specification: there is a negative relationship between communication costs and the transmission of a message with two elements. 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. Note that this result, and the similar results which follow, are surprising because the equilibrium predictions of the $c = 30$ and 50 treatments are identical.[11]

As a robustness check, we perform a similar analysis, but include the average payoffs entering the period, within the current match. We summarize the analysis below in Table 2.

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[11] Despite these equilibrium predictions, the previous analysis when restricted to $c = 30$ or 50, shows that communication costs are significantly related to the size of the language. These results are available from the corresponding author upon request.

Table 2-Size of Language and History in Match

	One or Two	Two	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^{**}

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 do not list the estimates of the intercepts and each regression has 1056 observations from 24 senders in 4 rounds of 11 periods.

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 higher average payoffs are associated with transmission of more expensive messages, in each of the three specifications. 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 lower 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.

5.3 Payoffs Relative to Equilibrium Payoffs

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.

We perform a test of the differences between the equilibrium payoffs and the actual payoffs within each communication cost treatment. Within each treatment, we find 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 analysis is summarized in Table 3.

Table 3-Equilibrium Payoffs and Actual Payoffs

	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

Results of paired t-tests each with 263 degrees of freedom, where ** indicates significance of a two-sided test at $p < 0.01$. Each cell is associated with 264 observations from 24 subjects across 11 periods.

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 3 suggests that as communication costs increase, the receivers are doing better relative to their equilibrium payoffs and yet the senders are doing worse relative to their equilibrium payoffs. In particular, Table 3 seems to suggest that the difference between the sender's actual and equilibrium payoffs is increasing in the cost of communication. Further, the difference between the receiver's actual and equilibrium payoffs are decreasing in the cost of communication. This is consistent with the contention that the senders are overcommunicating and the receivers are benefiting from this overcommunication. We perform the following analysis in order to more carefully test this speculation.

In regressions $(S1) - (S4)$ of Table 4, the dependent variable is the sender's actual payoffs minus the sender's equilibrium payoffs. In regressions $(R1) - (R4)$ of Table 5, 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.

Again note that in the regressions below, the communication costs enter linearly rather than as a categorical variable. This is because the sender's payoffs are linear in the cost of communication and the receiver is aware of this linear relationship. Further, we account for a possible nonlinear relationship between communication costs and behavior by subtracting the equilibrium payoffs from the actual payoffs. We summarize this analysis in Tables 4 and 5.

Table 4-Sender's Payoffs Minus Equilibrium Payoffs

	($S1$)	($S2$)	($S3$)	($S4$)
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 Dummies	No	No	Yes	Yes
R^2	0.04	0.23	0.21	0.40

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 $p < 0.05$. Each regression has 1056 observations from 24 senders in 4 rounds of 11 periods.

Table 5-Receiver's Payoffs Minus Equilibrium Payoffs

	($R1$)	($R2$)	($R3$)	($R4$)
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 Dummies	No	No	Yes	Yes
R^2	0.03	0.21	0.09	0.26

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 $p < 0.05$. Each regression has 1056 observations from 24 receivers in 4 rounds of 11 periods.

First, note that in Table 4, 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 5 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.

In our view, the results of Table 4 are not consistent with an equilibrium selection explanation. Most notably, if $c > 10$ then there does not exist an equilibrium where a message with two elements is sent. However, we often see senders transmitting such messages despite their high cost.[12] It is this overcommunication which appears to be driving the results above.

The results summarized in Tables 4 and 5 provide evidence that the senders are overcommunicating. In other words, the senders are not sufficiently conserving expensive messages and as a result, there is a negative relationship between communication costs and sender payoffs relative to equilibrium payoffs.

5.4 Another Look at Overcommunication

The questions are then, how robust is the finding that senders are overcommunicating, and is the positive relationship between communication costs and receiver payoffs relative to equilibrium 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.[13] 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:

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

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[12] See Appendix B.

[13] Note that we are not performing a quantal response equilibrium analysis (McKelvey and Palfrey, 1998). Quantal response equilibrium seems to not be appropriate since we find evidence that the senders are becoming less strategic as communication costs increase, and there is evidence of the opposite for receivers. Quantal response equilibrim would not be able to provide evidence regarding this.

In expression (3), the term $\overline{u_{m'}}(s;c)$ is the observed expected sender payoffs 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', in all matches. Note that better decisions on the part of the senders are associated with larger λ_c^S.

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 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, in all matches. Note that better decisions on the part of the receivers are associated with larger λ_c^R. In Table 6 below, we present a summary of our estimates.

