Fragile Meaning - An Experiment*

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Abstract

Absence of a shared language is an evident barrier to effective communication. The impact of lack of common knowledge of a shared language is potentially more insidious. We induce lack of common knowledge of a shared language in a sender-receiver game experiment by having message availability be uncertain. We consider an environment in which agents agree on the optimal action in every state, there are equilibria in which messages with pre-specified meanings are used in accordance with those meanings, and these equilibria maximize both sender and receiver payoffs. We do find, however, that these equilibria are fragile. Observed behavior is more consistent with pooling equilibria, in which receivers ignore messages. This effect is stronger when the pooling action is optimal for a larger set of receiver beliefs.

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1 Introduction

Absence of a shared language is an evident barrier to effective communication. The impact of lack of common knowledge of a shared language is less obvious, less likely to leave observable traces in field data, and potentially more insidious. The paper investigates, with a laboratory experiment, whether it can also be a threat to successful communication. We study this problem in a sender-receiver game in which incentives are strongly aligned: sender and receiver agree on the optimal action in every state of the world. We induce lack of common knowledge of a shared language by varying the messages available to senders and making message availability the senders' private information.

Farrell [15] proposes giving language a role in communication games by taking it as given that message meaning is understood and suggests a credibility test for messages relative to an equilibrium candidate. Rabin [26] defines credibility independent of an equilibrium. Stalnaker [30], using one of Rabin's examples, discusses how "ignorance or error about credibility" may arise, even when sender and receiver have the same preferred action in every state of the world: A sender message that identifies a state of the world s may fail to be credible when there is doubt about the credibility of a message referring to another state of the world, s'. A sender who is unable to credibly signal state s' may want to pretend that the state is s, as a second-best option. This, in turn, undermines the credibility of the message that is meant to identify state s. This failure of credibility is contagious and, in the example, threatens to undermine the ability to communicate either state of the world.

In the absence of uncertainty about message availability, the incentive structure in our experiment is that of Rabin's example, adapted to a larger set of states.[1] We induce credibility concerns, by making message availability uncertain. We say that a message has a *focal meaning* if it has a pre-specified meaning that refers to one of the payoff states of the game. Senders without access to messages whose focal meanings match the payoff state then may have an incentive use substitute messages with alternative focal meanings. As in Stalnaker's illustration, this possibility of substitution may undermine the focal meanings of messages. Our central hypothesis is that when play has converged, receivers will take the pooling action, the action that is optimal given prior beliefs, regardless of the message they receive. We refer to this non-reliance on focal meanings as *fragility of meaning*. The experimental results mostly support our central hypothesis. The support is stronger in games where the pooling action is optimal for a larger set of receiver beliefs.

In many important economic interactions, language barriers can introduce frictions in the ability to communicate. This is typical for communication between experts, who use technical language, and non-experts. Doctor-patient communication, for example, is known to suffer from gaps between medical and everyday language. Doctors frequently fail to recognize patients' attempts to switch to medical language, and doctors and patients have substantively different interpretations of widely used psychological terms, such as "depression, migraine, and eating disorder" (Ong, de Haes, Hoos and Lammes [25]). Williams, Davis, Parker, and Weiss [33] document the limited "health literacy" of patients. They cite one study of hospital patients, in which only 35% understood the word "orally," 22% "nerve", 18% "malignant," and 13% "terminal". According to Williams et al., such deficiencies in health literacy have a dramatic impact on health care costs.

[1] We modify payoffs slightly to mitigate social preference confounds.

Indeed, there is a wealth of evidence across a broad range of domains about how language barriers inhibit and shape communication. Tushman [31] studies communication patterns in R&D settings and observes that "oral communication is effective only where a shared coding scheme or language exists, or where the actors are sufficiently alike in background or perspective that they can rapidly develop a common language." Zenger and Lawrence [34] find that age and tenure distributions within a firm affect communication patterns. Bechky [2] documents misunderstandings due to differing occupational codes in manufacturing. Galison [17] describes how scientific disciplines create *trading zones* to mediate communication across subcultures within the disciplines. While specialized "organizational codes" (Arrow [1]) facilitate communication within organizations, they may create barriers to communication with the outside world. "Language compatibility" (March and Simon [24]) has an impact on which communication channels are activated. If different areas within an organization have their own specialized codes, this segmentation can affect the patterns of communication, and thereby the overall performance of the organization.

Plainly, absence of a shared language adversely impacts communication. It is less clear, and more difficult to document in the field, whether communication might already be vulnerable to differences in knowledge and beliefs about whether there is a shared language. Can communication fail in situations where there is a shared language, but this fact is not commonly known? While field data about internal states, including agents' knowledge, are not readily available, differences in knowledge are easily induced in the laboratory. With that in mind, we create a scenario in the laboratory, in which theory predicts communication failure due to the absence of common knowledge of a shared language, even when such a shared language does exist.

Our intent is to exhibit a potential vulnerability of communication as starkly as possible. Toward this end, we deliberately minimize some of the countervailing factors that might help sustain effective communication. This is not to deny the importance of learning, alternative communication protocols, psychological salience of messages, and other factors that might enhance communication. We believe, however, that the role of these mitigating forces can be better understood against a clear benchmark.

We study a sender-receiver game in which the sender has private information of two kinds. The sender knows the *payoff state,* which together with the receiver's action determines both players' payoffs. In addition, the sender knows the *language state*, which corresponds to the set of messages available to her. Messages are of two sorts, *focal messages*, a, b, $\ldots$, which are evocative of the payoff states, A, B, $\ldots$, and *neutral messages*, $*$, $\&$, $\ldots$, which bear no obvious resemblance to the payoff state. For some realizations of the language state, the sender lacks the focal message, e.g. message b, that matches the realized payoff state, here B. In that case, we say that sender and receiver lack a shared language. Importantly, whether or not there is lack of a shared language is the sender's private information. Both a lack of a shared language, and it being private information, constitute *language barriers.*

Conditional on the payoff state, sender and receiver agree on the optimal action. Thus, in the absence of language barriers, there is no conflict between incentives and efficiency. The payoff structure, however, also has the following feature. With lack of a shared language, if receivers' interpretations of focal messages are consistent with their focal meanings, i.e., they take the action appropriate for payoff state B in response to message b etc., and neutral messages remain meaningless, then senders have an incentive to substitute available focal messages for unavailable focal messages. Since message availability is private information, the receiver has reason to suspect message substitution for every focal message he receives. This rules out equilibria in which receivers interpret focal messages in a manner that is consistent with their focal meanings and interpret neutral messages as meaningless. As a result, language barriers undermine plausible ways of achieving efficiency. We implement this environment in the laboratory. Our working hypothesis is that with enough experience, when play has settled down, the predominant receiver action will be the pooling action, and the resulting outcome will be inefficient.

There are equilibria in which the interpretations of focal messages are consistent with their focal meanings. These *focal equilibria* maximize both sender and receiver payoffs among all equilibria. They yield substantially higher payoffs than pooling equilibria. Focal equilibria do, however, require that neutral messages become meaningful. The difficulty of endogenously assigning meanings to neutral messages renders these equilibria, and with them focal message meanings, fragile.

Thus, the mere possibility of an absence of a shared language can lead to incentive problems that reduce efficiency, where there would be no inefficiencies if it were common knowledge that were are no such barriers. In the seminal work of Crawford and Sobel [13], efficiency losses arise because expert and decision maker disagree about the optimal action in each state of the world and therefore the expert has an incentive to misrepresent the state. In our experiment, it is only through language barriers that incentive problems emerge.

In this paper we report an experiment with the incentive structure just described. The main experiment consists of two conditions. One of these, the *Treatment* condition, has language barriers, and the other condition *Control*, has no such barriers. As indicated previously, the intent of our design is to highlight a potential problem that may afflict communication. For that reason, the design to a large degree minimizes countervailing factors that might favor efficient communication: the chosen sets of possible messages rule out intuitive coordination strategies and the set of receiver beliefs for which the pooling action is optimal is large. At the same time, our design does not rule out that factors favoring effective communication might have an impact. If senders view sending focal messages that do not match the payoff state as lying and are sufficiently strongly lying averse, focal message use is an equilibrium even if neutral messages do not acquire meaning. The same holds if senders have strong social preferences. Finally, since subjects interact repeatedly, there is the possibility of shared meanings emerging endogenously for *a priori* meaningless messages.[2] To provide a setting in which such effects might more easily emerge, we also study simpler treatments, with fewer payoff states, to see whether these countervailing factors can overcome the tendency to pool. These simpler settings are called the *3-payoff-state* and *2-payoff-state* conditions.

Our results for the relatively complex *Treatment* condition, with six payoff states, show that when play has settled down, pooling is the most frequent receiver response following a focal message. This is in sharp contrast to our *Control* condition, which differs from the *Treatment* condition only in that it is public knowledge that all focal messages are always available. In the *Control* condition, receivers's interpretations of focal messages overwhelmingly are consistent with their focal meanings, while in the *Treatment* condition,

[2] We have subjects interact for as many rounds as have been found sufficient for the emergence of meaning in simple common-interest, sender-receiver games (Blume et al. (1998, 2001), Bruner et al. (2014).)

meaning is fragile – receivers tend to ignore focal message meanings.

Terminal behavior in our simpler *3-payoff-state* condition is comparable to that in the more complex *Treatment* condition. Here also, receivers predominantly fail to interpret focal messages in accordance with their focal meaning. In the least complex condition, *2-payoff-state*, pooling is no longer the most frequent response to focal messages. This is consistent with the fact that in the *2-payoff-state* condition, the set of receiver beliefs that rationalize pooling is dramatically smaller (less than half the size) than in the *Treatment* condition. With pooling more difficult to rationalize, there is more scope for other factors, including lying aversion, social preferences, or the emergence of meaning to play a role. Still, even in the *2-payoff-state* condition average receiver payoffs are closer to the pooling payoff than to the efficient payoff that could be achieved in this game.

Overall, uncertainty about whether there is a shared language has a significant effect on the interpretation of focal messages and is detrimental to efficiency. This effect is somewhat mitigated in very simple games, where the incentive structure is less favorable to pooling. That is, countervailing forces appear to have some role, especially in sufficiently simple environments, but they are never entirely decisive. Efficiency is significantly negatively impacted in all three conditions with language uncertainty.

2 Setup and equilibrium predictions

In our experiment, we implement a sender-receiver game with language barriers, the *Treatment* condition, and compare the results with a *Control* condition, in which it is common knowledge that there are no language constraints. In both *Treatment* and *Control* there are six payoff states. We also subject our results to a stress test by examining sender-receiver games with language barriers that have only three and two payoff states, respectively. We refer to these as the *3-payoff-state* and *2-payoff-state* conditions.

2.1 Treatment and Control

The games that we implement in the *Treatment* and *Control* conditions use the payoff table shown in Table 1. Each row corresponds to one of six possible (payoff) states, A, B, C, D, E, and F. Each column represents one of the seven possible actions of the receiver. The actions T, U, V, W, X, and Y, can be thought of as the adoption of one of six possible projects and the action Z as not adopting any project. The actions T, U, V, W, X, and Y are optimal for both parties in states A, B, C, D, E, and F, respectively, yielding a payoff of 10 to both players. The action Z represents choosing not to undertake a project, and results in a sure payoff of 7 to both sender and receiver. If a project that is inappropriate for the current state is undertaken, then the sender receives a relatively attractive payoff of 9, while the receiver gets 0.

