Experimental Implementations and Robustness of Fully Revealing Equilibria in Multidimensional Cheap Talk*

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Abstract

We design experiments that capture the essence of the theoretical environments studied in multidimensional cheap talk. Two senders transmit information to a receiver over a 2×2 state space. Interests are overall misaligned, but common interests exist between each sender and the receiver along different dimensional components of the state, which are exploited in equilibrium for full revelation. Observed frequencies of receivers identifying the state are significantly higher in two-sender games than in the control game with one sender, in a manner consistent with the respective fully and partially revealing equilibria. By manipulating message/state space to control for out-of-equilibrium beliefs, we investigate the robustness of the fully revealing equilibrium and observe significantly lower adherence when the equilibrium requires support of "implausible beliefs." Introducing a fraction of honest senders to the equilibrium model rationalizes our findings.

Keywords: Strategic Information Transmission; Multidimensional Cheap Talk; Fully Revealing Equilibrium; Robust Equilibrium; Laboratory Experiment; Honest Senders

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1 Introduction

A defining hallmark of modern economies is the high degree of specialization that occurs in both physical production and the more intangible domain of decision making and information handling. Comparative advantage may not only dictate decision makers to pass the job of gathering information to experts, but may also guide different experts to specialize in offering advice on separate areas. When conflicts of interests are present, strategic considerations may provide yet another reason for decision makers to consult different experts on different issues—even when comparative advantage is not a deciding factor. For instance, a legislator who consults an interested advisor on the potential impacts of a bill may obtain impartial advice on some areas but not the others, seeding the need to cross-check with another advisor who might be forthright in a different manner. In a seminal paper on multidimensional cheap talk, Battaglini (2002) provides a formal strategic argument for otherwise equally informed experts to specialize in giving advice on different dimensions.[1]

The theory of multidimensional cheap talk contrasts sharply with its unidimensional counterpart. In the canonical model of Crawford and Sobel (1982), a sender transmits information to a receiver whose uncertainty is unidimensional. The analysis renders a clear picture, which survives modeling variations within the single-sender-single-dimension environment: unless players' interests are perfectly aligned, only partial information can be transmitted, the extent of which is decreasing in the sender's bias.[2] The picture changes drastically when one more sender is introduced and the uncertainty becomes multidimensional. Battaglini (2002) demonstrates how the receiver can fully identify the state with two biased senders providing information on different dimensions over a multidimensional (unbounded) state space. More strikingly, the fully revealing equilibrium survives regardless of how biased the senders are.

The different informational properties of the equilibria represent only one disparity that the departure from the single-sender environment brings—robustness is another. With one sender, out-of-equilibrium beliefs arise only after unused messages, which can be disregarded without any impact on equilibrium outcomes.[3] With two senders, out-of-equilibrium beliefs can arise when the senders' messages present inconsistent information. Unlike the case of

[1]Cheap-talk models have been a theoretical arena for studying the strategic interactions between experts and decision makers. Other than the interactions between legislators and advisors (Gilligan and Krehbiel, 1989; Krishna and Morgan, 2001b), they have shed light on, for example, the interactions between stock analysts and investors (Morgan and Stocken, 2003) and those between doctors and patients (Kőzegi, 2006).

[2]Such informational property of the equilibrium is invariant to, for example, the introduction of additional round of communication (Krishna and Morgan, 2004), noise in the communication channel (Blume et al., 2007), and the introduction of mediator (Goltsman et al., 2009; Ivanov, 2010).

[3]In cheap-talk games, for any equilibrium with unused messages there exists another outcome-equivalent equilibrium in which all messages are used. Accordingly, alternative specifications of the receiver's beliefs after unused messages do not rule out any equilibrium outcome. See, for example, the discussion in Farrell (1993).

unused messages, this can have robustness implications for equilibrium outcomes. Battaglini (2002), for example, points out that while fully revealing equilibrium also exists with two senders when the state space is unidimensional, it is not robust in that it requires the support of implausible out-of-equilibrium beliefs.[4] Even though in Battaglini's (2002) equilibrium construction for multidimensional state space messages will never convey inconsistent information because they are about different dimensions, Ambrus and Takahashi (2008) point out that out-of-equilibrium beliefs can still arise if the state space is bounded: after a deviation, the messages may point to a "state" that lies outside the state space. Intuitively, when one investment advisor advocates strongly for stocks and another strongly for bonds, investors are likely to question if no economic condition exists that warrants heavy investments in both. Robust fully revealing equilibrium in multidimensional cheap talk is an issue that cannot be sidestepped, and various authors have drawn different conclusions using different criteria.[5]

We design cheap-talk games that allow us to replicate Battaglini's (2002) equilibrium construction in a simple discrete environment suitable for experimental implementations. While the plausibility of equilibria is typically evaluated on theoretical grounds in reference to certain robustness criteria, experimental research may bring in empirical regularity as a complementary criterion for the inquiry, which may in turn inform the theory. Our simple design allows us to control for the scenarios in which out-of-equilibrium beliefs arise. With the control at our disposal and guided by a robustness criterion, we explore empirically the plausibility of the fully revealing equilibrium in multidimensional cheap talk. Our main finding is that theoretically robust equilibria are also empirically plausible: they are more likely to be implemented in the laboratory than are equilibria that require the support of implausible beliefs.

In one of our baseline games, Game T, two senders (he), Sender 1 and Sender 2, transmit information to a receiver (she) over a 2 (horizontal dimension) $\times$ 2 (vertical dimension) state space. The receiver chooses an action out of four after receiving the senders' simultaneous messages. Each sender's message space contains four messages, which are costless and framed in the experiment as non-binding recommendations. Senders' and receiver's interests are misaligned: in each state, their ideal actions do not coincide. Yet, when each sender's influence on the receiver is restricted to a distinct dimension, the sender and the receiver share a common

[4] Analysis of unidimensional (or discrete) state space with multiple senders starts with Gilligan and Krehbiel (1989) and Austen-Smith (1993), followed by Krishna and Morgan (2001a,b). Battaglini (2002) revisits the problem with more complete characterizations. Ambrus and Lu (2010) and Lu (2011) further investigate robust equilibria in such environment. For analysis of multidimensional state space with single sender, see Levy and Razin (2007) and Chakraborty and Harbaugh (2007, 2010). For papers that introduce additional receiver, see Farrell and Gibbons (1989) and Goltsman and Pavlov (2011).

[5] Under different information structures, Battaglini (2004) shows that the fully revealing equilibrium under unbounded state space is robust to noise in senders' observations, whereas Levy and Razin (2007) show that it is not. Ambrus and Takahashi (2008) show that imposing the so-called "diagonal continuity" drastically reduces the possibility of full revelation under bounded state space. Kim (2010) proposes yet another criterion—"outcome-robustness"—and shows that no fully revealing equilibrium in Levy and Razin (2007) survives.

ranking of the relevant actions. By prescribing Sender 1 to reveal on the horizontal dimension and Sender 2 the vertical dimension, such preference structure is exploited in equilibrium, allowing the receiver to fully identify the state even when interests are overall misaligned.

We implement Game T in the laboratory, comparing it to another baseline game, Game S, where there is only one sender and equilibrium predicts partial information revelation. Providing support to the theoretical predictions, the receivers in Game T identify the true state and take the ideal actions significantly more often than do the receivers in Game S. Consistently, higher receivers' payoffs (as predicted under full revelation) are noted in Game T. Observed message uses are also consistent with the fully revealing equilibrium: Senders 1 and Senders 2 truthfully reveal only on, respectively, the horizontal and the vertical dimension. They babble on the other dimensions by randomizing over messages approximately uniformly. On the receiving end, the receivers exhibit the sophistication to identify who to listen to for which dimension, most notably when the senders' messages are inconsistent. In Game S, as predicted such observations only occur for the horizontal dimension.

We manipulate the sizes of the message/state space to control for the emergence of out-of-equilibrium beliefs, resulting in two additional games, Game T′ and Game R. Game T′ is similar to Game T but with binary message spaces. The truncated message spaces eliminate, in the laboratory, the occurrence of inconsistent messages and, in the theory, any out-of-equilibrium beliefs for the fully revealing equilibrium. Game R provides a discrete analog of the restricted state space considered in Ambrus and Takahashi (2008); otherwise the same as Game T′, it has only three states. In its fully revealing equilibrium, out-of-equilibrium beliefs arise in a unique way: when after a deviation senders' messages point to the "state" that is now nonexistent. We use Battaglini's (2002) robustness criterion, which requires the receiver's beliefs to be continuous transiting from equilibrium to off-equilibrium paths. We show that the fully revealing equilibrium in Game R is not robust, while that in Game T′, given that it is free of out-of-equilibrium beliefs, inevitably passes the test. The analysis serves as a theoretical basis for our empirical inquiry.