Also note that we estimate a single λ for each condition, rather than an estimate for each subject within each condition. The latter would require a calculation of expected payoffs for each subject, however these would be poorly defined due to empty cells. For instance, consider the calculation of the expected value of sending a message m given state s. If the particular subject never sent message m, then it is not possible to calculate the expected payoff for sending message m. It is for this reason that these estimates are across all subjects.

Table 6-Multinomial Choice 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)

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 from 24 players in 11 periods.

Table 6 presents evidence that the quality of the best responses to the distribution of the play of the opponents is negatively related to the communication costs. The sender estimates in Table 6 corroborate the evidence found in Table 4, namely that the senders are making worse decisions as communication becomes costly. On the other hand, the receiver estimates in Table 6 suggest that the positive relationship between receiver payoffs relative to equilibrium payoffs and communication costs is not due to better decision making, but rather that the receivers are benefiting from the overcommunication of the senders.

5.5 Coordination Imperfections and Labels

Finally, we investigate the relationship between coordination and the experimental labels. One might expect that the ability to coordinate would not depend on the labels of the states. Here we investigate whether there is evidence that the labels are related to the coordination outcomes.

In the analysis which follows, we use a coordination dummy variable as the dependent variable.[14] This coordination dummy will attain a value of 1 if the sender and receiver coordinated according to a minimum precision. For instance, we first investigate the coordination outcomes when $c = 10$. In this case, we would expect that subjects would fully coordinate. Therefore we consider the coordination thresholds of $U^R = 100$ (perfect coordination) and $U^R \geq 94$ (where the action is within 0.5 of the state).

Since the state is an unordered categorical variable, and it is the primary focus of the remaining analysis, we present the Wald χ^2 statistic of each variable in the tables below. In the analysis below, we include a repeated dummy variable, where a 1 indicates that the state has been repeated within the match, and a 0 otherwise. We also include the Number of Elements variable. Note that for the remaining analysis, we include the data from all periods because we are interested in all data in which subjects attained a minimum coordination. The analysis for $c = 10$ is summarized in Tables 7 and 8.

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[14] We provide a summary of these coordination outcomes in Appendix C.

Table 7-Coordination of $U^R = 100$ where $c = 10$

	(1)	(2)	(3)	(4)
State	44.92**	47.43**	44.74**	50.65**
Repeated	–	10.15**	10.15**	8.44**
State-Repeated Interaction	–	–	1.16	1.56
Number of Elements	–	–	–	8.97**
-2 log L	442.360	431.90	430.71	421.37
LR χ^2	44.92**	51.14**	49.78**	55.59**

Results of logistic regressions where subjects coordinated on an outcome of $U^R = 100$ for $c = 10$ where ** indicates significance at $p < 0.01$. Each regression has 360 observations, from 24 subjects in 15 periods. The Wald χ^2 statistics are listed listed.

Table 8-Coordination of $U^R \geq 94$ where $c = 10$

	(1)	(2)	(3)	(4)
State	36.72**	39.74**	36.36**	41.34**
Repeated	–	9.62**	9.22**	7.81**
State-Repeated Interaction	–	–	3.48	3.76
Number of Elements	–	–	–	8.76**
-2 log L	412.65	402.785	399.04	389.93
LR χ^2	36.72**	43.194**	41.22**	46.88**

Results of logistic regressions where subjects coordinated on an outcome of $U^R \geq 94$ for $c = 10$ where ** indicates significance at $p < 0.01$. Each regression has 360 observations, from 24 subjects in 15 periods. The Wald χ^2 statistics are listed listed.

The results of Tables 7 and 8 suggest, despite that full communication is predicted on all states, the ability of subjects to coordinate is affected by the state. Also the results of Tables 7 and 8 provide evidence that the repeated variable is significantly related to coordination. In particular, there is evidence that subjects are better able to coordinate if the state has already occurred in the match. Perhaps surprisingly, there is not a significant relationship between coordination and the interaction variable. Finally, we note that the number of elements variable is significant. That is, despite that we expect to observe coordination on each state, the number of elements in the message sent is related to coordination.

The analysis summarized in Tables 7 and 8 suggests that subjects are affected the labels of the states and the messages for the case of $c = 10$. We now perform a similar analysis for the case of $c = 30$ and 50. In each state, the equilibrium behavior would imply that the receiver would obtain a payoff of at least $U^R = 75$. Therefore, we set the coordination threshold to be $U^R \geq 75$ (where the action is within 1 of the state).