The timing of the game is as follows. The *payoff state* is drawn from a uniform distribution over the set $\{A, B, C, D, E, F\}$. The sender privately learns the payoff state (her *payoff type*). In the *Treatment* condition, in addition, the sender privately learns which messages are available to her, the *language state* (her *language type*.) The sender then sends a message to the receiver. Under *Treatment*, the message she sends has to belong to her *language type*. After observing the sender's message the receiver chooses an action. After the choice

	T	U	V	W	X	Y	Z
A	10,10	9,0	9,0	9,0	9,0	9,0	7,7
B	9,0	10,10	9,0	9,0	9,0	9,0	7,7
C	9,0	9,0	10,10	9,0	9,0	9,0	7,7
D	9,0	9,0	9,0	10,10	9,0	9,0	7,7
E	9,0	9,0	9,0	9,0	10,10	9,0	7,7
F	9,0	9,0	9,0	9,0	9,0	10,10	7,7

Table 1: Payoffs in the Treatment and Control Conditions

Note: In the table, the columns indicate the actions available to receiver, and the rows indicate the payoff state. The first entry in each cell is the sender's payoff and the second entry is the receiver's payoff from the receiver's action, given the payoff state.

is made, the receiver learns both the payoff state and the language state and both parties realize their payoff.

The prior probability of each of the six payoff types is $\pi(A) = \pi(B) = \pi(C) = \pi(D) = \pi(E) = \pi(F) = \frac{1}{6}$. Under *Control*, the message space is commonly known to be $\{a, b, c, d, e, f\}$. In the *Treatment* the message space is $M = \{*, \#, \%, @, \hat{}\ , a, b, c, d, e, f\}$. We say that messages a, b, c, d, e and f have *focal meanings* and that messages $*, \#, \%, @$ and $\hat{}$ are *neutral.*[3] In the theoretical analysis it is helpful to make focal meanings of messages explicit, using the following notation: messages $a, b, \ldots$ have focal meanings $[\![a]\!]$=“The state is A,” $[\![b]\!]$=“The state is B”, $\ldots$, respectively. There is no prior specification of the meanings of $*$ and $\#$, which we express via $[\![*]\!] = [\![\#]\!] =?$.[4]

In *Treatment*, in addition to her payoff type, the sender privately learns her language type, the subset of messages available to her. The language type space is $\Lambda = \{\lambda_a, \lambda_b, \lambda_c, \lambda_d, \lambda_e, \lambda_f, \lambda_{abcdef}\}$, where $\lambda_a = \{a, *, \#, \%, @, \hat{}\ \}$, $\lambda_b = \{b, *, \#, \%, @, \hat{}\ \}$, $\lambda_c = \{c, *, \#, \%, @, \hat{}\ \}$, $\lambda_d = \{d, *, \#, \%, @, \hat{}\ \}$, $\lambda_e = \{e, *, \#, \%, @, \hat{}\ \}$, $\lambda_f = \{f, *, \#, \%, @, \hat{}\ \}$ and $\lambda_{abcdef} = \{a, b, c, d, e, f\}$. The language type distribution assigns equal probability to all language types: $q(\lambda_a) = q(\lambda_b) = q(\lambda_c) = q(\lambda_d) = q(\lambda_e) = q(\lambda_f) = q(\lambda_{abcdef}) = \frac{1}{7}$. Language types and payoff types are drawn independently. The sender privately learns her payoff and language type and

[3]This terminology is suggested by the fact the labels of focal messages and of payoff types only differ in that the former are lower case letters and the latter are upper case letters. We do not suggest this focal interpretation of messages to subjects.

[4]In the experiment, instead of guaranteeing that “neutral messages” are *a priori* meaningless by using the randomization scheme of Blume et al. (1998, 2001), we allow for nuisance focal points (unintended associations between states and messages). Such nuisance focal points might facilitate the emergence of meaning. This strengthens our result, if we nevertheless observe that pooling dominates.

sends a message from her language type to the receiver. After seeing the sender's message, the receiver takes one of the actions in the set $\{T, U, V, W, X, Y, Z\}$.

	W	X	Y	Z
A	10,10	9,0	9,0	7,7
B	9,0	10,10	9,0	7,7
C	9,0	9,0	10,10	7,7

Table 2: Payoffs in the 3-payoff-state Condition

Columns indicate the actions available to receiver, and rows indicate the payoff state. The first entry in each cell is the sender's payoff and the second entry is the receiver's payoff from the receiver's action, given the payoff state.

2.2 The 3-payoff-state and 2-payoff-state conditions

We consider two additional parameterizations, each of which takes a step in the direction of weakening the attraction of the pooling action for the receiver. As before, in both parameterizations, payoff types and language types are drawn from independent uniform distributions; the number of available messages is always equal to the number of payoff states. If the receiver chooses an action that is optimal given the payoff state, both players receive a payoff of 10. If the receiver takes the pooling action, both players receive a payoff of 7. Finally, if the receiver takes any other action, the sender receives a payoff of 9 and the receiver receives 0.

The *3-state condition* uses the payoff table shown in Table 2. The message space is $M = \{*, \#, a, b, c\}$. The language type space is $\Lambda = \{\lambda_a, \lambda_b, \lambda_c, \lambda_{abc}\}$, where $\lambda_a = \{a, *, \#\}$, $\lambda_b = \{b, *, \#\}$, $\lambda_c = \{c, *, \#\}$ and $\lambda_{abc} = \{a, b, c\}$.

The *2-state condition* uses the payoff table shown in Table 3. The language type space is $\Lambda = \{\lambda_a, \lambda_b, \lambda_{ab}\}$ with $\lambda_a = \{a, *\}$, $\lambda_b = \{b, *\}$, and $\lambda_{ab} = \{a, b\}$.

2.3 Equilibrium Analysis

The sender-receiver games we consider have a finite set of payoff types Θ for the sender, a finite set R of actions for the receiver, and a finite set of messages, M. There is a unique action $Z \in R$ that is the receiver's best reply to beliefs concentrated on the (uniform) prior π over the set of payoff types. There are two kinds of messages: *Focal messages* have a meaning that is a (single) payoff type. *Neutral messages* have no pre-specified meaning.

For each payoff type θ in Θ there is a single message m_θ in the universe of all messages, M, whose meaning is θ. Let $[\![]\!] : M \to \Theta \cup \{?\}$ be a mapping that assigns either a meaning

	X	Y	Z
A	10,10	9,0	7,7
B	9,0	10,10	7,7

Table 3: Payoffs in the 2-payoff-state Condition

Columns indicate the actions available to receiver, and rows indicate the payoff state. The first entry in each cell is the sender's payoff and the second entry is the receiver's payoff from the receiver's action, given the payoff state.

$\theta \in \Theta$ to a message or declares the message neutral. Then, for each $\theta \in \Theta$, the message m_θ has meaning $[\![m_\theta]\!] = \theta$. If a message $m \in M$ is neutral, then $[\![m]\!] = ?$.

In addition to her payoff type θ the sender privately learns her language type $\lambda \in \Lambda = 2^M \backslash \emptyset$.[5] Language types are drawn from a commonly known distribution q. The sender chooses a message given the language she has available and the payoff state she has observed. For any finite set X, $\Delta(X)$ is the set of distributions over X. The sender strategy $\sigma : \Theta \times \Lambda \to \Delta(M)$ must satisfy the constraints that $\sigma(\theta, \lambda) \in \Delta(\lambda)$ for all $\theta \in \Theta$ and $\lambda \in \Lambda$; i.e., the sender can only use the messages that are available to her. Given her language type λ and her payoff type θ, her strategy σ assigns probability $\sigma(m|\theta, \lambda)$ to message $m \in \lambda$.

We say that the sender's strategy σ is *focal* if $m_\theta \in \lambda \Rightarrow \sigma(m_\theta|\theta, \lambda) = 1$ and $\sigma(m_{\theta'}|\theta, \tilde{\lambda}) = 0$ for all $\theta' \neq \theta$ and all $\tilde{\lambda} \in \Lambda$. With such a strategy, if her payoff type is θ and the message m_θ whose meaning is θ, $[\![m_\theta]\!] = \theta$, is available, she will send message m_θ; if her payoff type is θ and the message m_θ is not available, she will not send an alternative focal message $m_{\theta'}$, with $\theta' \neq \theta$. In our treatment condtion, for example, a plausible focal strategy for the sender would be to send messages $a, \ldots, e$, and f when the payoff state is $A, \ldots, E$ and F respectively whenever the message corresponding to the realized payoff state is available, and to send $*$ otherwise.

The receiver's strategy $\rho : M \to \Delta(R)$ prescribes a probability distribution over actions conditional on the message he has received. Thus, given any message $m \in M$, $\rho(r|m)$ is the probability that the receiver assigns to action $r \in R$. In the games we consider, the receiver has a unique best reply, r_θ, whenever his beliefs are concentrated on θ, and $r_\theta \neq r_{\theta'}$ for $\theta \neq \theta'$.

We say that the receiver strategy ρ is focal if $\rho(r_\theta|m_\theta) = 1$ for all m_θ. That is, a strategy is focal for the receiver if his interpretations of focal messages are consistent with their focal meanings. In response to any focal message m_θ it assigns the unique best reply to believing that the payoff type is θ.

A strategy profile (σ, ρ) is focal if the sender sends focal messages if and only if they match the payoff state and the receiver's interpretations of focal messages are consistent with their focal meanings. An equilibrium (σ, ρ, μ), where μ denotes the belief system, is focal if the corresponding strategy profile is focal.

The receiver's strategy is said to be *neutral* if $\rho(Z|m) = 1$ for all m with $[\![m]\!] = ?$. Under

[5] We use female pronouns for senders and male pronouns for receivers in the analysis of the game.

a neutral strategy, the receiver chooses Z in response to neutral messages. A strategy profile (σ, ρ) is neutral if ρ is neutral. An equilibrium (σ, ρ, μ) is neutral if ρ is neutral. The key characteristic of neutral equilibria is that they do not require players to coordinate on meanings for neutral messages. Finally, an equilibrium (σ, ρ, μ) is a *pooling equilibrium* if $\rho(Z|m) = 1$ for all m that are sent with positive probability in equilibrium.

The following result shows that all neutral equilibria must be pooling equilibria and contrasts the payoffs from neutral equilibria with the maximal payoffs that are achievable in equilibrium. It also shows that the maximal payoffs can be achieved with focal equilibria. That is, optimal equilibrium play is consistent with players using focal messages in accordance with their focal meaning. The difficulty with reaching optimal equilibria arises from the fact that those equilibria also require coordination on meanings for neutral messages. If that coordination cannot be achieved, the focal edifice collapses and the receiver responds to all messages, including focal messages, with the pooling action.

Proposition. *In all three conditions, all neutral equilibria are pooling equilibria, with a common payoff of 7. In the treatment condition there is a unique maximal equilibrium payoff profile, with a payoff of* 9.88 *for the sender and* 8.81 *for the receiver. In the 2- and 3-payoff-state conditions there is unique maximal equilibrium payoff profile, with a payoff of* $9.8\overline{3}$ *for the sender and* $8.\overline{3}$ *for the receiver. In all three conditions the maximal equilibrium payoffs can be achieved with focal equilibria.*[6]

We believe that neutral equilibria are more plausible than focal equilibria for the three experimental conditions with language barriers, because of the difficulty of agreeing on meanings for initially meaningless messages. Therefore, since all neutral equilibria are pooling equilibria, we predict that pooling will be observed when behavior has converged, even though there are equilibria with substantially higher payoffs for both players than from pooling.

Let player 1 be the sender and player 2 the receiver. Then for any player $i = 1, 2$ and any outcome $\omega \in \Delta(A \times T)$, $U^i(\omega)$ denotes player i's expected payoff from that outcome. An outcome $\omega^* \in \Delta(A \times T)$ is efficient if there is no other outcome $\omega \in \Delta(A \times T)$ with $U^i(\omega) \geq U^i(\omega^*)$, $i = 1, 2$, and a strict inequality for at least one player. This notion of efficiency ignores both language and equilibrium constraints. An equilibrium outcome $\omega^* \in \Delta(A \times T)$ is equilibrium efficient if there is no other equilibrium outcome $\omega \in \Delta(A \times T)$ with $U^i(\omega) \geq U^i(\omega^*)$, $i = 1, 2$, and a strict inequality for at least one player. This notion of efficiency respects both language and equilibrium constraints. The proposition shows that the equilibrium efficient payoffs are unique and it identifies those payoffs.