The qualitative robustness properties are reflected quantitatively in our findings. In Game R, while full revelation outcomes still occur more often than what can be attributed to chance alone, they occur significantly less often than do those in Game T′. The receivers in Game R never respond to out-of-equilibrium message pairs with the action that is required to support the fully revealing equilibrium, lending empirical support to the implausibility of the non-robust equilibrium. In addition, while the receivers are still best responding to the senders, some of the senders use messages in ways that do not constitute best responses to the receivers' actions. Motivated by individual subject data that suggest some senders always tell the truth while others are best responding, we deploy a behavioral model with a positive fraction of non-strategically honest senders to rationalize the findings from Game R.

The experimental literature of communication games has focused on games with one sender and one receiver.[6] Our contribution on the experimental front lies in augmenting the laboratory environment with one more sender. In a study in political science, Minozzi and Woon (2011) also examine games with two senders, but in a single dimensional environment where senders' bias is private information. Battaglini and Makarov (2011) introduce additional receiver, testing the prediction of Farrell and Gibbons (1989). A common experimental finding from single-sender-single-receiver games is the "over-transmission of information" (e.g., Dickhaut et al., 1995; Blume, et al., 1998, 2001; Cai and Wang, 2006; Kawagoe and Takizawa, 2009). Although not the main focus of our study, our finding from the single-sender Game S, in which partial information is transmitted as predicted, contrasts with these prior findings.

Section 2 presents the four cheap-talk games. Section 3 formulates our experimental hypotheses and describes the experimental procedures. Section 4 reports and analyzes our findings. Section 5 concludes. Proofs are relegated to Appendix A. Appendix B contains a sample of (translated) experimental instructions. (Appendices C and D, not intended for publication, contain additional analysis/tables/figures and the original instructions in Chinese.)

2 Two-Dimensional Cheap-Talk Games

2.1 The Strategic Environment

In all but one of our cheap-talk games, uncertainty is represented by a discrete state of the world that consists of two dimensional components, each being a binary variable: $(x, y) \in \{x_1, x_2\} \times \{y_1, y_2\}$.[7] The common priors are that the four possible states are equally likely. Players consist of a receiver and one or two senders. We proceed by describing the case with two senders. After observing the state, Sender i, $i = 1, 2$, sends a cheap-talk message, $m \in M_i$, to the receiver.[8] The senders' messages are sent simultaneously, upon the receipt of which the receiver takes an action $a \in A = \{a_{11}, a_{21}, a_{12}, a_{22}\}$. A behavioral strategy of Sender i is $\sigma_i : \{x_1, x_2\} \times \{y_1, y_2\} \to \Delta M_i$ and that of the receiver is $\rho : M_1 \times M_2 \to \Delta A$. The receiver's

[6]See Crawford (1998) for a survey of earlier studies and Sánchez-Pagés and Vorsatz (2007, 2009) for two recent studies.

[7]Our design is shaped by two considerations: to create an environment as simple as possible that is conducive to subjects' comprehension of the problem (Binmore, 1999) and to capture the essence of Battaglini's (2002) equilibrium construction. The simplification necessarily entails discrepancies with Battaglini (2002). For instance, while "dimension" in his paper refers to the dimension of a vector space (the two-dimensional Euclidean state space), we use the term to refer to the components of our discrete state.

[8]Theoretically, there is no restriction on the message spaces as long as their cardinality does not constrain the set of equilibrium outcomes. Our design covers both binary message spaces and spaces with four messages.

beliefs function is $\mu : M_1 \times M_2 \to \Delta(\{x_1, x_2\} \times \{y_1, y_2\})$. Payoffs are determined by state and action. The equilibrium solution is perfect Bayesian equilibrium, where strategies are optimal given beliefs and beliefs are derived from Bayes' rule whenever possible.

Table 1: Preference Orders over State-Action

	(x_1, y_1)	(x_2, y_1)	(x_1, y_2)	(x_2, y_2)
Sender 1	$\max_{\succsim}(a_{12}, a_{22}) \succsim a_{11} \succsim a_{21}$	$\max_{\succsim}(a_{12}, a_{22}) \succsim a_{21} \succsim a_{11}$	$\max_{\succsim}(a_{11}, a_{21}) \succsim a_{12} \succsim a_{22}$	$\max_{\succsim}(a_{11}, a_{21}) \succsim a_{22} \succsim a_{12}$
Sender 2	$\max_{\succsim}(a_{21}, a_{22}) \succsim a_{11} \succsim a_{12}$	$\max_{\succsim}(a_{11}, a_{12}) \succsim a_{21} \succsim a_{22}$	$\max_{\succsim}(a_{21}, a_{22}) \succsim a_{12} \succsim a_{11}$	$\max_{\succsim}(a_{11}, a_{12}) \succsim a_{22} \succsim a_{21}$
Receiver	$a_{11} \succsim a_{22} \succsim a_{12} \succsim a_{21}$	$a_{21} \succsim a_{12} \succsim a_{22} \succsim a_{11}$	$a_{12} \succsim a_{21} \succsim a_{11} \succsim a_{22}$	$a_{22} \succsim a_{11} \succsim a_{21} \succsim a_{12}$

Battaglini's (2002) equilibrium construction leverages on the common interests shared between the senders and the receiver in a lower dimension, even though in a higher dimension their interests are misaligned. There are more than one way to capture this preference structure in our setting. Table 1 presents the possible preference orders over actions in each state, which serve as our guide for assigning payoffs for the games we experiment on. The overall interests are misaligned: in each two-dimensional state senders' and receiver's ideal actions do not coincide. For example, in state (x_1, y_2), Sender 1's ideal action is either a_{11} or a_{21} [$\max_{\succsim}(a_{11}, a_{21})$], whereas the receiver's is a_{12}.[9] Yet each sender shares a common ranking of actions with the receiver when the action choices are restricted to be in a lower, single dimension. In particular, the following is relevant for the construction of fully revealing equilibrium:

1. Sender 1 and the receiver
   (a) Fixing $y = y_1$, both prefer a_{11} to a_{21} when $x = x_1$ and a_{21} to a_{11} when $x = x_2$.
   (b) Fixing $y = y_2$, both prefer a_{12} to a_{22} when $x = x_1$ and a_{22} to a_{12} when $x = x_2$.
2. Sender 2 and the receiver
   (a) Fixing $x = x_1$, both prefer a_{11} to a_{12} when $y = y_1$ and a_{12} to a_{11} when $y = y_2$.
   (b) Fixing $x = x_2$, both prefer a_{21} to a_{22} when $y = y_1$ and a_{22} to a_{21} when $y = y_2$.

To illustrate how these conditionally aligned interests can be exploited for full revelation, suppose (x_1, y_2) is realized. Given that ideal actions do not coincide, the receiver cannot

[9] We implement games with different ideal actions for the senders in some states. The weak preferences are in most cases implemented in strict preferences, ensuring that ideal actions are unique in each state. Although players are assumed to be von Neuman-Morgenstern utility maximizers and thus carry cardinal preferences, the illustration in this subsection remains intact if the preference orders are considered ordinal.

count on a single sender to pin down the truth. The situation changes when she can have both senders provide information to her. Suppose Sender 1 truthfully reveals (only) that $x = x_1$ (and the receiver believes him). This makes Sender 2's ideal action, $\max_{\succsim}(a_{21}, a_{22})$, out of reach, forcing him a choice between a_{11} and a_{12}, the respective actions that the receiver will take when she believes that the state is (x_1, y_1) and (x_1, y_2). Since Sender 2 prefers a_{12} to a_{11} in state (x_1, y_2), he will prefer to tell that $y = y_2$. And given that Sender 2 truthfully reveals that $y = y_2$, Sender 1 will also, by a similar argument, prefer to tell that $x = x_1$. The true state (x_1, y_2) is thus revealed to the receiver. In effect, a sender truthfully reveals along a dimension to help align the interests of the other sender with the receiver's.

2.2 Two Baseline Games

We induce the above environment for experimentations. Figure 1 depicts the payoff profiles of two baseline games, Game T (two senders) and Game S (single sender), which we use to address, among other things, the comparative statics with respect to the number of senders.