Table 9-Coordination of $U^R \geq 75$ where $c = 30$ and 50

	(1)	(2)	(3)	(4)
State	16.14*	16.01*	17.89**	17.80**
Repeated	–	13.89**	12.96**	13.03**
State-Repeated Interaction	–	–	14.26*	13.78*
Number of Elements	–	–	–	$3.42^{\dagger}$
-2 log L	614.83	600.70	583.59	580.17
LR χ^2	16.14*	29.14**	34.85**	38.14**

Results of logistic regressions where subjects coordinated on an outcome of $U^R \geq 75$ for $c = 30$ and 50, where ** indicates significance at $p < 0.01$, * indicates significance at $p < 0.05$, and † indicates significance at $p < 0.1$. Each regression has 720 observations, from 24 subjects across 2 rounds of 15 periods. The Wald χ^2 statistics are listed listed.

As in the analysis summarized in Tables 7 and 8, we again observe that the state is related to the ability to coordinate. Further, we again see that the repeated variable is significant. However, unlike the results found in Table 7 and 8, we find that the interaction term is significant. In particular, it seems that the effect on coordination of having a state within a match can vary among the states. In summary, the analysis summarized in Tables 7-9 suggests that the relationship between the experimental labels and success at coordination is robust across different experimental treatments.

6 Conclusions

We report on 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 (2012) do not perform particularly well, our experimental results do corroborate some of the qualitative predictions. In particular, we find that the size of the language emerges 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, the sender's payoffs relative to equilibrium payoffs are decreasing in the cost of communication. The receivers benefit from this overcommunication, as we observe that their payoffs relative to equilibrium payoffs are increasing in the cost of communication. This conclusion is also supported by a discrete choice multinomial analysis which finds evidence that the quality of the receiver's best responses are decreasing in the cost of communication.

We also observe coordination imperfections on the basis of the labels of the states and messages. In particular, subjects in the treatment where full communication is predicted, are affected by the state on which coordination is sought. Further, we find a similar result for the case of intermediate communication costs. To summarize, we find evidence that the experimental labels of states and messages affect the ability of subjects to coordinate.

Although to our knowledge, we are the first paper to examine the experimental implications of costly and discrete communication, our results could also be of interest to experimental cheap talk researchers. Sobel (2012) notes that models of costly communication with aligned preferences can have parallel results to models of costless communication where preferences are not aligned (or cheap talk models). As a basic prediction of the models, Sobel notes that increases in communication costs will decrease the quality of communication in a fashion similar to that in response to increases in the difference of the preferences of sender and receiver in the cheap talk models. This is precisely what is found in the laboratory. Previous studies of experimental cheap talk have found that diverging preferences will lead to lower quality communication. We find the analogous effect for increases in communication costs.

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 (2012) 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 the theoretical and experimental issues related to costly and discrete communication.

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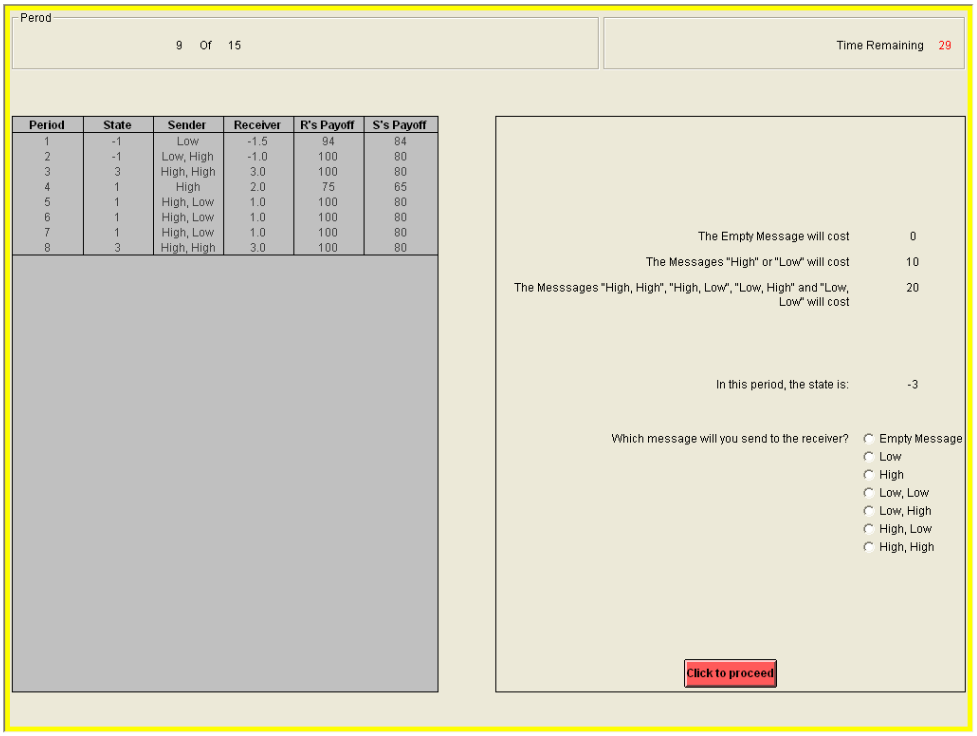
Appendix A