We come to this pooling prediction using a simple parameter-free benchmark model. This is in the interest of clearly highlighting a potential problem that may affect communication, the lack of common knowledge of a shared language. Evidently, there are numerous other factors that may impinge on behavior in our experiment that we leave out in this model, including lying aversion, the possibility of emergence of shared meanings, social preferences, and risk aversion. Some of these factors, e.g., risk aversion, might strengthen our pooling prediction, while others such as lying aversion, might weaken it. Attempting to incorporate all these forces into our model would detract from the central message, that a lack of common

[6]The proof is provided in the appendix.

knowledge of a shared language may undermine effective information transmission even if sender and receiver agree on the preferred action in every state of the world. We do, however, feel that it is useful to briefly examine the robustness of our pooling equilibrium prediction to small departures from the model. To this end we vary the sizes of the sets of receiver beliefs in our three games that make it optimal to take the pooling action. We expect the validity of our pooling prediction to increase with the size of these pooling-best-reply sets. The model is intended to apply to a relatively large state space and we view the *3-payoff-state* and *2-payoff-state* conditions as stress tests of the model, that push the limits of its applicability.

One rationale for the claim that the pooling equilibrium outcome is more plausible for environments with a larger number of states is based on the different sizes of the basins of attraction for this outcome. All three of the games we examine belong to a class of n-payoff-state games with payoff state space $S = \{s_1, \ldots, s_n\}$, action space $A = \{a_1, \ldots, a_n, a_{n+1}\}$, and (normalized) payoff function

$$U^R(s_i, a_j) = \begin{cases} 1 & \text{if} \quad i = j \\ 0 & \text{if} \quad i \neq j \text{ and } j \neq n+1 \\ \alpha & \text{if} \quad j = n+1 \end{cases}$$

for the receiver, where $\alpha \in \left(\frac{1}{2}, 1\right)$. The set of all possible beliefs of the receiver is the set of probability distributions over the n payoff states. This is the simplex formed by the origin and the $n-1$ basis vectors e_ℓ, $\ell = 1, \ldots, n-1$. This simplex has volume $\frac{1}{(n-1)!}$. The set of beliefs that make it optimal for the receiver to take action a_j for $j \neq n+1$ is a simplex that is congruent to the one formed by the origin and the vectors $(1-\alpha) \cdot e_\ell$, $\ell = 1, \ldots, n-1$, where e_ℓ is the ℓth basis vector. There are n such simplices, each of which has volume $\frac{(1-\alpha)^{n-1}}{(n-1)!}$ Therefore, the fraction of beliefs that make it optimal to take the pooling action is

$$\beta_n(\alpha) := \frac{\frac{1}{(n-1)!} - n\frac{(1-\alpha)^{n-1}}{(n-1)!}}{\frac{1}{(n-1)!}}.$$

Observation. *The fraction of receiver beliefs for which the pooling action is optimal in the n-payoff-state game equals*

$$\beta_n(\alpha) = 1 - n(1-\alpha)^{n-1}.$$

For the three games considered in this paper, in which $\alpha = .7$, these fractions are

$$\begin{aligned} \beta_2\left(\tfrac{7}{10}\right) &= 0.4 \textit{ for the 2-payoff-state condition} \\ \beta_3\left(\tfrac{7}{10}\right) &= 0.73 \textit{ for the 3-payoff-state condition} \\ \beta_6\left(\tfrac{7}{10}\right) &= 0.98542 \textit{ for the Treatment condition} \end{aligned}$$

Thus, the pooling action is a best response under a far larger set of beliefs in the *Treatment* than in the *3-payoff-state* or *2-payoff-state* conditinos. We believe that this makes it relatively more likely that the pooling action would be employed in the *Treatment* condition.

3 Experimental Procedures

3.1 Procedures and timing within sessions

We conducted 13 sessions at the Economic Science Laboratory at the University of Arizona. There were four different conditions, two main conditions of *Control* and *Treatment*, each with six payoff states, and two other conditions, *3-payoff-state* and *2-payoff-state*. Each session consisted of 120 periods in total and two conditions. Each of the two conditions was in effect for 60 periods.[7] On average, a session lasted for 90 minutes, including initial instruction and final payment of the subjects. The instructions were read aloud by a computer in a neutral tone, while the subjects followed along with printed copies. Some information about the sessions is presented in Table 4, including the number of subjects, the conditions in effect, and the sequence in which they occurred.

The role of each player, as a sender or receiver, was fixed within each 60-period condition, but was always switched to the other role at the beginning of the next condition. Each player was re-matched with another player in each period randomly. It was common knowledge that, although interacting with the same group in the laboratory, the possibility of being matched with the same participant in two consecutive rounds was small. The interaction was anonymous in the sense that players could not associate a player with her action in any way that would allow them to keep track of a particular player's action.

Subjects were paid for every period, at a conversion rate of $1.00 per 37 units of experimental currency, in which the game payoffs were denominated. Participants earned an average of 24 dollars. The 152 subjects participating were recruited from the subject pool of the Economic Science Laboratory. The pool is open for registration to full-time undergraduate students of the University of Arizona. We programmed the experiment using z-Tree [16].

Upon arrival at their session, subjects were randomly assigned to computers in the laboratory. At the beginning of each condition, one trial period was conducted to help subjects better understand the experiment. The payoff in the trial period for each subject was revealed, but was not counted in their final payment. During the 60 periods of each condition that counted toward their earnings, subjects knew the period they were in and the number of periods remaining. Earnings from all 120 periods (after the one practice period) counted toward participant payment for the session.

In each period, subjects played a two-stage game. In the first stage, the sender observed the realized payoff state and language state (the set of available messages), and then decided on the message to send to the receiver. In the second stage, after receiving the message from the sender, the receiver chose his action. Then, both sender and receiver were informed of their own payoffs. Messages were displayed on the screen in the same order for both players and this order was constant over time. The realized payoff state, the realized language state, the message she sent to the receiver, and own earnings in all previous periods were available in a table on the sender's screen for her to review. The history of messages he received, the actions he chose and his own earnings in all previous periods were recorded in a table for the receiver to review on his screen. For both players, this history information remained

[7] There was one exception. Session 12 was terminated after the first 60 periods due to the slow pace of decision making in that session.

Session Number	Number of Subjects	Condition in Effect in Periods 1 - 60	Condition in Effect in Periods 61 - 120
1	12	Treatment	2-payoff-state
2	14	2-payoff-state	Treatment
3	14	3-payoff-state	Treatment
4	18	Treatment	3-payoff-state
5	14	3-payoff-state	2-payoff-state
6	12	2-payoff state	3-payoff-state
7	18	Treatment	2-payoff state
8	16	2-payoff-state	Treatment
9	16	Control	Treatment
10	18	Treatment	Control
11	20	Treatment	(None)
12	18	Control	Treatment
13	14	Treatment	Control

Table 4: Session Information

available at all times.

3.2 The four conditions

3.2.1 Treatment and Control conditions

Both *Treatment* and *Control* allow for six possible payoff states, A, B, C, D, E, and F, which are equally likely. The realized payoff state is observed only by the sender. In the Control it is commonly known that the messages available to the sender are a, b, c, d, e and f. In the Treatment, at the time the payoff state is revealed to the sender, senders are also informed of the language state, the set of messages they are able to use. There are six possible language states: $\{a, b, c, d, e, f\}$, $\{a, *, \#, \hat{}, @, \%\}$, $\{b, *, \#, \hat{}, @, \%\}$, $\{c, *, \#, \hat{}, @, \%\}$, $\{d, *, \#, \hat{}, @, \%\}$, $\{e, *, \#, \hat{}, @, \%\}$, and $\{f, *, \#, \hat{}, @, \%\}$. In the first one all messages with a focal meaning, a, b, c, d, e, and f are available. In the remaining language states one of the focal messages and all of the neutral messages $*, \#, \hat{}, @$, and $\%$ are available. All seven language states are equally likely in a given period. Language states and payoff states are drawn independently in each period and for each pair of players within the period. After learning the payoff state and the language state, each sender chooses a message from the available language set to send to the receiver she is paired with.

Receivers cannot observe the realized payoff state and language state in the *Treatment* condition. The only information that they have available to make their decisions are their payoff table, the history of their own actions and payoffs, and the message they received from the sender they are matched with. Both senders and receivers are provided with the payoff structure of the game. The payoff structure of the *Treatment* and *Control* conditions

Condition	Possible Payoff States	Possible Language States
Treatment	A, B, C, D, E, F	{a, b, c, d, e, f}, {a, *, #, ˆ , @, %}, {b, *, #, ˆ, @, %}, {c, *, #, ˆ, @, %}, {d, *, #, ˆ, @, %}, {e, *, #, ˆ, @, %}, {f, *, #, ˆ , @, %}
Control	A, B, C, D, E, F	{a, b, c, d, e, f}
3-payoff-state	A, B, C	{a, b, c}, $\{a, *, \#\}$, $\{b, *, \#\}$, $\{c$, *, #}
2-payoff-state	A, B	$\{a, b\}, \{a, *\}, \{b, *\}$

Table 5: Condition parameters

is shown in Table 1. Comparing the treatment to the 6-state control condition isolates the impact of language barriers.

3.2.2 The 3-payoff-state and 2-payoff-state conditions

The payoff structures in the *3-payoff-state* and *2-payoff-state* conditions have a similar pattern as in *Treatment* and *Control*, as shown in Table 5. In each condition, there is a number of language states equal to the number of payoff states plus 1. The sets of possibly available messages always includes one that contains all focal messages, with the remaining ones consisting of one focal and a number of neutral messages equal to the number of payoff states minus one. In all conditions and for each payoff state, sender and receiver agree on the optimal action for that payoff state. If the receiver chooses an action other than the safe action Z, both players receive a payoff of 10 in one of the payoff states, while in all other payoff states, the sender gets a payoff of 9, and the receiver earns zero. By playing the safe action, the receiver ensures a payoff of exactly 7 to both parties. Decreasing the number of payoff states, while leaving the payoff structure intact, lets us examine the impact of the attraction of the pooling action for the receiver. As we have argued earlier, the smaller the number of payoff states, the less attractive is the pooling action, and the more scope there is for forces to play a role that might counter the predicted tendency toward pooling.

4 Results

This section is organized as follows: In subsection 4.1 we report observed behavior and payoffs in the treatment and control in the last ten rounds, and contrast the observations from our experiment with the theoretical predictions. In section 4.2 we report findings from a robustness check in which we reduce the number of payoff states, and with it the set of beliefs for which the pooling action is optimal. Section 4.3 contains our findings regarding initial behavior in the treatment and control. In Section 4.4 we report regression results that shed additional light on the determinants of behavior in the treatment.

4.1 Terminal behavior and payoffs

In this subsection we report observed behavior and payoffs in the treatment and control. We focus on the last ten periods, when play has settled down, and compare experimental observations with theoretical predictions.

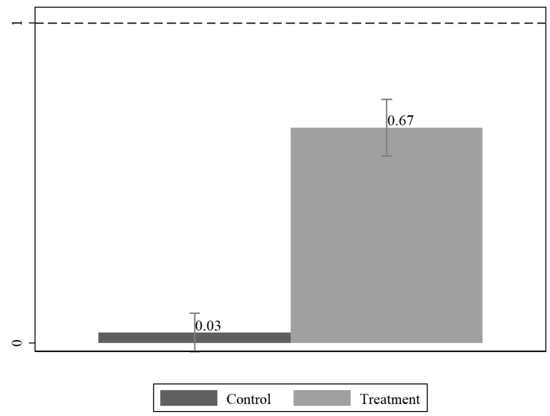

Figure 1: Average percentage of instances in which receiver chooses the pooling action Z in response to focal messages during the last 10 periods.