State: (L, U)						
Action	left			right		
up	20	20	50	0	50	0
down	50	0	0	10	10	20

State: (R, U)						
Action	left			right		
up	0	50	0	20	20	50
down	10	10	20	50	0	0

State: (L, D)						
Action	left			right		
up	50	0	0	10	10	20
down	20	20	50	0	50	0

State: (R, D)						
Action	left			right		
up	10	10	20	50	0	0
down	0	50	0	20	20	50

(a) Game T

State: (L, U)				
Action	left		right	
up	20	50	0	0
down	50	0	10	20

State: (R, U)				
Action	left		right	
up	0	0	20	50
down	10	20	50	0

State: (L, D)				
Action	left		right	
up	50	0	10	20
down	20	50	0	0

State: (R, D)				
Action	left		right	
up	10	20	50	0
down	0	0	20	50

(b) Game S

Figure 1: Payoff Profiles: Baseline Games

In the experiment, we label the state as $(H, V) \in \{L, R\} \times \{U, D\}$ and the action as $(h, v) \in \{(\text{left, up}), (\text{right, up}), (\text{left, down}), (\text{right, down})\}$. The information transmission problem is framed as the sender(s) providing recommendations to the receiver, where we assign literal meaning to messages which is the same as the labels for actions: $M_i = \{$"(h,v)"$|$"(left, up)", "(right, up)", "(left, down)", "(right, down)"$\}$.[10]

Each cell in Figure 1 contains players' payoffs when an action is taken in a state. In Game T, the numbers represent (Sender 1's payoff, Sender 2's payoff, receiver's payoff), with Sender 2's payoff omitted in Game S. The payoffs are assigned according to Table 1. To provide salience, the rankings of actions are, except for the receiver's two least preferred actions, implemented in strict preferences. To give the fully revealing equilibrium a best chance to be implemented in the laboratory, we choose the set of preference orders where it is "dominant" for a sender to truthfully reveal on a dimension regardless of what the other sender reveals on the other.[11] Note, however, that the "dominance" holds only when the receiver believes the sender, which makes the problem faced by subjects not strategically trivial.

Babbling equilibrium always exists in cheap-talk games. Throughout the equilibrium analysis, we focus on informative equilibria. As discussed in Section 2.1, the receiver cannot hope to fully identify the state when there is only one sender providing information. Yet, given some common ranking of actions between a sender and the receiver (which means their interests are partially aligned), partitional information can still be transmitted as in Crawford and Sobel (1982). In particular, in Game S information can be transmitted along dimension H:[12]

Proposition 1. *There exists a partially revealing equilibrium in Game S in which the single sender truthfully reveals only on dimension H. Furthermore, the information partition $\{\{(L,U),(L,D)\},\{(R,U),(R,D)\}\}$ that the receiver receives in the equilibrium is the only partition that is consistent with equilibrium.*

While the equilibrium information partition is unique, there is a continuum of equilibrium outcomes, depending on how the receiver randomizes over actions. As a cheap-talk game, there is also an inessential multiplicity of equilibria with different uses of messages supporting a given equilibrium outcome. One example of message use involves the sender randomizing between messages "(left, up)" and "(left, down)" when the state consists of L and between "(right, up)" and "(right, down)" when it consists of R. How messages are used to support a given outcome as well as which outcome prevails in a game are part of our empirical inquiry.[13]

[10]For expositional clarity, throughout the paper we use quotation marks to distinguish between actions and messages. No such distinction is made in the experiment.

[11]In state (x_i, y_j), $i,j = 1,2$, of Game T, Sender 1 and Sender 2 order the actions according to, respectively, $a_{i(3-j)} \succ a_{ij} \succ a_{(3-i)(3-j)} \succ a_{(3-i)j}$ and $a_{(3-i)j} \succ a_{ij} \succ a_{(3-i)(3-j)} \succ a_{i(3-j)}$. Indifference is induced for the receiver's two least preferred actions so that Sender 1 and Sender 2 face a symmetric payoff environment.

[12]Game S is similar to the special case Battaglini (2002, p.1389) discusses where with one sender full revelation occurs for only one dimension. Otherwise, our choice of Sender 1 as the single sender has been arbitrary; had it been Sender 2, information would have been transmitted along another single dimension (V).

[13]Despite the multiplicity of equilibria, throughout the paper we shall use the singular "equilibrium" to

Given that payoffs are assigned according to Table 1, the illustration in Section 2.1 makes it clear that full revelation of the state is possible in Game T:

Proposition 2. *There exists a fully revealing equilibrium in Game T in which each sender truthfully reveals on at least one dimension. Two major classes of senders' strategy profiles that constitute a fully revealing equilibrium are: 1) both Sender 1 and Sender 2 truthfully reveal on both dimensions H and V; and 2) Sender 1 truthfully reveals only on dimension H and Sender 2 only on dimension V, and both babble by means of randomization on the other respective dimensions.*

We comment on the types of out-of-equilibrium messages that may emerge in Game T, setting the stage to introduce additional games for robustness investigation. A fully revealing equilibrium in Game T may or may not involve out-of-equilibrium messages. Under the first class of strategy profiles, they arise in the form of *inconsistent message pairs*. Since both senders truthfully reveal the state, in equilibrium the receiver expects to receive messages that indicate the same (H, V). Out-of-equilibrium messages therefore arise when a message pair indicating different values for H, V, or both are received. When a sender only reveals on one dimension, inconsistent message pairs will not arise. A sender's babbling dimension is the truth-revealing dimension of the other sender, so there is nothing to be inconsistent with. However, out-of-equilibrium messages may still arise in the form of *unused messages*. Since each sender reveals only a binary variable, two messages suffice for each to separate, leaving the possibility that the other two messages will be unused in equilibrium. In cheap-talk games, however, unused messages are a trivial type of out-of-equilibrium messages. In Game T, one can have all messages used without changing the information each sender provides by prescribing the senders to randomize when they babble. This is the second class of strategy profiles. Without any out-of-equilibrium messages, inconsistent or unused, a fully revealing equilibrium constituted by this class is free of out-of-equilibrium beliefs.[14]

2.3 Robustness and Additional Games

We contribute to the robustness inquiry of the fully revealing equilibrium by combining theoretical consideration with empirical investigation. A prerequisite for addressing in the laboratory an issue related to out-of-equilibrium beliefs is to be able to control the scenarios in which they arise. Toward this end, we introduce Game T′ and Game R (Figure 2).

refer to a class of equilibria unless the plural form is called for to convey specific points.

[14]The two classes of strategy profiles in Proposition 2 are meant to be representative but not exhaustive. A fully revealing equilibrium can be constituted by, for example, a third class of strategy profiles as hybrids of the existing two, where Sender 1 truthfully reveals on both dimensions and Sender 2 only on dimension V.

State: (L, U)						
Action	left			right		
up	20	20	50	0	50	0
down	50	0	0	10	10	20

State: (R, U)						
Action	left			right		
up	0	$\underline{15}$	0	20	20	50
down	10	$\underline{30}$	20	50	0	0

State: (L, D)						
Action	left			right		
up	$\underline{15}$	0	0	$\underline{30}$	10	20
down	20	20	50	0	50	0

State: (R, D)						
Action	left			right		
up	10	10	20	50	0	0
down	0	50	0	20	20	50

(a) Game T$'$

State: (L, U)						
Action	left			right		
up	20	20	50	0	50	0
down	50	0	0	10	10	20

State: (R, U)						
Action	left			right		
up	0	15	0	20	20	50
down	10	30	20	50	0	0

State: (L, D)						
Action	left			right		
up	15	0	0	30	10	20
down	20	20	50	0	50	0

No State

(b) Game R

Figure 2: Payoff Profiles: Games for Addressing Robustness

The different possibilities for out-of-equilibrium messages in Game T creates difficulty for identifying and interpreting any observed behavior as out-of-equilibrium. Our first step in controlling out-of-equilibrium beliefs is to entirely eliminate the scenarios in which they emerge. In Game T$'$, the message spaces are truncated and relabeled as $M_1 = \{$“h”|“left”, “right”$\}$ and $M_2 = \{$“v”|“up”, “down”$\}$. The binary message spaces ensure that neither inconsistent message pairs nor unused messages will arise in a fully revealing equilibrium. Game T$'$ also carries different payoff numbers (underlined in Figure 2(a)), which preserve the preference orders in Table 1 but make it not “dominant” for Sender 1 to truthfully reveal on dimension H in state (L, D) and for Sender 2 on dimension V in state (R, U). In summary, we have:

Proposition 3. *There exists a fully revealing equilibrium in Game T$'$ in which Sender 1 truthfully reveals on dimension H and Sender 2 on dimension V. There exists no other class of senders' strategy profiles that constitutes a fully revealing equilibrium. Furthermore, any fully revealing equilibrium in Game T$'$ is free of out-of-equilibrium beliefs.*

Our next step in controlling out-of-equilibrium beliefs is to have them arise under specific scenarios that can be more readily identified in the data. In this, we leverage on Ambrus and Takahashi's (2008) insight on the cause of out-of-equilibrium messages under a restricted state space, where after a deviation a message pair may point to a nonexistent "state." To capture this, we eliminate state (R, D) in Game T$'$ and adjust the prior so that the remaining three states are equally likely. This gives us Game R, which also has binary message spaces.

To register a difference from inconsistent message pairs, we call out-of-equilibrium messages arisen due to restricted state space *irreconcilable message pairs*. Fully revealing equilibrium also exists in Game R, but now out-of-equilibrium beliefs, which emerge uniquely after irreconcilable message pairs, play a crucial role. Consider a deviation by Sender 2 when the state is (R, U). In Game T$'$, the receiver, being told by the truthful Sender 1 that the state consists of R and by the deviating Sender 2 that it consists of D, cannot detect that there is a deviation. She will take action (right, down) as when (R, D) is truthfully revealed in equilibrium. A deviation does not lead to the receipt of out-of-equilibrium messages because every possible message pair is expected in equilibrium. What deters Sender 2 from deviating is the fact that, in state (R, U), (right, down) is not as attractive as the equilibrium (right, up). In Game R, the same deviation creates an entirely different scenario. Given that state (R, D) no longer exists, the receiver can detect that there is a deviation because under no circumstance will she receive such message pair, now irreconcilable, in equilibrium. The deviation does lead to the receipt of out-of-equilibrium messages, and certain beliefs, as stated in the following proposition, are required to deter the deviation.