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

		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
State	**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



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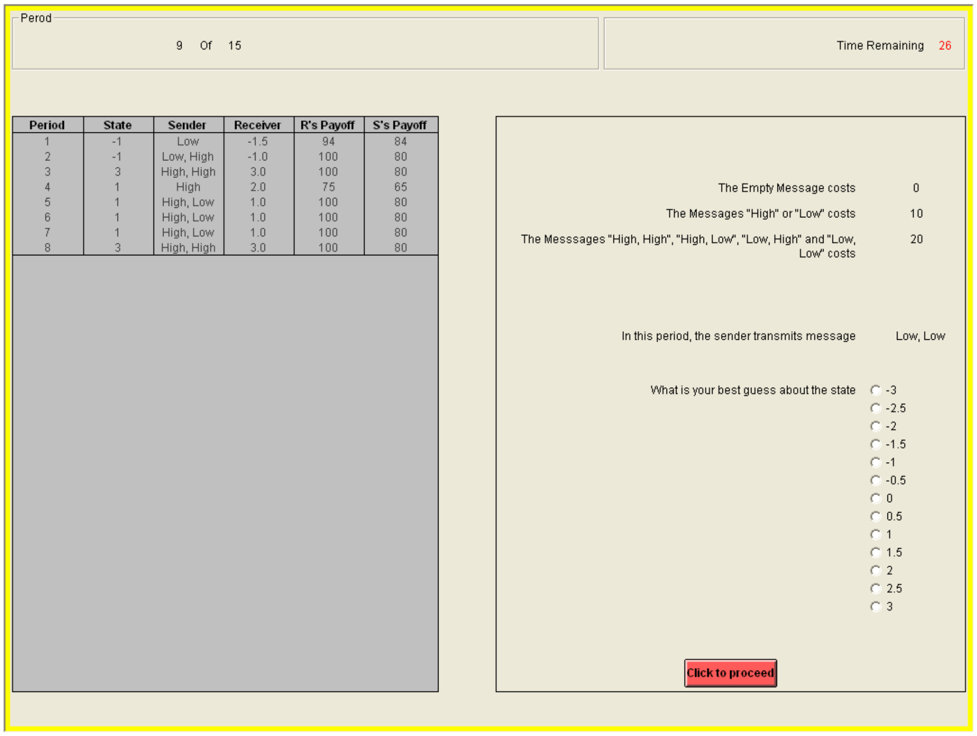
Time Remaining 29

Period	State	Sender	Receiver	R's Payoff	S's Payoff
1	-1	Low	-1.5	94	84
2	-1	Low, High	-1.0	100	80
3	3	High, High	3.0	100	80
4	1	High	2.0	75	65
5	1	High, Low	1.0	100	80
6	1	High, Low	1.0	100	80
7	1	High, Low	1.0	100	80
8	3	High, High	3.0	100	80

The Empty Message will cost	0
The Messages "High" or "Low" will cost	10
The Messsages "High, High", "High, Low", "Low, High" and "Low, Low" will cost	20
In this period, the state is:	-3

Which message will you send to the receiver?
○ Empty Message
○ Low
○ High
○ Low, Low
○ Low, High
○ High, Low
○ High, High

Sender's Screen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Time Remaining 26

Period	State	Sender	Receiver	R's Payoff	S's Payoff
1	-1	Low	-1.5	94	84
2	-1	Low, High	-1.0	100	80
3	3	High, High	3.0	100	80
4	1	High	2.0	75	65
5	1	High, Low	1.0	100	80
6	1	High, Low	1.0	100	80
7	1	High, Low	1.0	100	80
8	3	High, High	3.0	100	80

The Empty Message costs 0

The Messages "High" or "Low" costs 10

The Messsages "High, High", "High, Low", "Low, High" and "Low, Low" costs 20

In this period, the sender transmits message Low, Low

What is your best guess about the state
○ -3
○ -2.5
○ -2
○ -1.5
○ -1
○ -0.5
○ 0
○ 0.5
○ 1
○ 1.5
○ 2
○ 2.5
○ 3