Our central theoretical prediction is that in the treatment receivers gravitate toward taking the pooling action in response to focal messages. In contrast, in the control it is natural to expect receivers to take focal actions in response to focal messages. Figure 1 shows that, consistent with our theoretical prediction, the incidence of pooling actions following focal messages is much higher in the treatment (67%) than in the control (3%).[8]

The game in the control has a plausible equilibrium that induces an efficient outcome. In that equilibrium both sender and receiver achieve their maximal payoff for every state of the world. A necessary condition for efficiency is that action Z is never taken. This is close to what we find.

The game in the treatment has equilibrium efficient equilibria that entail only a small payoff loss relative to efficiency (there are no efficient equilibria). A necessary condition for equilibrium efficiency is, once again, that action Z is never taken. This is far from what we find, but in line with our theoretical prediction based on neutral equilibria.

In the treatment the pooling action Z is frequently taken in response to focal messages. The dashed line at the top of Figure 1 indicates the frequency of action Z following a focal message that corresponds to our prediction. While the observed frequency (67%) is bounded away from the predicted frequency (100%), it is closer to the neutral equilibrium prediction than to the frequency required for an equilibrium efficient outcome (0%). Note that observed receiver behavior implies a failure of efficiency even conditional on all messages being available. This illustrates the importance of information about message availability.

In addition to action Z never being taken, efficiency in the control and equilibrium efficiency in the treatment require that each payoff type induces the receiver's best reply

[8]Throughout, error bars indicate 95% confidence intervals, treating each subject as an independent observation

for that payoff type, to the extent that language constraints do not prevent it. There are equilibria that have this feature in which the receiver's responses to focal messages match the focal meanings of focal messages; i.e., the receiver responds with action T to message a, with action U to message b, and so on.

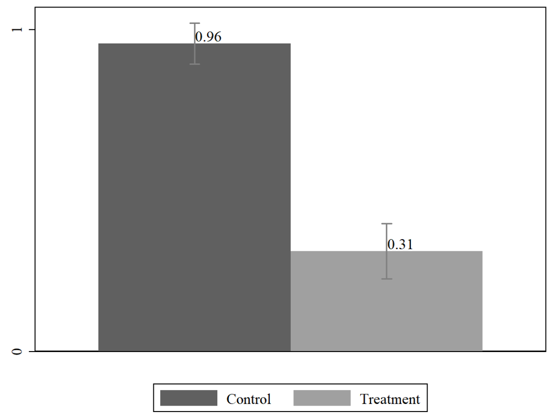

Figure 2: Average percentage of instances in which the receivers' responses match the focal meanings of focal messages during the last 10 periods.

Figure 2, in combination with Figure 1, shows that receivers who do not take action Z overwhelmingly take actions that match the focal meanings of focal messages. In the control, where only focal messages are available, in 96% of the cases receivers take an action that matches the focal meaning of the message they receive, as indicated in the left bar of Figure 2. Given that in the control in 97% of the cases (see Figure 1) receivers do not take the pooling action, it follows that only 1% of the time they take an action that either does not match the focal meaning of the message received or is the pooling action.

The right bar of Figure 2 shows that in 31% of the cases of a receiver observing a focal message in the treatment his action matches that message's focal meaning. Figure 1 implies that in the treatment in 33% of the cases in which a receiver observed a focal message he responds with an action other than the pooling action Z. Together these two observations imply that in the treatment receivers who observe a focal message and do not respond with action Z overwhelmingly respond with an action that matches that message's focal meaning. Thus in the treatment, when receiving a focal message, with a few exceptions, receivers either take the safe action Z or an action that matches that message's focal meaning. This lends support to our characterization of these messages as focal. It suggests that receiver behavior in response to focal messages in most cases is systematic rather than purely random.

Theory predicts that in the treatment receivers take action Z, regardless of whether they receive a neutral or a focal message. We already saw that for focal messages, while action Z is the modal response, it is not the only response. Figure 3 shows that the same is true for neutral messages. The left bar in the figure indicates that in 85% of the cases when receivers observe a neutral message they respond with the pooling action Z. Action Z is the modal response after neutral messages, but not the only response.

In addition, Figure 3 suggests that there is a difference in the incidence of of the pooling

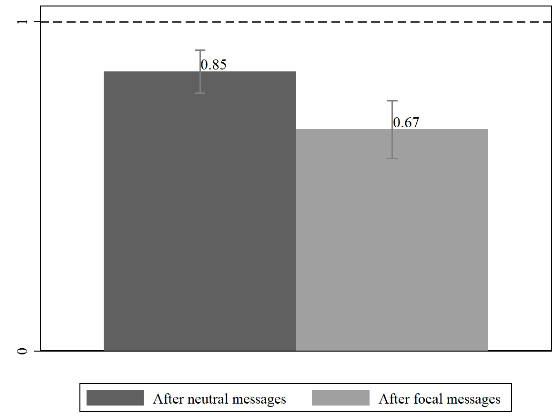

Figure 3: Average percentage of choices of action Z in the treatment in response to a neutral messages compared to focal messages in the last ten periods.

action following neutral (85%) and focal messages (67%) in the treatment. A t-test for differences of the means rejects the null hypothesis of equal means ($p = 0.0017$). Given that for neutral messages there is no straightforward association between messages and action, finding a difference between the responses to neutral and focal messages is not entirely surprising. Slightly more surprising is the fact that in a non-negligible fraction of cases (15%) of receivers observing neutral messages they respond with an action other than Z.

This can be understood in terms of players making attempts at endowing neutral messages with meaning. The theory (based on neutral equilibria) postulates that neutral messages induce action Z. In the experiment this is made plausible by using abstract keyboard symbols for neutral message that have no immediate association with the labeling of payoff types (unlike for focal messages), and are meaningless in that sense. Note, however, that we make only a minimal effort to keep neutral messages truly meaningless. We do not privatize messages as in Blume et al. [3], do not control for keyboard order, and do not randomize the order on the computerized display. This is intentional. If we find convergence to the pooling outcome in the present environment, then it strengthens the pooling prediction for an environment in which neutral messages are meaningless by construction. In the setup of the present paper participants (1) might be tempted to exploit the common and fixed ordering of "meaningless messages" on the computerized display, (2) might try to form associations between keyboard order of neutral messages and alphabetical order of payoff-type labels, (3) might try to uncover less obvious focal associations between neutral messages and payoff states (e.g. use @ to indicate payoff state A), and (4) might try learn to attach meaning to *a priori* meaningless messages (as in the experiments of Blume et al. [3] and Bruner et al. [9]). The fact that there are multiple plausible avenues for attaching meaning to neutral messages creates a coordination problem that makes it more likely that neutral messages remain meaningless. This is consistent with our finding that ultimately the predominant choice of action after receiving a neutral message is the pooling action Z.

Unlike for receiver behavior, the theory does not place tight constraints on sender behavior. The set of sender strategies that the support a neutral equilibrium outcome is large.

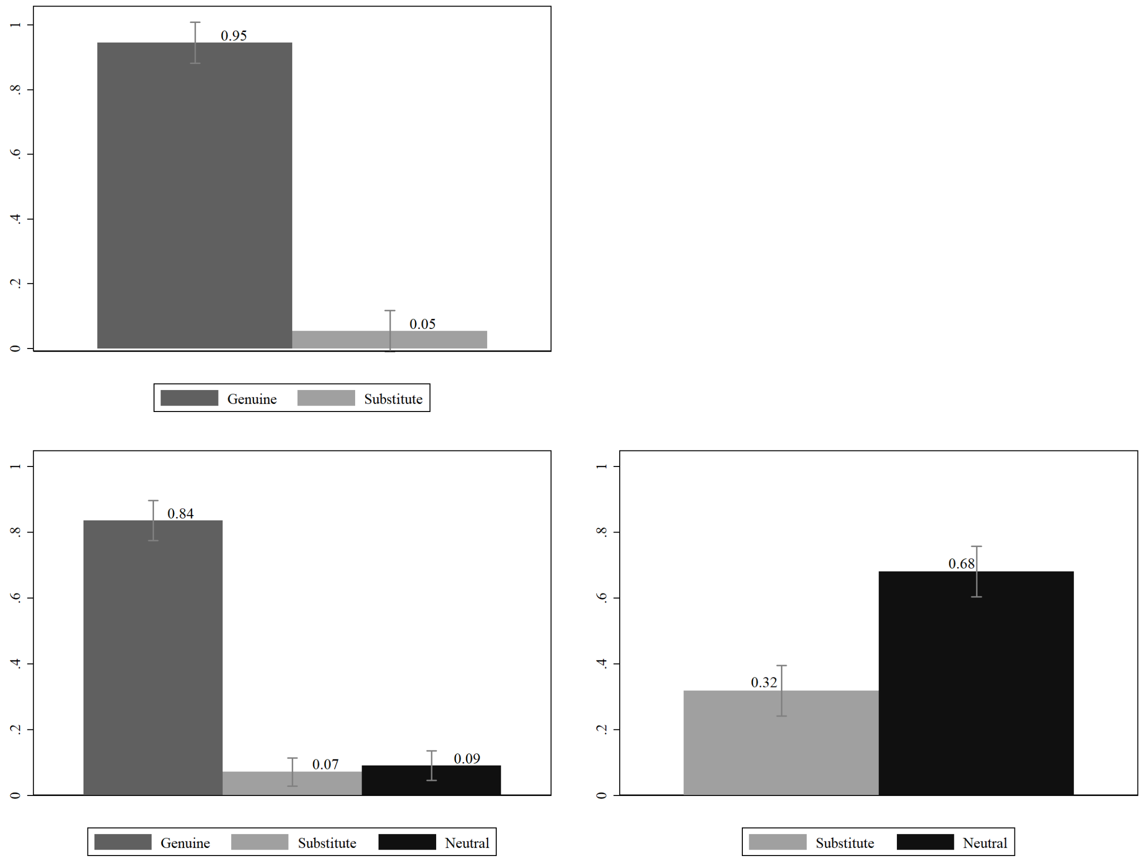

Figure 4: Sender behavior – average percentage of choices of genuine focal, substitute focal, and neutral messages during the last ten periods. The top row refers to the control, the bottom row to the treatment, the left column to the case in which a genuine focal message is available, and the right column to refers to the case in which no genuine focal message is available.

It includes all pure strategies in which all sender types send a common message, all mixed strategies in which the sender mixes over messages independently of her type, as well as a host of other strategies. Nevertheless, it may be interesting to see what senders do.

Figure 4 reports sender behavior in the last ten rounds of the control (the panel in the top row) and the treatment (the panels in the bottom row) as function of whether the sender has access to a focal message that matches her payoff type (left column) or not (right column). It is convenient to call a focal message that matches the sender's payoff type a "genuine" focal message and a focal message that does not match the sender's payoff type a "substitute" focal message.

The figure shows that in the control, senders overwhelmingly use the focal strategy of sending a genuine focal message (95% of the time). Doing so is the unique best reply, given observed receiver behavior. Hence, the fact that in 5% of the cases senders in the control send a substitute focal message has no straightforward explanation. In the treatment, when a genuine focal message is available, senders send it with high frequency (84% of the time). The 16% of the cases in which they do not sent a genuine focal message when available now need not be a mistake if they result from attempts to assign meanings to neutral messages or reassign meanings to focal messages. The observation about sender behavior that is perhaps most interesting is that when a genuine focal message is not available senders frequently (in 32% of the cases) send a substitute focal message. This makes sense, given that, as we saw, whenever receivers don't respond with the pooling action action to a focal message the action matches the focal meaning. It does however corrupt the focal meanings of focal messages. Sending neutral messages, as occurs in the remaining 68% of the cases, can also be rationalized: it might be part of an attempt to assign meaning to neutral messages.

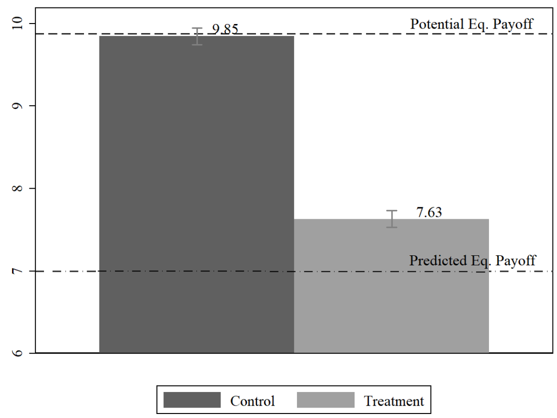

Figure 5: Average sender payoffs in control and treatment during the last ten periods. The dashed lines indicate the potential and the predicted payoffs in the treatment.