Proposition 4. *There exists a fully revealing equilibrium in Game R in which Sender 1 truthfully reveals on dimension H and Sender 2 on dimension V. There exists no other class of senders' strategy profiles that constitutes a fully revealing equilibrium. Furthermore, any fully revealing equilibrium in Game R is supported by out-of-equilibrium beliefs that induce the receiver to take action (left, up) with probability at least $\frac{1}{2}$ after an irreconcilable message pair.*

We adopt Battaglini's (2002) criterion for our robustness analysis, which imposes continuity on beliefs. We define for each game a corresponding ε-perturbed game: with independent probability ε_i Sender i's observation of the state is subject to mistake and he observes a random state drawn from a probability distribution, g_i, that puts positive probability on all possible states. The following definition is the same as that in Battaglini (2002):

Definition 1. *An equilibrium is robust if there exists a pair of probability distributions (g_1, g_2) and a sequence $\varepsilon^n = (\varepsilon_1^n, \varepsilon_2^n)$ converging to zero such that out-of-equilibrium beliefs of the equilibrium are the limit of the beliefs that the equilibrium strategies would induce in an ε-perturbed game as $\varepsilon^n \to 0$.*

We apply the robustness criterion to the fully revealing equilibria in the three games with two senders. For Game R, we have:

Corollary 1. *None of the fully revealing equilibria in Game R is robust.*

Suppose the message uses that support the fully revealing equilibrium in Game R are that "left" and "right" are used by Sender 1 to reveal L and R and "up" and "down" by Sender 2 to reveal U and D. Accordingly, ("right", "down") is the irreconcilable message pair. In an ε-perturbed game, the receiver considers to have received the message pair after at least one sender has made a mistake. And her posterior beliefs are always derived from Bayes' rule. When ε is small, the event that both senders have made a mistake is irrelevant; the receiver believes that one of the messages, "right" or "down", conveys information about the state, and in the limit she assigns zero probability to (L, U). In the original game, the out-of-equilibrium beliefs required to support the fully revealing equilibrium have to put positive probability on (L, U), and this "discontinuity" in beliefs render the equilibrium not robust.[15]

A fully revealing equilibrium in Game T constituted by the second class of strategy profiles in Proposition 2 is free of out-of-equilibrium beliefs, which necessarily makes it robust. Under the first class, one can construct both robust and non-robust equilibria.[16] We thus have:

Corollary 2. *Some, but not all, fully revealing equilibria in Game T are robust.*

Finally, given that any fully revealing equilibrium in Game T′ is free of out-of-equilibrium beliefs, the robustness criterion is trivially satisfied:

Corollary 3. *All fully revealing equilibria in Game T' are robust.*

3 Experimental Hypotheses and Procedures

3.1 Hypotheses

Table 2 summarizes the properties of the four games, which constitute our experimental treatments. In formulating our hypotheses, we focus on information revelation outcomes that

[15]Battaglini (2002) uses senders' mistaken observations as a vehicle to impose restriction on out-of-equilibrium beliefs that parallels the consistency requirement of sequential equilibrium. Given that our games are finite, we can directly apply the refinement of sequential equilibrium, which for Game R also rules out the fully revealing equilibrium. We use Battaglini's (2002) definition to be as close as possible to the theoretical literature of multidimensional cheap talk.

[16]For an example of non-robust equilibrium, suppose in equilibrium each sender sends "(left, up)" for state (L, U), "(right, up)" for (R, U), "(left, down)" for (L, D) and "(right, down)" for (R, D). Consider a deviation by Sender 2 in state (R, D) in which he sends "(right, up)". If the receiver responds to the inconsistent message pair, ("(right, down)", "(right, up)"), by taking action (left, up), Sender 2 will be deterred from deviating. However, the fully revealing equilibrium will not be robust: in taking (left, up), the receiver is induced by out-of-equilibrium beliefs that cannot be rationalized as limit of equilibrium beliefs in a perturbed game.

are consistent with the equilibria, although what strategies lead to the observed outcomes will also be a major part of our data analysis.

Table 2: Properties of the Games

Game/Treatment		No. of Senders	Size of Sender's Message Space	No. of States	Out-of-Equilibrium Messages	Fully Revealing Equilibrium	Robust
Baseline	Game S	1	4	4	0–2	No	N/A[a]
	Game T	2	4	4	0–12	Yes	Some
Robustness	Game T′	2	2	4	0	Yes	Yes
	Game R	2	2	3	1	Yes	No

[a]We focus our robustness analysis on fully revealing equilibria, and thus it does not cover Game S.

Our first hypothesis compares the two baseline games, where the treatment variable is the number of senders. The comparative statics is informed by the partially revealing equilibrium in Game S (Proposition 1) and the fully revealing equilibrium in Game T (Proposition 2):

Hypothesis 1. *The receivers in Game T identify the true state more often than do the receivers in Game S.*

Our second hypothesis compares Game T′ and Game R, where the treatment variable is the number of states. The comparative statics is informed by the non-robust fully revealing equilibrium in Game R (Corollary 1) and the robust one (Corollary 3) in Game T′. In translating the robustness results into empirical hypotheses, we rely on the presumption that equilibria that are robust or plausible present behavioral rule that is more intuitive for subjects to discover and follow. We anticipate that non-robust equilibrium is followed less often, which manifests in terms of information revelation outcomes as:

Hypothesis 2. *The receivers in Game R identify the true state less often than do the receivers in Game T′.*

3.2 Procedures

All four games share the same experimental procedures. Four sessions are conducted for each game using between-subject design. All sessions are conducted in Chinese using z-Tree (Fishchbacher, 2007) at the Taiwan Social Science Experimental Laboratory (TASSEL) affiliated with the National Taiwan University. A total of 260 subjects without prior experience in our experiment are recruited from the undergraduate/graduate population of the university.

Games with two senders are implemented in five, six or seven groups.[17] Two sessions of

[17]Our target is to recruit six groups per session and set a lower limit of five groups. We meet our target for all four sessions of Game T. For Game T′, we use the lower limit for three sessions while the remaining session has seven groups. For Game R, two sessions are conducted in six groups and two in five.

Game S are conducted in seven groups with the other two in five and nine. Upon arrival at the laboratory, subjects are instructed to sit at separate computer terminals. Each receives a copy of the experimental instructions. To ensure that the information contained in the instructions is induced as common knowledge among the participants, the instructions are read aloud, accompanied by slide illustrations.

In each session, subjects first participate in three rounds of practice and then 50 official rounds. Random matching is used. Using Game T as an illustration, subjects form groups of three: Member A (Sender 1), Member B (Sender 2), and Member C (receiver). The roles are randomly assigned and last throughout the session. At the beginning of each round, the computer randomly draws one of (L, U), (R, U), (L, D) or (R, D). The draws are independent across groups and rounds. The drawn outcome is revealed on the screens of Member A and Member B, after which they input their recommendation for Member C. Each sender's recommendation is input in two steps. Member A inputs "left"/"right" first, followed by "up"/"down". The opposite order is used for Member B.[18] The four inputs, two by each sender, are combined and revealed to Member C in one step. The screen of Member C will show, for example, that "Member A recommends left; Member A recommends up; Member B recommends right; Member B recommends up." Member C then chooses one of (left, up), (right, up), (left, down) or (right, down). After the action decision, the round's data—the computer's draw, Member A's and Member B's recommendations, Member C's action and the subject's payoff—is shown on each subject's screen, after which the round ends. In every step of the decisions, the payoff profiles in Figure 1(a) are shown on each subject's screen.[19]

A payoff of 10 translates into a real payment of NT\$5. A subject is paid his or her sum of rewards from all 50 rounds plus a NT\$100 show-up fee. Subjects earned on average NT\$768.77 (≈US\$26.91), ranging from NT\$355 (≈US\$12.43) to NT\$1300 (≈US\$45.50).