Receiver's Screen

Appendix B

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

$c = 10$		Messages						
		E	H	L	L L	L H	H L	H H
States	-3	1	1	1	31	3	2	0
	-2	1	1	21	4	19	1	0
	-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						
		E	H	L	L L	L H	H L	H H
States	-3	0	1	5	26	0	1	0
	-2	0	0	27	5	5	3	0
	-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						
		E	H	L	L L	L H	H L	H H
States	-3	2	0	23	14	0	0	2
	-2	1	1	32	0	3	0	0
	-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						
		E	H	L	L L	L H	H L	H H
States	-3	4	2	20	18	1	1	0
	-2	8	0	12	1	2	2	0
	-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 the communication costs

$c = 10$		Action												
		-3	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5	3
	E	0	0	0	0	0	0	36	1	0	0	0	0	0
	H	0	0	0	0	0	0	0	0	1	2	22	7	2
	L	3	2	19	11	6	3	1	1	6	1	0	0	0
Messages	L L	30	2	0	0	2	0	0	1	1	0	0	0	0
	L H	3	3	14	4	10	1	1	0	6	3	0	1	0
	H L	0	0	3	0	2	0	0	0	15	7	6	0	0
	H H	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
	E	0	0	0	0	0	2	49	0	0	0	0	0	0
	H	0	0	0	0	0	0	1	0	3	8	22	17	3
	L	2	6	20	9	6	0	1	0	2	0	1	0	0
Messages	L L	28	0	1	0	0	0	1	0	1	0	0	0	0
	L H	0	0	4	1	11	1	1	0	5	0	2	0	0
	H L	0	0	4	1	2	0	2	0	9	4	7	0	0
	H H	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
	E	0	1	2	0	1	2	59	5	4	1	1	0	0
	H	1	0	1	0	0	0	0	0	6	3	15	15	8
	L	6	12	16	18	20	2	2	0	3	3	0	0	0
Messages	L L	14	1	0	0	2	0	0	0	0	0	0	0	0
	L H	0	0	2	0	6	0	0	2	2	1	0	0	0
	H L	0	0	0	0	0	1	0	0	2	2	7	1	0
	H H	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
	E	3	4	1	7	4	4	58	8	8	6	4	1	2
	H	0	1	1	0	0	0	1	1	3	2	17	9	16
	L	11	6	12	3	8	1	0	0	5	0	0	2	0
Messages	L L	18	1	0	0	1	0	0	1	0	0	0	0	1
	L H	0	0	1	0	6	0	0	1	0	0	0	0	0
	H L	0	0	0	0	2	0	0	0	5	1	1	0	0
	H H	0	0	0	0	0	0	0	0	0	0	0	1	15

Appendix C

A summary of the coordination outcomes. Note that Periods 1-15 are included in the tables below.

$c = 10$		Messages								
		E	H	L	L L	L H	H L	H H	$U^R = 100$	Total
	-3	0	0	0	31	2	0	0	33	50
	-2	0	0	13	0	12	1	0	26	59
States	-1	0	0	3	0	10	3	0	16	44
	0	44	0	0	0	0	0	0	44	51
	1	0	0	4	0	1	18	0	23	66
	2	0	16	0	0	0	3	0	19	45
	3	0	3	0	0	0	0	30	33	45

$c = 10$		Messages								
		E	H	L	L L	L H	H L	H H	$U^R \geq 94$	Total
	-3	0	0	0	33	2	0	0	35	50
	-2	0	0	22	1	15	1	0	39	59
States	-1	0	0	6	0	13	3	0	22	44
	0	45	0	0	0	0	0	0	45	51
	1	0	2	4	0	3	20	0	29	66
	2	0	22	0	0	1	8	2	33	45
	3	0	7	0	0	0	0	32	39	45

$c = 30$		Messages								
		E	H	L	L L	L H	H L	H H	$U^R \geq 75$	Total
	-3	0	0	7	33	0	1	0	41	49
	-2	0	0	33	5	6	3	0	47	56
States	-1	8	1	10	0	13	2	0	34	40
	0	39	0	0	0	1	1	0	41	48
	1	16	8	2	0	5	11	0	42	53
	2	0	37	0	0	3	13	0	53	57
	3	0	15	0	0	0	0	37	52	57

$c = 50$		Messages								
		E	H	L	L L	L H	H L	H H	$U^R \geq 75$	Total
	-3	0	0	20	16	0	0	2	38	50
	-2	0	1	40	0	1	0	0	45	56
States	-1	17	0	19	0	7	0	0	43	56
	0	51	0	3	0	0	0	0	54	60
	1	22	2	3	0	0	4	0	31	55
	2	1	39	0	0	3	10	0	53	58
	3	0	16	0	0	0	0	15	31	36