Figure 5 reports average sender payoffs in control and treatment during the last ten periods. For ease of reference, the figure includes two dashed lines. Both refer to the treatment. The top line indicates the expected payoff in an equilibrium that achieves equilibrium efficiency in the treatment. The sender's equilibrium efficient payoff is unique and equals 9.88. The bottom line indicated the sender's payoff in a neutral equilibrium in the treatment, which equals 7.

The control has an intuitive equilibrium in which the sender receives the maximally attainable payoff of 10. The observed payoff (9.85) in the control closely approximates that maximally attainable payoff. In contrast, in the treatment the observed payoff (7.63) is closer to the predicted neutral equilibrium payoff of 7 than to the maximally attainable equilibrium payoff of 9.88. As one might expect, the observed payoff is slightly higher than the predicted payoff: the sender's predicted payoff of 7 is a lower bound for the sender payoff, and, regardless of type, each time the receiver takes an action other than Z the sender's payoff exceeds that lower bound.

Figure 6 reports average receiver payoffs in control and treatment during the last ten periods. In the control, observed payoffs (9.35) are are not too far from the maximally achievable payoffs of 10. In the treatment, in contrast, observed payoffs (6.67) are are closer to predicted payoffs (7) than to maximally achievable equilibrium payoffs (8.81). Observed payoffs for receivers are below predicted payoffs, in contrast to senders for whom they are above predicted payoffs. This is interesting because receivers can guarantee themselves at

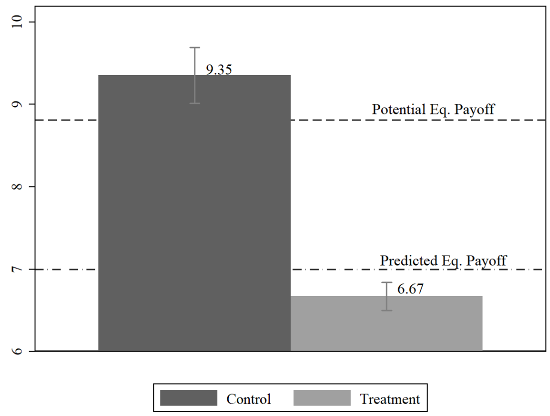

Figure 6: Average receiver payoffs in control and treatment during the last ten periods. The dashed lines indicate the potential and the predicted payoffs in the treatment.

least the predicted payoff by simply taking the pooling action after every message. It can be understood by realizing that senders frequently use substitute focal messages when genuine focal messages are not available. Therefore any time the receiver takes an action that matches the focal meaning of the received message, there is a high probability of the receiver obtaining a low payoff.

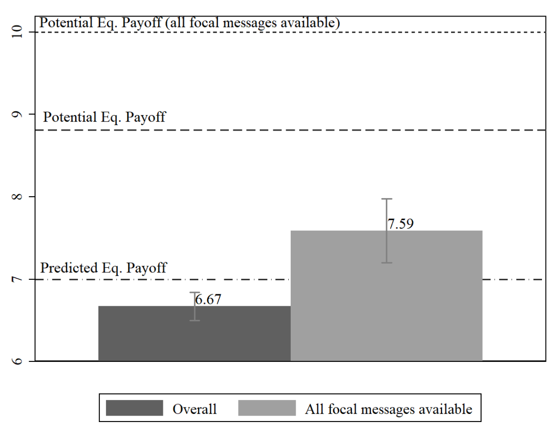

Figure 7: Average receiver payoffs – overall and when all focal messages are available during the last ten periods

For the treatment, Figure 6 shows the average receiver payoff (6.67) across both situations in which the sender has all focal messages available and situations in which this is not the case. Since in the control all focal messages are always available, it is of interest to compare overall average receiver payoffs in the treatment with average receiver payoffs in those periods of the treatment when all focal messages are available.

This comparison is shown in Figure 7. The receiver payoff when all focal messages are available (7.59) is higher than the overall receiver payoff. More important, however, is that the receiver's payoff conditional on all focal messages available falls well short of the overall maximal potential equilibrium payoff (8.81) and is not anywhere close to the maximal equilibrium payoff conditional on all messages being available (10). This is a stark reminder of the fact that in our treatment, even when all messages are available and even though in that case the maximal payoff of 10 is feasible in equilibrium, the receiver's payoff remains closer to the pooling payoff of 7.

4.2 Robustness

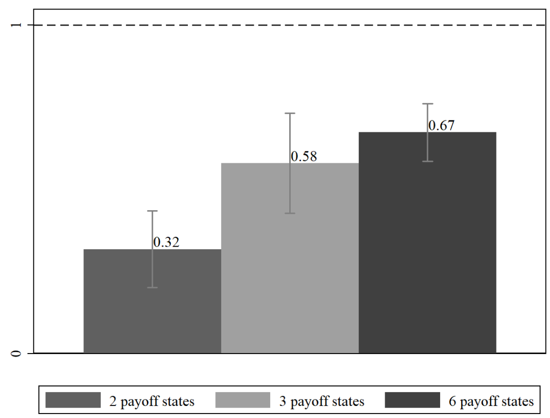

Figure 8: Average percentage of choices of action Z in response to a focal message in the last ten periods – comparison of 6 payoff states, 3 payoff states, and 2 payoff states.

For a robustness check, we compare the results in our treatment with those for two conditions with essentially the same structure of the equilibrium set, but a smaller fraction of beliefs that make it optimal to take the pooling action Z. In the two- and three-payoff state conditions, as in our treatment, in equilibrium-efficient equilibria action Z is never taken. At the same time, our prediction (based on neutral equilibria) remains that action Z is taken after every message.

The smaller sizes of the basin of attraction of the pooling action suggests that receivers might take the pooling action Z less frequently. That might make it easier for equilibrium-efficient behavior to emerge. In addition, both conditions have fewer messages, possibly facilitating the assignment of meaning to neutral messages during the course of repeated play.

Figure 8 shows the average frequency of action Z in response to focal messages in the last ten periods, comparing our treatment (6 payoff states), with the 3-payoff states condition and the 2-payoff states condition. The frequency of the pooling action is slightly lower with 3 payoff states, and substantially lower with 2 payoff states. A t-test for differences of the means rejects the null hypothesis of equal means for the 2-payoff states and 3-payoff-states conditions ($p = 0.0081$). The same test does not reject the null hypothesis of equal means for the 3-payoff states and 6-payoff-states conditions ($p = 0.3016$). Finally, it is worth noting that while reducing the number of payoff states does significantly lower the frequency of the pooling action with 2 payoff states, it does not drive it down to near zero, as would be required for equilibrium efficiency.

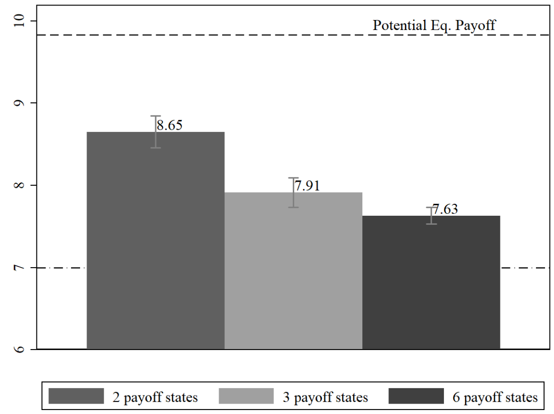

Figure 9: Average sender payoffs in the last ten periods in the treatment (6 payoff states), with 3 payoff states, and with 2 payoff states.

Figure 9 shows the impact on sender payoff in the three conditions. Payoffs are slightly higher with 3 payoff states than in the treatment, and still higher with 2 payoff states. This mirrors our observation about receiver behavior (Figure 8): Regardless of type, the sender benefits whenever the receiver does not take action Z. Hence, the lower incidence of action Z with 3 and 2 payoff states directly translates into a higher observed average sender payoff.

In all three conditions sender payoffs remain bounded away from maximal equilibrium payoffs. The dashed line labeled "Potential Eq. Payoffs" marks the highest expected sender payoff across all equilibria in the conditions with 3 and 2 payoff states (that payoff is slightly higher with 6 payoff states). The observed sender payoffs are all well below maximal equilibrium payoffs, indicating that while there is a decrease in the incidence of action Z with 2 and 3 payoff states, that action still has significant drawing power, preventing players from making the best use of available messages.

Figure 10 shows receiver payoffs in the three conditions. Again, payoffs are slightly higher with 2 and 3 payoff states than in the treatment. That effect, however, is much more muted than for senders. Indeed, with 3 payoff states the observed receiver payoff is lower than and not significantly different from the predicted equilibrium payoff. In all three conditions observed payoffs are significantly lower than the maximum obtainable equilibrium payoffs. The dashed line labeled "Potential Eq. Payoffs" marks the highest expected receiver payoff across all equilibria in the conditions with 3 and 2 payoff states (that payoff is slightly higher with 6 payoff states).

Overall, while there is a significant drop in the use of action Z in the 2-payoff states condition, this is not the case for the 3-payoff states condition, and in all three conditions action Z plays a key role in determining outcomes and payoffs. Receiver payoffs with 3 payoff states are well below predicted payoffs, as in the treatment, and in all three conditions receiver payoffs are far from maximal equilibrium payoffs. Pooling remains a better predictor of receiver payoffs than equilibrium efficiency.

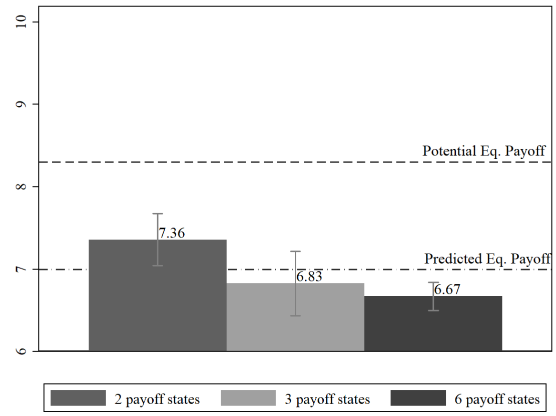

Figure 10: Average receiver payoffs in the last ten periods in the treatment (6 payoff states), with 3 payoff state, and with 2 payoff states.

4.3 Initial behavior

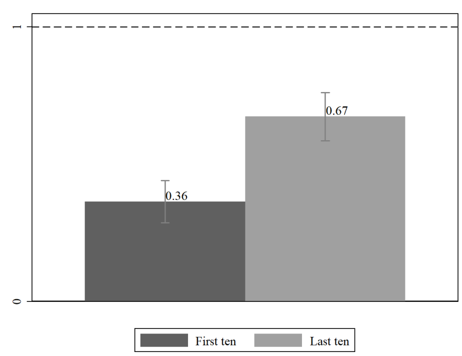

Figure 11: Average percentage of choices of action Z in response to a focal message in the first ten periods and in the last ten periods

We briefly consider initial behavior. Figure 11 compares the frequency of the pooling action Z in response to focal messages in the first and last ten periods of the treatment. Two observations stand out. The initial incidence of action Z in response to focal messages is lower in the first than the last ten periods (a t-test for differences of the means rejects the null hypothesis of equal means ($p = 0.00$)), and action Z is already a frequent response to focal messages in the first ten periods (36% of the time). Importantly, the control, where action Z is rarely taken, and treatment are already clearly differentiated in the first ten periods. This shows that focal message meaning is fragile and that fragility is compounded by experience.