4 Findings and Analysis

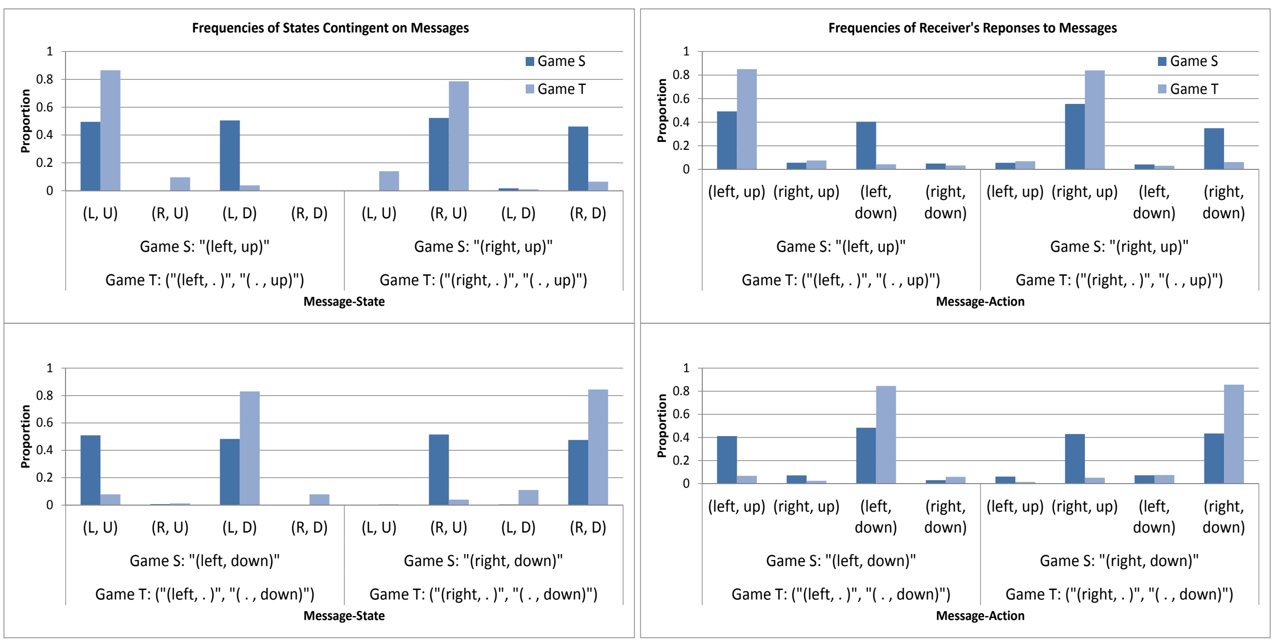
4.1 Baseline Games: Game S and Game T

We begin by analyzing how subjects use and interpret messages that would result in the information revelation outcomes we hypothesize on. In cheap-talk games, meaning of a message

[18]Since in Game T′ and Game R, Member A inputs only "left"/"right" and Member B "up"/"down", we intend to maintain consistency across games so that both members in Game T are inputting first on the only dimensions their counterparts in Game T′ and Game R enter.

[19]Refer to Appendix B for an English translation (by the authors) of the experimental instructions for Game T. While the original instructions are in Chinese (Appendix D), the notation for the state, (L, U), (R, U), (L, D) or (R, D), is presented "as is" to the subjects.

is determined in equilibrium, which deprives the theory of direct guidance for interpreting observed behavior. We seek guidance from the data themselves. As an anchoring point of our analysis, we examine the frequencies of states contingent on messages. Figure 3(a) presents the frequencies aggregated across last 30 rounds of all sessions.[20] The frequencies indicate, given actual uses of messages, what are their correct interpretations. Take message cases ("(left, .)", "(. , up)") in Game T as an example. The frequencies of (L, U), (R, U), (L, D), and (R, D) are, respectively, 87%, 10%, 3% and 0%.[21] When one of these message pairs is received, a receiver's "correct beliefs" are to put exceedingly high weight on (L, U), which render action (left, up) her best response. Accordingly, in interpreting observed behavior we consider as if "recommend (h, v)" carried the literal meaning of "it is in your best interest to take action (h, v)" and infer that subjects coordinate over such meanings when interests allow. The inference also applies when it is in the senders' interests to reveal only one dimension; for instance, in Game S the true state is exclusively $(L, \cdot)$ when the message "(left, up)" is used.



(a) State Contingent on Messages

(b) Receiver's Responses

Figure 3: Frequencies of States Contingent on Messages/Receiver's Responses to Messages: Game S and Game T (Last 30 Rounds)

Table 3A presents, for senders' strategies, the frequencies of state-message alignments for each dimension. Table 3B presents the same for message-action alignments for receivers' strategies. The alignments are defined with the aid of our inference above. For example, an instance of state-message alignments on dimension H is recorded when the pair $(L, .)$-"(left,

[20] Given the fairly complicated nature of the games, we report data after reasonable amount of time has been allowed for learning to occur. All our formal statistical tests also use data from the last 30 rounds.

[21] In Figure 10 (Appendix C), the cases in Game T are further divided into different message combinations.

.)" occurs. Our findings about subjects' strategies are consistent with the predictions in Propositions 1 and 2:

Result 1. *1) Senders in Game S use the literal meanings of messages to reveal on dimension H. The observed message uses provide no information on dimension V where approximately uniform randomization over messages is observed. Receivers follow the literal meanings of messages on dimension H but not on dimension V. 2) Observed message uses of Senders 1 in Game T resemble those of the senders in Game S. Senders 2 use the literal meanings of messages to reveal on dimension V and provide no information on dimension H by randomizing approximately uniformly. Receivers follow the literal meanings of messages of Senders 1 on dimension H and of Senders 2 on dimension V.*

Truthful revelation on a dimension gives a predicted frequency of state-message alignments of 100%, whereas randomized babbling gives a predicted frequency of 50%. Table 3A, Column (1), shows that in Game S the observed frequencies for dimension H average at 95% in the first 20 rounds and converge to 100% in the last two rounds. For dimension V, Column (2) shows that the frequencies under three different aggregations are all in the neighborhood of 50%. In Game T, the frequencies of Senders 1 follow a similar pattern of those of the senders in Game S but in most cases with lower values. Columns (3) and (4) report the frequencies of Senders 2. For dimension V, the frequencies average at 89% in the first 20 rounds and converge to 92% in the last two rounds; for dimension H, the frequencies are in the neighborhood of 50%.[22]

In Game S, the receivers only follow the literal meanings of messages on dimension H: Table 3B shows that the frequencies of message-action alignments average at 86% in the first 20 rounds and converge to 92% in the last two rounds. The most remarkable result from Game T is the receivers' sophistication to identify who to listen to for which dimension. The frequencies of message-action alignments for dimension H with Senders 1's messages follow a similar pattern with the frequencies for dimension V with Senders 2's messages: they average at $85\% - 89\%$ in the first 20 rounds, converging to $92\% - 96\%$ in the last two rounds. For the respective remaining dimensions, the frequencies are in the neighborhood of 50%. Figure 3(b) further confirms the findings. For Game T, the frequencies of receiver's responses are calculated contingent on, for instance, message pairs ("(left, .)", "(. , up)") which include the cases when the two messages are inconsistent such as ("(left, down)", "(right, up)"). Even in these cases, the receivers are able to filter, selectively listening to each sender on distinct dimension.[23] The highly similar patterns of the frequencies in Figures 3(a) and 3(b) also show that the receivers are best responding to the senders' messages.

[22]Figure 9 in Appendix C further provides a breakdown of the state-message alignments for each state. Using the literal meaning of messages, senders reveal on their "assigned" dimension and babble with close-to-uniform randomization on the other dimension.

[23]Figure 11 in Appendix C further divides the cases into different message combinations. For the entirely

Table 3: Summary Statistics

	Rounds	(1) State-Message 1 $(H,.) \leftrightharpoons$ "$(h,.)$"	(2) State-Message 1 $(.,V) \leftrightharpoons$ "$(.,v)$"	(3) State-Message 2 $(H,.) \leftrightharpoons$ "$(h,.)$"	(4) State-Message 2 $(.,V) \leftrightharpoons$ "$(.,v)$"
A. Frequencies of State-Message Alignments					
Game S	$1-20$	0.95	0.45	–	–
	$21-50$	0.99	0.50	–	–
	$49-50$	1.00	0.43	–	–
Game T	$1-20$	0.87	0.49	0.45	0.89
	$21-50$	0.89	0.39	0.47	0.94
	$49-50$	0.98	0.35	0.52	0.92
Game T′	$1-20$	0.90	–	–	0.92
	$21-50$	0.89	–	–	0.97
	$49-50$	0.93	–	–	0.95
Game R	$1-20$	0.84	–	–	0.82
	$21-50$	0.80	–	–	0.78
	$49-50$	0.71	–	–	0.78

	Rounds	(1) Message 1-Action "$(h,.)$" $\leftrightharpoons (h,.)$	(2) Message 1-Action "$(.,v)$" $\leftrightharpoons (.,v)$	(3) Message 2-Action "$(h,.)$" $\leftrightharpoons (h,.)$	(4) Message 2-Action "$(.,v)$" $\leftrightharpoons (.,v)$
B. Frequencies of Message-Action Alignments					
Game S	$1-20$	0.86	0.58	–	–
	$21-50$	0.89	0.54	–	–
	$49-50$	0.92	0.52	–	–
Game T	$1-20$	0.85	0.51	0.55	0.89
	$21-50$	0.91	0.44	0.60	0.92
	$49-50$	0.92	0.35	0.50	0.96
Game T′	$1-20$	0.94	–	–	0.94
	$21-50$	0.95	–	–	0.96
	$49-50$	0.95	–	–	0.95
Game R	$1-20$	0.79	–	–	0.86
	$21-50$	0.83	–	–	0.83
	$49-50$	0.83	–	–	0.87