Figure 12 shows the average frequency of action Z in response to a neutral message in the first and in the last ten periods. The initial incidence of action Z is lower initially (a t-test for differences of the means rejects the null hypothesis of equal means ($p = 0.0011$)), perhaps reflecting greater optimism about being able to assign meaning to neutral messages. Notice also that in the first ten periods action Z is more frequently taken in response to neutral than to focal messages, justifying the terminological distinction.

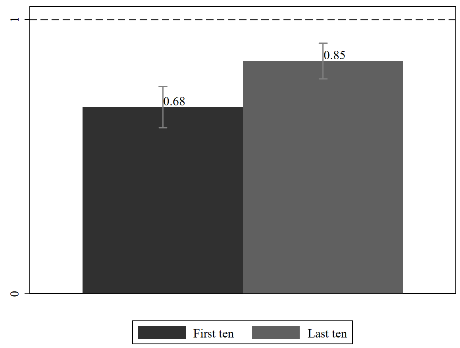

Figure 12: Average percentage of choices of action Z in response to a neutral message in the first ten periods and in the last ten periods.

Figure 13 compares sender decisions in the first ten periods (top two panels) and last ten periods (bottom two panels) of the treatment. Sender behavior appears remarkably consistent over time. For example, when genuine focal messages are not available, substitute focal messages are only used slightly less frequently in the the initial ten periods that in the terminal ten periods (27% versus 32%). A t-test does not reject the null hypothesis of equal means ($p = 0.3759$).

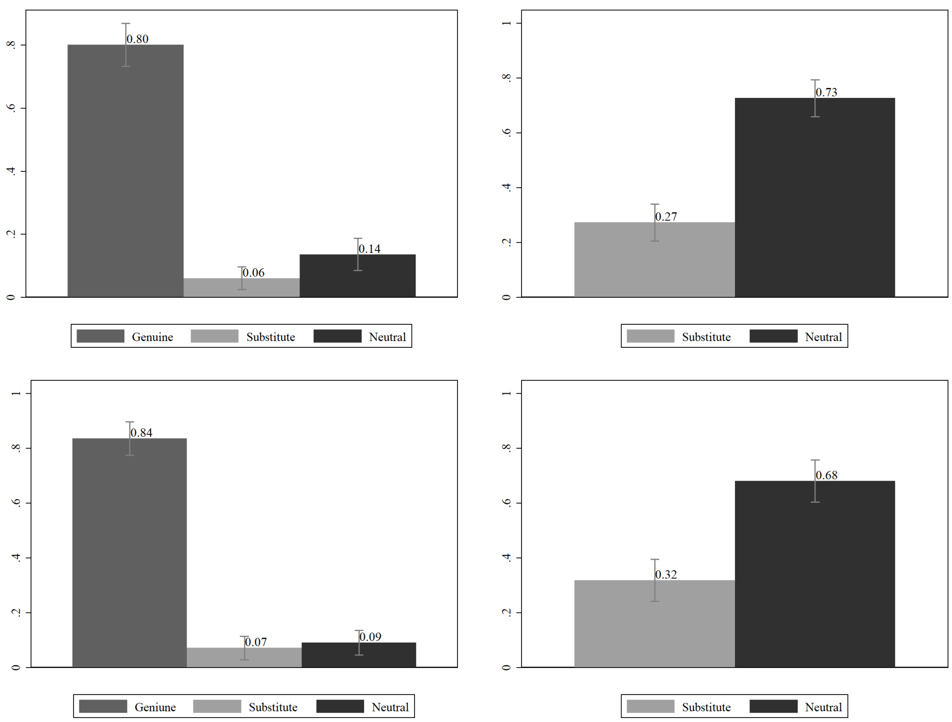

Figure 13: Sender behavior – average percentage of choices of genuine focal, substitute focal, and neutral messages. The top row refers to the first ten periods and the bottom row to the last ten periods. The left column refers to the case in which a genuine focal message is available, and the right column to the case in which no genuine focal message is available.

Overall, while terminal behavior of receivers differs from their initial behavior, the meaning of focal messages proves fragile from the beginning and becomes more fragile over time. Sender behavior is fairly stable throughout and justifies receivers being suspicious about senders' use of focal messages.

4.4 Determinants of behavior

Theory, based on selecting neutral equilibria, predicts that receivers take the pooling action Z regardless of which messages they receive. While modal behavior conforms with this prediction, we also observe a number of systematic deviations from the theory: (1) the frequency of action Z in terminal rounds is bounded away from the predicted frequency; (2) the initial frequency of action Z is further away from the prediction than the terminal frequency; and, (3) the frequency of action Z in response to focal messages is lower than in response to neutral messages.

To gain a better understanding of receiver behavior and motivations, we regress Z, an indicator variable that takes the value 1 when a receiver subject i takes action Z in period t and zero otherwise, on F, an indicator variable that takes the value 1 if that subject observes a focal message in period t, on S_{-1}, an indicator variable that takes the value 1 if the subject successfully interpreted a focal message in the previous period as being genuine, and on $F \times S_{-1}$, an indicator variable that takes the value 1 if the currently observed message is focal and the subject in the previous period had a success with interpreting a focal message as being genuine. Written compactly, we are running the following regression (here expressed as a linear probability model):

$$Z = \alpha_0 + \alpha_1 F + \alpha_2 S_{-1} + \alpha_3 (F \times S_{-1}) + \epsilon.$$

The success variable S, which appears lagged in the regression, is defined as $S := F \times H \times \overline{Z}$, where $\overline{Z}$, the complement of Z, indicates that the subject takes any action other than Z, and H is an indicator variable that takes the value 1 if that subject's payoff in that period equals the maximal achievable payoff of 10.[9]

Under a strict interpretation of the neutral-equilibrium prediction, we would expect all coefficients but the constant to be equal to zero, and the constant, α_0, to be strongly positive. If we believe that receivers have a tendency to take actions that match the meanings of focal messages they receive, we expect α_1 to be negative. If we believe that receivers are more likely to take actions that match the focal meanings of messages if they were successful having done so in the past, we expect α_3 to be negative. Neither theory nor a behavioral intuition pins down any expectation for the sign of α_2.

Table 6 reports the finding from our receiver regression. The large and significant positive coefficient on the constant is in line with the theory prediction for receivers to take action Z. Contrary to theory, this tendency is somewhat attenuated when receivers observe a focal message. Observing a focal messages reduces the probability of receivers taking the pooling action by slightly more than 10 percentage points. We observe the strongest departure from theory in cases where receivers observe a focal message and had successfully interpreted such a message as being genuine in the previous period. In that case the probability of taking action Z drops by more than 25 percentage points. The results are robust to different specifications (ordinary least squares, including individual fixed effects, probit, and probit with random effects).[10]

Next, we turn to the determinants of sender behavior. Toward this end, we regress B, an indicator variable that takes the value 1 whenever a sender subject uses a substitute focal

[9] The subscript $_{-1}$ indicates a one-period lag.

[10] The probit regressions report the average marginal effects.

Table 6: Determinants of receiver's choice of Z, treatment condition

	OLS	Panel FE	Probit	Probit RE
F	-0.120***	-0.145***	-0.118***	-0.171***
	(0.0125)	(0.0107)	(0.0123)	(0.0435)
S_{-1}	-0.0985***	0.0865***	-0.100***	0.036
	(0.0205)	(0.0182)	(0.0199)	(0.0293)
$F \times S_{-1}$	-0.399***	-0.404***	-0.307***	-0.269***
	(0.0301)	(0.0255)	0.0290	(0.0494)
Constant	0.825***	0.805***		
	(0.00861)	(0.00737)		
Observations	5428	5428	5428	5428
Adjusted R^2	0.129	0.112		

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

message, on $\overline{A}$, an indicator variable that takes the value 1 when the genuine focal message is unavailable, on S_{-1}, an indicator variable that takes the value 1 if the sender subject successfully used a substitute focal message in the previous period, and on $\overline{A} \times S_{-1}$. Written succinctly, we are running the following regression (here expressed as a linear probability model):

$$B = \beta_0 + \beta_1 \overline{A} + \beta_2 S_{-1} + \beta_3 (\overline{A} \times S_{-1}) + \epsilon$$

The success variable S, which appears lagged in the regression, is defined as $S := B \times H$, where H is an indicator variable that takes the value 1 if that subject's payoff in that period equals the maximal achievable payoff of 10.

The neutral-equilibrium prediction of the theory does not place tight constraints on sender behavior. Behaviorally, one might expect that senders would be more inclined to use a substitute focal message if no genuine focal message is available. In that case β_1 would be positive. Success with a substitute focal message in the previous period per se need not either encourage or discourage the use of substitute focal messages, leaving the expected sign of β_2 ambiguous. If, however, currently the genuine focal message is unavailable then prior success with a substitute focal message might encourage the use of substitute focal messages. This suggests that we might expect β_3 to be positive.

Our findings, reported in Table 7 are in line with these expectations. Senders are more

Table 7: Determinants of sender's choice of a substitute focal message, treatment condition

	OLS	Panel FE	Probit	Probit RE
$\overline{A}$	0.173***	0.163***	0.214***	0.221***
	(0.0123)	(0.0108)	(0.0149)	(0.0291)
S_{-1}	0.0554*	-0.191***	0.094**	-0.079**
	(0.0269)	(0.0242)	(0.0308)	(0.0293)
$\overline{A} \times S_{-1}$	0.388***	0.371***	0.211***	0.178***
	(0.0323)	(0.0281)	(0.0341)	(0.0373)
Constant	0.0576***	0.101***		
	(0.0104)	(0.00909)		
Observations	5428	5428	5428	5428
Adjusted R^2	0.157	0.096		

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

inclined to use substitute focal messages when genuine focal messages are unavailable and this effect is stronger when they had prior success with using substitute focal messages. The results are robust to different specifications (ordinary least squares, including individual fixed effects, probit, and probit with random effects).

Overall, we find that the observed behavior of both senders and receivers is sensitive to current information and prior experience. The neutral-equilibrium prediction does not prescribe this for senders and rules it out for receivers. At the same time, the behaviors we observe – the use of substitute focal messages by senders and sensitivity to past success by receivers – help propel overall behavior in the direction of the predicted outcome by increasing the incidence of the pooling action Z over time.

5 Related literature

The literature offers two types of formal models of language constraints, those with availability constraints and those with symmetry constraints. Crémer, Garicano and Prat [14], Jäger, Metzger, and Riedel [20], and Sobel [29] study availability constraints, which consist of restricted vocabularies. They consider common-interest games, so that it is meaningful to study optimal strategy profiles. Crémer, Garicano and Prat are concerned with the design of an optimal organizational code. The code is used to describe states that are drawn from a known distribution. An optimal code is an optimal assignment of words to subsets of the state space. The choice of an organizational code interacts with organizational structure because there is a trade-off between the quality of communication within and across groups in an organization. Blume [4] [6], extending ideas from Crawford and Haller [12], uses symmetry constraints to describe situations in which some messages may be meaningless to some of the agents. One use of this approach is to show how grammar can facilitate language learning, the association of meaning to *a priori* meaningless messages (for a related approach to thinking about structure in language see Rubinstein [27]). In our experiment we implement both availability constraints, by sometimes limiting the sender's access to messages, and symmetry constraints, by employing (at least initially) meaningless messages in addition to focal message. Focal messages, in the sense of Schelling [28]), provide a clue that makes it possible to agree on their interpretation. The co-occurrence of both focal and meaningless messages is a novel feature of our experiment.

Blume and Board [7] introduce private information about language constraints, which take the form of availability constraints: an agent's language type is the set of messages available to the agent.[11] Each player's private information is two-dimensional, described by her payoff and language types. In sender-receiver games, in which senders have private information about which messages they have access to, receivers, who only care about payoff relevant information, face a signal extraction problem. Receivers do not know to what extent the message they observe is determined by the sender's language type. This produces a sense in which misunderstandings can arise in equilibrium, since payoff relevant information is confounded by information about language competence. Blume and Board show that this confounding of information about payoffs with information about language is optimal in common-interest games (in contrast, say, to only using messages which are commonly known to always be available). This line of work has recently been extended by Giovannoni and Xiong [18] and Hagenbach and Koessler [19]. Our experiment explicitly relies on this language-type paradigm. An innovation is that, unlike in Blume and Board, in our experiment there is a distinction between focal and meaningless messages, and a tension between efficient and focal message use.

Prior experiments involving language constraints focus either on the emergence of meaning from initially meaningless messages or on the process of adapting natural language to novel situations. Blume, DeJong, Kim and Sprinkle [3] (BDKS98) investigate the emergence of meaning of messages in sender-receiver games with common interests, inspired by Lewis [23]. They look at games with two payoff states and enforce initial absence of meaning by randomizing over private representations of messages. They find that in simple common-interest games with feedback about population behavior, message meaning gradually emerges to the point where after 20 periods players are fully coordinated. Bruner, O'Connor, Rubin and Huttegger [9] (BORH) obtain similar results without feedback about population behavior, having subjects interact for more periods. Our experiment also uses meaningless messages, except that they are available concurrently with focal messages, and there is a temptation to use focal messages to mislead. This temptation is a result of players' agreeing only on the

[11] Blume [8] uses this language-type paradigm to investigate the impact of higher-order uncertainty about language on efficiency in common-interest games.

most preferred action in each state, and not the entire ranking of actions, as in BDKS and BORH. That is, we are looking at common-maximum games, whereas BDKS and BORH focus on the smaller class of common-interest games.

Krauss and Weinheimer [21] [22] experimentally study the evolution of reference phrases for novel items (non-standard geometric objects). Subjects use free-form communication with natural language as opposed to a restricted set of pre-fabricated messages. They find that the length of a reference phrase used to describe a figure is inversely related to the frequency with which it is mentioned and decreases over time. Reference phrases are shorter with two-way than one-way communication. Weber and Camerer [32] use a picture identification task to study cultural conflict and mergers in organizations. Senders describe office scenes to receivers, using free-form communication. The sender is given pictures in a particular order and describes them to the receiver. Payoffs depend on how quickly the receiver identifies the correct order. Over time, teams develop succinct descriptions for each figure and these descriptions differ across teams. These conflicting languages create problems when teams are merged. Post-merger completion times at first significantly increase, and while they drop subsequently, they never achieve pre-merger levels. Weber and Camerer achieve mismatch of codes, and as a result efficiency losses, by merging teams with team-specific languages. We impose mismatches by fixing the receiver language while privately randomizing the sender language. Weber and Camerer document dramatic reductions in efficiency right after a merger and a partial recovery thereafter. In our setting, in the treatment we observe both an initial departure from efficiency, and a further gradual decline in efficiency, as receivers learn to doubt the focal meanings of messages.

6 Summary and discussion

In this paper, we consider communication in a setting with lack of common knowledge of message availability. This lack of common knowledge threatens to compromise pre-established, focal, message meanings. There are what we refer to as focal equilibria, in which focal messages are used in agreement with their pre-established meaning. These equilibria are equilibrium efficient – they maximize both the sender's and the receiver's equilibrium payoffs. These equilibria, however, are fragile. They require players to assign meanings to neutral messages, which have no pre-established meaning. Without such an assignment, that is if neutral messages are interpreted as uninformative, focal use of focal messages is not consistent with equilibrium play; it tempts senders to substitute available but inappropriate focal messages for appropriate but unavailable focal messages. If neutral messages remain meaningless, only pooling equilibria survive. Pooling equilibria have substantially lower payoffs for both players than the equilibrium-efficient focal equilibria. Hence, if the assignment of meaning to meaningless messages proves difficult, pre-established meanings become fragile as well, entailing a significant efficiency loss.

We explore this environment in the laboratory. We find that behavior is more consistent with pooling than with equilibrium-efficient play. Focal messages end up not being interpreted in accordance with their focal meaning. This result is robust to a reduction in the number of payoff states and with it of the size of the basin of attraction of the pooling action. Payoffs are closer to equilibrium-efficient payoffs in the simplest *2-payoff-state* condition, but even there payoffs remain bounded away from equilibrium-efficiency. This pattern suggests that if there were a larger number of payoff states, the *fragility of meaning* would be even more pronounced.

Our key finding is that communication may be impeded not just by lack of a shared language, but also by uncertainty about which parts of language are shared. This suggests, for example, that when experts communicate with non-experts, as in doctor-patient communication, they should endeavor to establish a common understanding of terms that are central to their conversation. When interests are aligned, as in the common-maximum games we investigate in this paper, all sides benefit from establishing common knowledge of the meaning of terms.

How well do we understand each other? Even assuming away incentive concerns, it seems likely that public discourse faces considerable hurdles when the subject matter is difficult, experts communicate with laymen, or experts develop novel terminologies necessary to formulate new insights. The resulting communication failures are difficult to study in the field since we can only access intended meaning when we believe we understand. Frequently, intended meaning being private information, we are unable to evaluate how successful communication was and could have been. Therefore lab experiments can be useful. The lab makes it possible to induce lack of shared meaning and vary the degree to which meaning is shared.

Meaning in our setting is compromised because of the difficulty of finding suitable alternatives when meanings appropriate for the situation are not available. This creates the temptation for senders of using substitute focal messages, which in turn compromises the meaning of those messages. In our experiment, we have chosen a middle ground for the difficulty of finding alternatives for unavailable focal meanings. On one hand, the task is made difficult by having fewer neutral messages than there are payoff states, by using a random matching protocol, and by only providing history information at the population level. On the other hand, the task is facilitated by the fact that there are focal equilibria that entail only a minimal payoff loss relative to ex post efficiency, and by not eliminating potential focal characteristics of neutral messages (like keyboard ordering, ordering of symbols in the instructions, intrinsic characteristics of symbols, etc.). This suggests a number of alternative setups worth exploring. We suspect that with fixed matching message meaning will be less fragile, whereas with fewer options for using alternative messages (e.g., at the extreme eliminating all neutral messages) pre-established message meanings will be more fragile.

We use uncertainty about message availability as a device to create uncertainty about message meaning. There are other avenues for inducing uncertain meaning that one might consider. One possibility that comes to mind is to give subjects "translation manuals" that suggest meanings for otherwise meaningless messages. If these translation manuals are not all identical and translation manuals are private information, meaning will be uncertain.

A Appendix - proof of the proposition

Proof: In the 2-payoff-state game, suppose the receiver employs a neutral strategy, but there is a message after which the receiver responds with an action other than action Z. Without loss of generality, let that message be a. Then language type λ_a will send a regardless of the payoff type, since the sender is always worst off if the receiver chooses Z. The posterior probability of payoff type θ following message a is maximized if payoff type θ sends message a when all messages are available, and no other payoff type ever sends a. Suppose, again without loss of generality, that only payoff type A sends message a when all messages are available. Then the posterior probability of the sender having payoff type A following message a is $\frac{2}{3} < \frac{7}{10}$, and hence the unique best reply to message a is action Z. A similar argument holds for message b. The best response to any focal message is to play Z. The argument for the 3-and 6-payoff-state games is nearly identical, except that the maximal posterior probability of any payoff type is even lower than $\frac{2}{3}$. This establishes that, regardless of the condition, every neutral equilibrium is a pooling equilibrium.

Next, we provide an example of a non-pooling equilibrium for each of the three games and establish that that equilibrium achieves the maximal equilibrium payoff for both players.

For the 2-payoff-state game: Consider the following strategy profile: $\sigma(a|A, \lambda_{a,b}) = \sigma(b|B, \lambda_{a,b}) = \sigma(a|A, \lambda_a) = \sigma(*|B, \lambda_a) = 1$, $\sigma(*|A, \lambda_b) = \sigma(*|B, \lambda_b) = \frac{1}{2}$, $\rho(X|a) = \rho(Y|b) = \rho(Y|*) = 1$.

Given the receiver's strategy, the sender strategy is clearly optimal. Also, since the posterior probability of payoff type A is 1 following message a, it is uniquely optimal for the receiver to respond with action X to message a. Finally, the posterior probability of payoff type B after either message $*$ or b is $\frac{3}{4}$ and since $\frac{3}{4} \times 10 > 7$ it is (uniquely) optimal for the receiver to respond to both messages $*$ and b with taking action Y. This shows that (σ, ρ) is an equilibrium strategy profile. The sender payoff from this profile is $9.8\overline{3}$ and the receiver payoff is $8.\overline{3}$.

To see that this strategy profile achieves the maximal equilibrium payoff for the sender, note that the maximal payoff of the sender (from any strategy profile) can be achieved with a receiver strategy that does not respond with action Z to any message. If the receiver uses such a strategy, there must be at least at least one pair of messages that induce the same action. Hence, there is at least a $\frac{1}{6}$ chance that the sender's realized payoff is 9 or less. This implies that $\frac{5}{6} \times 10 + \frac{1}{6} \times 9 = 9.8\overline{3}$ is an upper bound on the sender's equilibrium payoff.

To see that this strategy profile achieves the maximal equilibrium payoff for the receiver, suppose that there is an equilibrium in which the receiver payoff exceeds $8.\overline{3}$. Then there must be a message that induces an action other than Z. Without loss of generality, let that message be a. Suppose that in addition action Z is induced with positive probability. Then both messages b and $*$ must induce action Z. This implies that both payoff types send message a when that message is available. Hence, the receiver's posterior assigns equal probability to both payoff types after observing message Z. This implies that message a must induce action Z, contrary to what we assumed. Therefore action Z is not taken in any equilibrium in which the receiver payoff exceeds $8.\overline{3}$. Once action Z is excluded from consideration, the receiver's payoffs are equivalent to the sender's payoffs up to an affine transformation. Therefore the problem of finding a receiver-optimal equilibrium becomes equivalent to that of finding a sender-optimal equilibrium. Hence, $8.\overline{3}$ is the maximal payoff of the receiver in any equilibrium.

For the 3-payoff-state game: Consider the following strategy profile: $\sigma(m_\theta|\theta, \lambda_{a,b,c}) = 1$ for all $\theta \in \Theta$. $\sigma(a|A, \lambda_a) = 1$, $\sigma(*|B, \lambda) = 1$ if $* \in \lambda$, $\sigma(\#|C, \lambda) = 1$ if $\# \in \lambda$, $\sigma(*|A, \lambda) = \sigma(\#|A, \lambda) = \frac{1}{2}$ if $a \notin \lambda$, $\rho(W|a) = 1$, $\rho(X|b) = 1$, $\rho(Y|c) = 1$, $\rho(X|*) = 1$, $\rho(Y|\#) = 1$. The sender's strategy is clearly optimal, given the receiver's strategy. Following messages a, b and c the receiver's beliefs are concentrated on a single payoff type and his response is clearly optimal. Following message $*$ the posterior probability of payoff type B is $\frac{3}{4}$ and therefore action X is uniquely optional. Following message $\#$ the posterior probability of payoff type C is $\frac{3}{4}$ and therefore action Y is uniquely optional. The sender payoff from this profile is $9.8\overline{3}$ and the receiver payoff is $8.\overline{3}$.

To see that this strategy profile achieves the maximal equilibrium payoff for the sender, consider any equilibrium in which the two neutral messages induce the same action. There is a $\frac{3}{4}$ chance that the sender has only one of the focal messages available. In that case, since two of the neutral messages induce the same action, the sender cannot induce one of the three actions W, X, or Y with the messages available to her. Therefore, there is at least a $\frac{1}{3}$ chance that she does not have a message to indicate her payoff type. Hence, there is at least a $\frac{3}{4} \times \frac{1}{3}$ chance that the sender's realized payoff is 9 or less. This implies that the sender's maximal payoff in such an equilibrium is bounded from above by $\frac{1}{4} \times 9 + \frac{3}{4} \times 10 = 9.75$. Thus, for the sender to receive a payoff that is higher than $9.8\overline{3}$, both neutral messages have to induce distinct actions that are different from action Z. Without loss of generality, suppose the two neutral messages induce the actions W and X. Suppose that for some action, $k \geq 2$ of the focal messages induce that action. There are two cases to consider:

Case 1: The action induced by these messages is action Y. Then there is a $\frac{1}{4}$ chance that the sender has only the focal messages available, in which case there is at least a $\frac{k-1}{3}$ chance that she lacks the message to indicate her payoff type. There is at least a $\frac{3-k}{4}$ chance that the sender has only one of the focal messages available and that message induces the same action as one of the neutral messages, in which case there is a $\frac{1}{3}$ chance that she lacks the message to indicate her payoff type. Combining these two observations, the probability of inducing an action with a payoff of 9 or less is at least $\frac{1}{4} \times \frac{k-1}{3} + \frac{3-k}{4} \times \frac{1}{3} = \frac{1}{6}$. Therefore in this case the sender's payoff is bounded from above by $\frac{1}{6} \times 9 + \frac{5}{6} \times 10 = 9.8\overline{3}$.