	Rounds	(1) State-Action $(H,.) \leftrightharpoons (h,.)$	(2) State-Action $(.,V) \leftrightharpoons (.,v)$	(3) State-Action $(H,V) \leftrightharpoons (h,v)$	(4) State-Message-Action $(H,V) \leftrightharpoons$ ("$(h,.)$", "$(.,v)$") $\leftrightharpoons (h,v)$
C. Frequencies of State-Action Alignments/State-Message-Action Alignments					
Game S	$1-20$	0.82	0.51	0.42	–
	$21-50$	0.89	0.50	0.45	–
	$49-50$	0.92	0.54	0.49	–
Game T	$1-20$	0.76	0.81	0.62	0.59
	$21-50$	0.83	0.86	0.73	0.71
	$49-50$	0.94	0.92	0.85	0.83
Game T′	$1-20$	0.86	0.88	0.75	0.75
	$21-50$	0.85	0.93	0.81	0.80
	$49-50$	0.89	0.90	0.81	0.81
Game R	$1-20$	0.76	0.78	0.70	0.59
	$21-50$	0.80	0.81	0.78	0.60
	$49-50$	0.76	0.78	0.71	0.55

Note: "Message 1" refers to Sender 1's message, similarly for "Message 2". For Game T′ and Game R with binary message spaces, "h" is used for "$(h,.)$", "v" for "$(.,v)$", and ("h", "v") for ("$(h,.)$", "$(.,v)$").

We turn to the information revelation outcomes. The observed strategies suggest that the outcomes should also be consistent with equilibrium. Table 3C reports different frequencies related to state-action alignments. Our findings confirm Hypothesis 1:

Result 2. *The receivers in Game T identify the true state significantly more often than do the receivers in Game S, in a manner that is consistent with the fully revealing equilibrium in Game T and the partially revealing equilibrium in Game S.*

In Game T, the frequencies of state-action alignments for both dimensions (Column (3) of Table 3C) average at 62% in the first 20 rounds and converge to 85% in the last two rounds. In Game S, the frequencies under different aggregations are all under 50%. Using aggregated frequency from the last 30 rounds of each session as an independent observation, we confirm that the frequency of the receivers identifying the true state is significantly higher in Game T than in Game S (the Mann-Whitney test renders $p = 0.01$).[24] Columns (1) and (2) indicate that the lower frequencies in Game S are results of lower frequencies of alignments for dimension V, which is consistent with the theoretical predictions.[25] Figure 4 further presents the round-by-round frequencies of state-action alignments aggregated across sessions. The figure provides a visualization of the convergence in Game T, which is absent in Game S. As a formal measure of the convergence, the Spearman rank-order coefficient between frequencies and rounds is 0.69 with $p < 0.0001$ for Game T. There is a small positive coefficient for Game S that is not statistically significant (0.12 with $p = 0.4$).

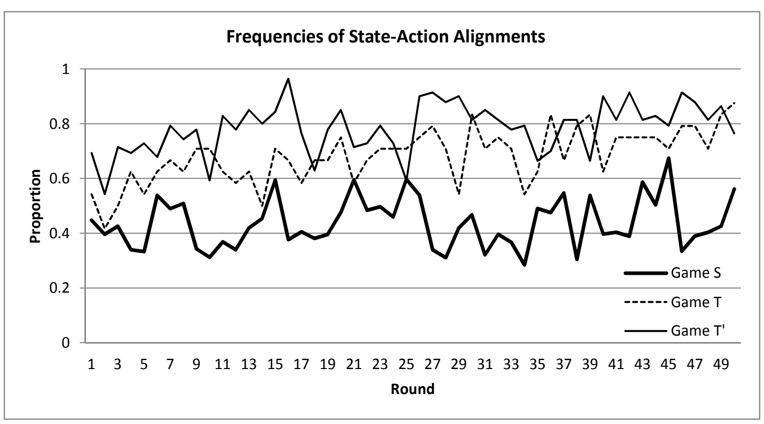


Figure 4: Frequencies of State-Action Alignments: Game S, Game T and Game T′

The receivers' average payoffs provide an alternative measure for information revelation outcomes, where theory predicts an expected payoff of 25 in Game S and 50 in Game T.

inconsistent message pair ("(left, down)", "(right, up)"), the frequency of action (left, up) is 84%; the receivers selectively follow "left" from Senders 1 and "up" from Senders 2. A similar pattern is observed for other cases.

[24] The p-values reported for all non-parametric tests are from one-tailed tests.

[25] As additional evidence, Figure 8 in Appendix C presents the frequencies of actions contingent on state.

Consistent with the findings above, the average payoffs are significantly higher in Game T than in Game S (the Mann-Whitney test renders $p = 0.01$). They also show similar convergence patterns to the predicted values: the average payoffs in Rounds $1-20$, $21-50$ and $49-50$ are, respectively, 22.53, 23.7, and 25.38 for Game S and 31.75, 37.01, and 43.54 for Game T.

We conclude this subsection with regression analysis. We use data of each subject (i) in each of the last 30 rounds (t) as an observation and use random effect regressions to minimize the impacts of interdependent play. For information revelation outcomes, we estimate the correlations between states and ideal actions for each dimension. For dimension H, the following regression is estimated using maximum likelihood with standard errors clustered at the subject level:

$$h_{it} = \beta_1^{h-H} H_{it} + \beta_2^{h-H}(H_{it} \times D_{it}^{GameS}) + \nu_i^{h-H} + \varepsilon_{it}^{h-H}, \tag{1}$$

where D_{it}^{GameS} is a Game S-dummy variable. A similar regression is run for dimension V. Table 4, Column (2), reports the regression results. Column (1) reports the results using Game S data alone and without the interaction term.

Table 4: Random Effect MLE Regressions: Action and Message on State (Last 30 Rounds)

Dimension H	(1) Action h_{it}	(2) Action h_{it}	(3) Message 1 "h_{it}"	(4) Message 1 "h_{it}"	(5) Message 2 "h_{it}"
H_{it}	0.979***	0.747***	1.001***	0.940***	-0.0403
	(0.00709)	(0.0294)	(0.00169)	(0.00986)	(0.0383)
$H_{it} \times D_{it}^{GameS}$	–	0.0957**	–	0.0584***	–
		(0.0315)		(0.0133)	
Dimension V	**(1) Action v_{it}**	**(2) Action v_{it}**	**(3) Message 1 "v_{it}"**	**(4) Message 1 "v_{it}"**	**(5) Message 2 "v_{it}"**
V_{it}	0.0380	0.747***	0.0393	-0.197***	0.983***
	(0.0359)	(0.0324)	(0.0360)	(0.0380)	(0.0103)
$V_{it} \times D_{it}^{GameS}$	–	-0.697***	–	0.228***	–
		(0.0445)		(0.0507)	
Game	Game S	Games S, T	Game S	Games S, T	Game T
No. of Observations	840	1560	840	1560	720
No. of Subjects	28	52	28	52	24

Note: "Message 1" refers to Sender 1's message, similarly for "Message 2". Standard errors are in parentheses; *** for p <0.001, ** for p <0.01, * for p <0.05.

The fully revealing equilibrium in Game T predicts correlations of one between states and actions for both dimensions; the partially revealing equilibrium in Game S predicts perfect correlation for dimension H but zero correlation for dimension V. While it is unlikely to observe point predictions in the data, statistically significant high correlations are observed in Game T for both dimensions ($\beta_1^{h-H}, \beta_1^{v-V} = 0.747$ with $p < 0.001$).[26] In Game S, the correlations are even closer to the predicted: the correlation for dimension H is exceedingly high ($\beta_1^{h-H} = 0.979$ with $p < 0.001$), while the correlation for dimension V is close to zero ($\beta_1^{v-V} = 0.038$, not significantly different from zero). We consider these as evidence that the observed information revelation outcomes are not results of random play.[27] The results from Game S contrast with findings from other single-sender communication game experiments, in which over-transmission of information (in reference to equilibrium predictions) is often observed. We speculate that the opportunity to provide truthful information on one dimension offers a channel for subjects to release the tendency to transmit information.

For senders' strategies, we estimate the correlations between messages and states in reference to the literal meanings, replacing h_{it} in equation (1) with "h_{it}", the first element of the sender's message (similarly for v_{it}). Regressions are run for both senders in Game T. For Senders 2, the regressions are run with Game T data alone without the interaction term. In Game S, the correlation is extremely high for dimension H ($\beta_1^{``h"-H} = 1.001$ with $p < 0.001$) and close to zero for dimension $V$ ($\beta_1^{``v"-V} = 0.0393$, not significantly different from zero). In Game T, the correlations for Senders 1 are similar to those of their incarnations in Game S ($\beta_1^{``h"-H} = 0.94$ with $p < 0.001$ and $\beta_1^{``v"-V} = -0.197$ with $p < 0.001$). The correlations for Senders 2 are orthogonal to those for Senders 1's ($\beta_1^{``h"-H} = -0.0403$, not significantly different from zero, and $\beta_1^{``v"-V} = 0.983$ with $p < 0.001$). For estimating receivers' strategies, we replace H_{it} in equation (1) with "h_{it}" (similarly for V_{it}). Receivers' actions in Game S are highly correlated with the senders' messages for dimension H ($\beta_1^{h-``h"} = 0.978$ with $p < 0.001$).[28] For dimension $V$, the correlation is positive but much lower ($\beta_1^{v-``v"} = 0.101$ with $p < 0.01$). A similar finding is obtained for Game T with Senders 1 ($\beta_1^{h-``h"} = 0.975$ with $p < 0.001$ and $\beta_1^{v-``v"} = -0.0845$ with $p < 0.05$). The correlations with Senders 2 are orthogonal to those with Senders 1 ($\beta_1^{h-``h"} = -0.0159$, not significantly different from zero, and $\beta_1^{v-``v"} = 0.974$ with $p < 0.001$). As a whole, the regression results confirm that the observed strategies are consistent with the equilibrium where literal meaning of message is used.

4.2 Robustness: Game T′ and Game R

To compare the information revelation outcomes in Game T′ and Game R, we introduce a new measure, the frequencies of state-message-action alignments (Table 3C, Column (4)). With

[26] For expositional convenience, we abuse terminology by referring to the coefficients as "correlations."

[27] As an alternative test, Blume et al. (1998, 2001) compare the observed frequencies of equilibrium outcomes with those predicted by chance alone. Using a similar approach with aggregate data on state-action alignments, we also reject random play (with 25% of full revelation outcomes) for both Game S and T (the Wilcoxon signed-rank tests render $p = 0.0625$, the lowest possible value with four observations/sessions).

[28] The detailed estimation results are reported in Table 6 in Appendix C.

only three states in Game R, the probability that the receivers take the ideal actions out of random play is 33%, higher than the 25% with four states; the state-action alignment does not provide the same ground for comparison. We use a more stringent measure by requiring alignments among states, the literal meaning of messages, and actions. While there is no theoretical ground for this measure because in cheap-talk games different message uses can support a given equilibrium outcome, our empirical findings so far indicate that subjects are using the literal meanings in their equilibrium play. Columns (3) and (4) of Table 3C also show that in Game T′ (and Game T as well) there is minimal difference between the two measures, whereas the frequencies drop significantly in Game R with state-message-action alignments, providing evidence that the three states are creating differences that are picked up by our new measure.[29] Based on this measure, we confirm Hypothesis 2:

Result 3. *The receivers in Game R identify the true state significantly less often through the equilibrium than do the receivers in Game T′. Furthermore, in Game R while the receivers' observed strategies constitute best responses to the senders, the senders' observed strategies are not best responses given the receivers' strategies.*

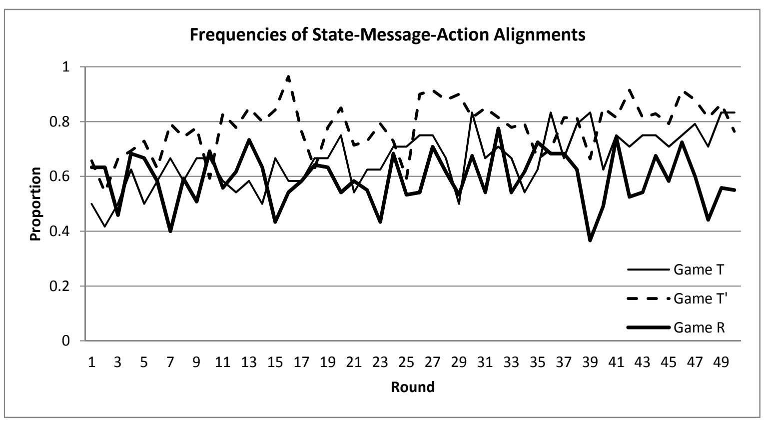


Figure 5: Frequencies of State-Message-Action Alignments: Game T, Game T′ and Game R

In Game T′, the frequencies of state-message-action alignments average at 75% in the first 20 rounds, 80% in the last 30 rounds and 81% in the last two rounds. The corresponding frequencies in Game R are all lower: 59%, 60%, and 55%. And the difference is statistically significant (the Mann-Whitney test renders $p = 0.03$). Figure 5 presents the round-by-round frequencies, providing a visualization of the differences.

[29] Testing the null hypothesis of no difference against the alternative that the more stringent measure results in lower frequencies, the Wilcoxon signed-rank tests render p-values of 0.4375 for Game T′, 0.125 for Game T, and 0.0625—the lowest possible value with four sessions/observations—for Game R.

We obtain further statistical support by estimating regression equation (for dimension H):

$$\begin{aligned} h_{it} =& \beta_1^{h-H} H_{it} + \beta_2^{h-H}(H_{it} \times D_{it}^{GameS}) + \beta_3^{h-H}(H_{it} \times D_{it}^{GameT}) \\ &+ \beta_4^{h-H}(H_{it} \times D_{it}^{GameT} \times D_{it}^{1-20}) + \beta_5^{h-H}(H_{it} \times D_{it}^{GameR}) + \nu_i^{h-H} + \varepsilon_{it}^{h-H}, \end{aligned} \tag{2}$$

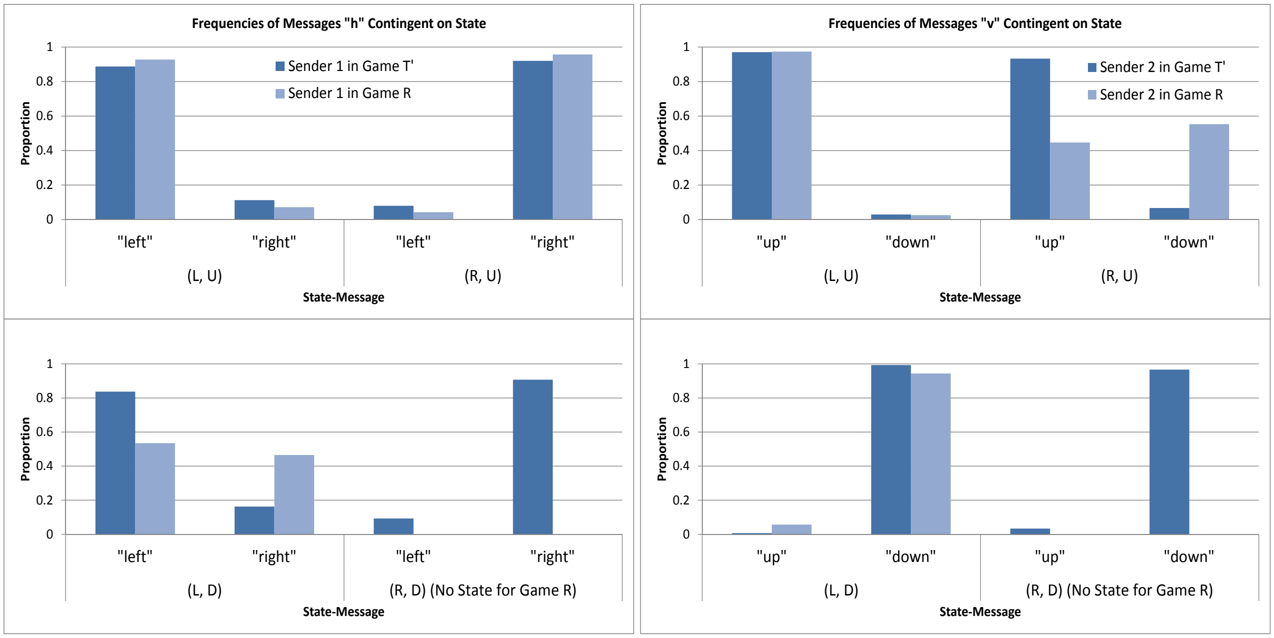
where D_{it}^{1-20} is a dummy variable for the first 20 rounds. A similar regression is run for dimension V. There are high correlations between actions and states in Game T′ ($\beta_1^{h-H} = 0.733$ and $\beta_1^{v-V} = 0.82$, both with $p < 0.001$).[30] The correlations are significantly lower in Game R ($\beta_5^{h-H} = -0.179$ and $\beta_5^{v-V} = -0.24$, both with $p < 0.001$).