Case 2: The action induced by these messages is an action other than Y. Then, again, there is a $\frac{1}{4}$ chance that the sender has only the focal messages available, in which case there is at least a $\frac{k-1}{3}$ chance that she lacks the message to indicate her payoff type. There is at least a $\frac{2}{4}$ chance that the sender has only one of the focal messages available and that message does not induce action Y, in which case there is a $\frac{1}{3}$ chance that she lacks the message to indicate her payoff type. Combining these two observations, the probability of inducing an action with a payoff of 9 or less is at least $\frac{1}{4} \times \frac{k-1}{3} + \frac{2}{4} \times \frac{1}{3} \geq \frac{1}{4} \times \frac{1}{3} + \frac{2}{4} \times \frac{1}{3} = \frac{3}{12}$. Therefore in this case the sender's payoff is bounded from above by $\frac{3}{12} \times 9 + \frac{9}{12} \times 10 = 9.75$.

Thus, in any equilibrium that yields a sender payoff of at least $9.8\overline{3}$, both neutral messages induce distinct actions different from Z and all focal messages induce distinct actions different from Z. For any receiver strategy that satisfies this condition, the sender's maximal payoff is $9.8\overline{3}$.

To see that this strategy profile achieves the maximal equilibrium payoff for the receiver, note that since there is an equilibrium with receiver payoff $8.\overline{3}$, any receiver-optimal equilibrium must achieve at least that payoff. To achieve this or a higher payoff, there has to be at least one message that induces an action other than action Z. Consider equilibria in which some message induces action Z. In this class, consider an equilibrium in which all focal messages induce action Z. Then one of the neutral messages must induce an action other than Z. Hence, whenever the sender has the neutral messages available she will induce an action other than Z and therefore not use the one focal message available. There is at least a $\frac{1}{3}$ chance that the neutral messages do not allow the sender to indicate her payoff type, in which case the receiver's payoff is zero. Therefore, the receiver's payoff in the postulated equilibrium cannot exceed $\frac{1}{4} \times 7 + \frac{3}{4} \times \frac{2}{3} \times 10 = 6.75$. Since the receiver can guarantee a payoff of 7, there is no such equilibrium. Consider equilibria in which action Z is induced with positive probability and at least one focal message induces an action other than Z. If there is a focal message that induces an action other than Z, then for action Z to be induced with positive probability, all neutral messages must induce action Z and at least one focal message must induce action Z. With probability $\frac{1}{4}$ all focal messages are available. Since there are both focal messages that induce and do not induce action Z, the highest expected payoff for the receiver in that case is $\frac{2}{3} \times 10$.

With probability at least $\frac{1}{4}$ only one focal message is available and that message induces action Z. In that case the expected payoff of the receiver is 7, remembering that all neutral messages must induce action Z.

This leaves the case in which only one focal message is available and that message induces an action other than Z. In that case the highest expected payoff of the receiver is $\frac{1}{3} \times 10$.

Hence, the upper bound on the receiver payoff from equilibria in this class is $\frac{1}{4} \times \frac{2}{3} \times 10 + \frac{3}{4} \times 7 = 6.91\overline{6}$. Since the receiver can guarantee a payoff of 7, there is no such equilibrium.This implies that there does not exist a receiver-optimal equilibrium in which action Z is induced with positive probability. Once action Z is excluded from consideration, the receiver's payoffs are equivalent to the sender's payoffs up to an affine transformation. Therefore the problem of finding a receiver-optimal equilibrium becomes equivalent to that of finding a sender-optimal equilibrium.

Recall that in any equilibrium that maximizes the sender's payoff both neutral messages induce distinct actions different from Z and all focal messages induce distinct actions different from Z. For any receiver strategy that satisfies this condition and any sender strategy that maximizes the sender's payoff against that receiver strategy, the receiver's payoff equals $8.\overline{3}$.

For the 6-payoff-state game: Consider the following strategy profile: $\sigma(m_\theta|\theta, \lambda_{a,b,c,d,e,f}) = \sigma(m_\theta|\theta, \lambda_{m_\theta}) = 1$ for all $\theta \in \Theta$. $\sigma(*|B, \lambda) = 1$ if $b \notin \lambda$, $\sigma(\#|C, \lambda) = 1$ if $c \notin \lambda$, $\sigma(\%|D, \lambda) = 1$ if $d \notin \lambda$, $\sigma(@|E, \lambda) = 1$ if $e \notin \lambda$, $\sigma(\hat{}\,|F, \lambda) = 1$ if $f \notin \lambda$, $\sigma(*|A, \lambda) = \sigma(\#|A, \lambda) = \sigma(\%|A, \lambda) = \sigma(@|A, \lambda) = \sigma(\hat{}\,|A, \lambda) = \frac{1}{5}$ if $a \notin \lambda$, $\rho(T|a) = 1$, $\rho(U|b) = 1$, $\rho(V|c) = 1$, $\rho(W|d) = 1$, $\rho(X|e) = 1$, $\rho(Y|f) = 1$, $\rho(U|*) = 1$, $\rho(V|\#) = 1$, $\rho(W|\%) = 1$, $\rho(X|@) = 1$, $\rho(Y|\hat{}\,) = 1$. Given the receiver strategy, the sender strategy is clearly optimal. Following messages a, b, c, d, e, f the receiver's beliefs are concentrated on a single payoff type and his response is clearly optimal. Following message $*$ the posterior probability of payoff type B is $\frac{5}{6}$ and therefore action U is uniquely optional. The argument for the remaining messages, #, %, @ and ˆ is the same up to exchanging the roles of payoff types and actions. The sender payoff from this profile is 9.88 and the receiver payoff is 8.81.

To see that this strategy profile achieves the maximal equilibrium payoff for the sender, consider any equilibrium in which two of the neutral messages induce the same action. There is a $\frac{6}{7}$ chance that the sender has only one of the focal messages available. In that case, since two of the neutral messages induce the same action, the sender cannot induce one of the six actions T, U, V, W, X, or Y with the messages available to her. Therefore, there is at least a $\frac{1}{6}$ chance that she does not have a message to indicate her payoff type. Hence, there is at least a $\frac{6}{7} \times \frac{1}{6}$ chance that the sender's realized payoff is 9 or less. This implies that the sender's maximal payoff in such an equilibrium is bounded from above by $\frac{1}{7} \times 9 + \frac{6}{7} \times 10 = 9.86$. Thus, for the sender to receive a payoff that is higher than 9.88, all five neutral messages have to induce distinct actions that are different from action Z. Without loss of generality, suppose the five neutral messages induce the actions T, U, V, W, and X. Suppose for some action $k \geq 2$ of the focal messages induce that action. There are two cases to consider:

Case 1: The action induced by these messages is action Y. Then there is a $\frac{1}{7}$ chance that the sender has only the focal messages available, in which case there is at least a $\frac{k-1}{6}$ chance that she lacks the message to indicate her payoff type. There is at least a $\frac{6-k}{7}$ chance that the sender has only one of the focal messages available and that message induces the same action as one of the neutral messages, in which case there is a $\frac{1}{6}$ chance that she lacks the message to indicate her payoff type. Combining these two observations, the probability of inducing an action with a payoff of 9 or less is at least $\frac{1}{7} \times \frac{k-1}{6} + \frac{6-k}{7} \times \frac{1}{6} = \frac{5}{42}$. Therefore in this case the sender's payoff is bounded from above by $\frac{5}{42} \times 9 + \frac{37}{42} \times 10 = 9.88$.

Case 2: The action induced by these messages is an action other than Y. Note that given the previous case, it suffice to consider the case where at most one of the remaining focal messages induces action Y. Then, again, there is a $\frac{1}{7}$ chance that the sender has only the focal messages available, in which case there is at least a $\frac{k-1}{6}$ chance that she lacks the message to indicate her payoff type. There is at least a $\frac{5}{7}$ chance that the sender has only one of the focal messages available and that message does not induce action Y, in which case there is a $\frac{1}{6}$ chance that she lacks the message to indicate her payoff type. Combining these two observations, the probability of inducing an action with a payoff of 9 or less is at least $\frac{1}{7} \times \frac{k-1}{6} + \frac{5}{7} \times \frac{1}{6} \geq \frac{1}{7} \times \frac{1}{6} + \frac{5}{7} \times \frac{1}{6} = \frac{6}{42}$. Therefore in this case the sender's payoff is bounded from above by $\frac{6}{42} \times 9 + \frac{36}{42} \times 10 = 9.86$.

Thus, in any equilibrium that yields a sender payoff of at least 9.88, all neutral messages induce distinct actions different from Z and all focal messages induce distinct actions different from Z. For any receiver strategy that satisfies this condition, the sender's maximal payoff is 9.88.

To see that this strategy profile achieves the maximal equilibrium payoff for the receiver, observe that since there is an equilibrium with receiver payoff 8.81, any receiver-optimal equilibrium must achieve at least that payoff. To achieve this or a higher payoff, there has to be at least one message that induces an action other than action Z. Consider equilibria in which some message induces action Z. In this class, consider an equilibrium in which all focal messages induce action Z. Then one of the neutral messages must induce an action other than Z. Hence, whenever the sender has the neutral messages available she will induce an action other than Z and therefore not use the one focal message available. There is at least a $\frac{1}{6}$ chance that the neutral messages do not allow the sender to indicate her payoff type, in which case the receiver's payoff is zero. Therefore, the receiver's payoff in the postulated equilibrium cannot exceed $\frac{1}{7} \times 7 + \frac{6}{7} \times \frac{5}{6} \times 10 = 8.14$. Hence no equilibrium of the postulated form can be optimal for the receiver.

Consider equilibria in which action Z is induced with positive probability and at least one focal message induces an action other than Z. If there is a focal message that induces an action other than Z, then for action Z to be induced with positive probability, all neutral messages must induce action Z and at least one focal message must induce action Z. With probability $\frac{1}{7}$ all focal messages are available. Since there are both focal messages that induce and do not induce action Z, the highest expected payoff for the receiver in that case is $\frac{5}{6} \times 10$.

With probability at least $\frac{1}{7}$ only one focal message is available and that message induces action Z. In that case the expected payoff of the receiver is 7, remembering that all neutral messages must induce action Z. This leaves the case in which only one focal message is available and that message induces an action other than Z. In that case the highest expected payoff of the receiver is $\frac{1}{6} \times 10$. Hence, the upper bound on the receiver payoff from equilibria in this class is $\frac{1}{7} \times \frac{5}{6} \times 10 + \frac{6}{7} \times 7 = 7.19$. This implies that there does not exist a receiver-optimal equilibrium in which action Z is induced with positive probability.

Once action Z is excluded from consideration, the receiver's payoffs are equivalent to the sender's payoffs up to an affine transformation. Therefore the problem of finding a receiver-optimal equilibrium becomes equivalent to that of finding a sender-optimal equilibrium. Recall that in any equilibrium that maximizes the sender's payoff both neutral messages induce distinct actions different from Z and all focal messages induce distinct actions different from Z. For any receiver strategy that satisfies this condition and any sender strategy that maximizes the sender's payoff against that receiver strategy, the receiver's payoff equals 8.81. $\square$

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