Despite our focus of comparing Game T′ with Game R, it may also be of interest to compare it with Game T. In terms of state-action/state-message-action alignments, Table 3C and Figures 4 and 5 suggest that the receivers in Game T′ identify the true state more often than do the receivers in Game T, although the difference is not subtantial (and also not statistically significant). Yet the difference is more prominent in the early rounds, suggesting that there is a faster convergence to equilibrium in Game T′. Subtracting for each round the aggregated frequencies of the alignments in Game T from those in Game T′, we find that the differences are negatively correlated with the rounds (the Spearman rank-order coefficients between the frequencies and rounds are -0.299 with $p = 0.035$ for state-action alignments and -0.305 with $p = 0.031$ for state-message-action alignments).[31] There are two structural differences between Game T′ and Game T, the sizes of the message spaces and the payoff numbers, and it appears that the binary message spaces play the major role in facilitating the faster convergence in Game T′. Blume et al. (2008) document that in sender-receiver games with *a priori* meaningless messages, restricting the message space does affect convergence to equilibrium. In our environment with two senders, restricting the message spaces can have effect along a different line in which it helps avoid subjects' potential confusion with inconsistent message pairs. And its conducive effect on convergence appears to override the potential negative effect of the loss of "dominance" in Game T′ for senders to reveal truthfully.

We turn to subjects' strategies, presenting evidence for the second part of Result 3. For senders' strategies, Table 3A shows that the frequencies of state-message alignments are lower

[30]The detailed estimation results are reported in Column (3) of Table 7 in Appendix C. A Sender 1-subject in Game T′ misreported on dimension H 70% of the time even in the last 30 rounds and explicitly stated in the post experimental survey that his strategy was to "choose the opposite in the middle 10 and the last 20 rounds..." Column (4) reports estimation results dropping all data involving this outlier (one group per round; 50 data points in total). Dropping this subject gives us stronger results but not by much, suggesting that our overall results are robust to subject's manipulation.

[31]Using the 20th round as the cutoff, the regression results also provide support to the observation. Relative to those in Game T′, the correlations between actions and states for dimension H are lower in Rounds $21-50$ of Game T ($\beta_3^{h-H} = -0.0732$ with $p < 0.05$), with an even larger difference in Rounds $1-20$ ($\beta_4^{h-H} = -0.04$ with $p < 0.01$). For dimension V, the negative difference is, however, quite stable across the two sets of rounds ($\beta_3^{v-V} = -0.117$ with $p < 0.001$ and $\beta_4^{v-V} = -0.0055$, essentially equal to zero).



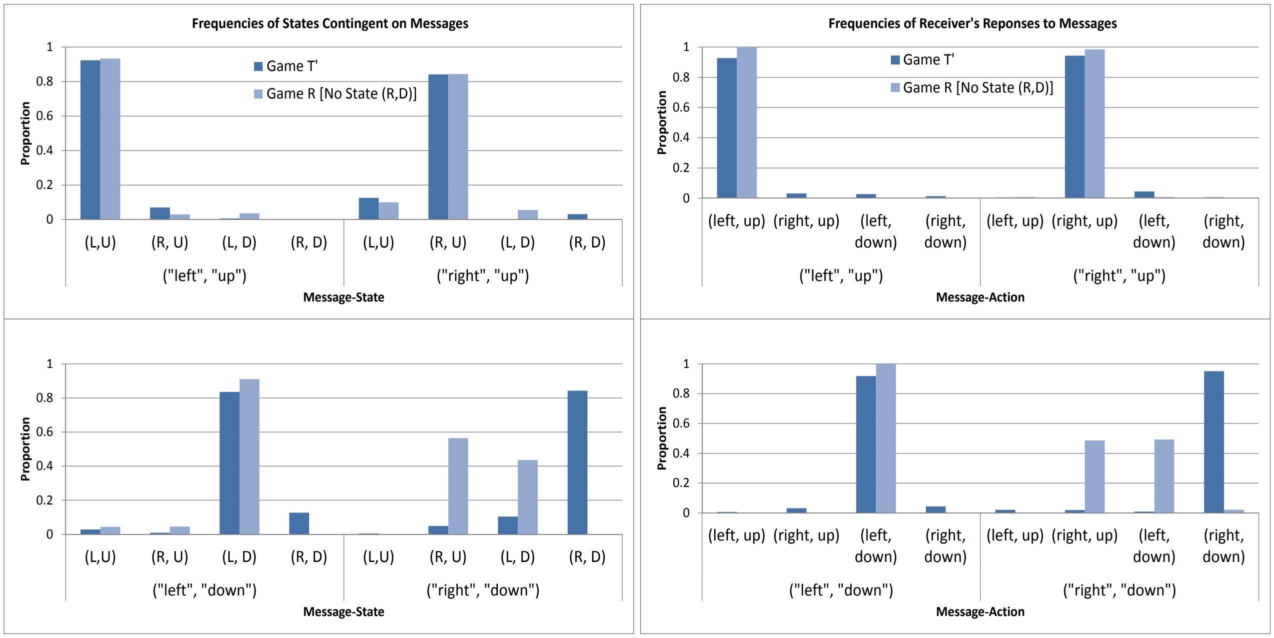
(a) Messages "h"　　　(b) Messages "v"

Figure 6: Frequencies of Messages Contingent on State: Game T′ and Game R (Last 30 Rounds)

in Game R than in Game T′. For receivers' strategies, Table 3B also shows that the frequencies of message-action alignments are lower in Game R.[32] A more detailed account of senders' message uses is presented in Figure 6. In Game R, while Senders 1 truthfully reveal when the state is (L, U) or (R, U), they send the two available messages approximately uniformly when the state is (L, D) (53% "left" and 47% "right"). Similarly, Senders 2 truthfully reveal when the state is (L, U) or (L, D) but use "up" and "down", again approximately uniformly (45% vs. 55%), when the state is (R, U). Although in state (L, D) it is not "dominant" for Sender 1 to truthfully reveal and the same is true for Sender 2 in state (R, U), message uses in Game T′ as a control show that this lack of "dominance" cannot be the major factor behind these observations. For the receivers in Game R, note that it will never be in the receivers' best interest to take (right, down) without state (R, D), so the message pair ("right", "down") is irreconcilable. And Figure 7(b) shows that the receivers respond to it by randomizing between (right, up) and (left, down) essentially uniformly (49%). The remaining 2% all comes from action (right, down). The action (left, up), required to support the fully revealing equilibrium, is *never* in the support of the empirical distribution of actions, providing evidence against the non-robust fully revealing equilibrium in Game R.

Figure 7 shows that the receivers in Game R are best responding to the senders' messages,

[32]Table 7 (Columns (7), (8) and (10)) and Table 6 (Columns (3) and (5)) in Appendix C report results from regressions similar to equation (2) with relevant changes of variables. Compared to Game T′, Game R has significantly lower state-message and message-action correlations.



(a) State Contingent on Messages (b) Receiver's Responses

Figure 7: Frequencies of States Contingent on Messages/Receiver's Responses to Messages: Game T′ and Game R (Last 30 Rounds)

even for the irreconcilable ("right", "down"). However, the senders' message uses in aggregate do not constitute best responses to the receivers. In state (L, D), Senders 1 are randomizing between the two messages. However, given Senders 2's sending "down" in state (L, D) and the receivers' responses of (left, down) after receiving ("left", "down") and of randomizing between (right, up) and (left, down) after receiving ("right", "down"), Senders 1 should strictly prefer to send "right". Similarly, in state (R, U), Senders 2, instead of randomizing between "up" and "down", should strictly prefer to send "down". Although the frequency of full revelation outcomes is lower in Game R, it is still higher than what would have predicted by chance alone.[33] The above suggests, however, that the observed full revelation outcomes in Game R, are, unlike other games, not constituted by equilibrium play. To look for an interpretation of these findings, we further examine data from individual sender-subjects.

4.3 Game R: A Behavioral Model with Honest Senders

Table 5 presents the frequencies of truthful revelations of each sender-subject in the last 30 rounds of Game R, grouped by whether the subject is Sender 1 (left panel) or Sender 2 (right panel). There are "honest" subjects who always or almost always truthfully reveal on

[33]The null hypothesis of random play is rejected in favor of equilibrium play (the Wilcoxon signed-rank test renders $p = 0.0625$, the lowest possible value with four observations/sessions).

their respective dimensions. And there is also a significant number of subjects who appear to be "strategic" in the sense of being selectively truthful. We explore the dichotomy more systematically with a simple classification. To identify between persistently truthful (honest) and selectively truthful (strategic) subjects, we use frequencies under state (L, D) for Senders 1 and state (R, U) for Senders 2. We adopt an arbitrary but rather robust cutoff of 70%: a subject will be classified as honest if and only if he/she truthfully reveals $(L, D)/(R, U)$ more than 70% of the time. Overall, 19 subjects (11 Sender 1-subjects and 8 Sender 2-subjects) are classified as honest (highlighted in Table 5), representing 43% of all sender-subjects in Game R.[34] The changes to the classification result are limited to ± 2 subjects for cutoffs $70\% \pm 10\%$.

Table 5: Frequencies of Truthful Revelations by Individual Subjects in Game R (Last 30 Rounds)

Frequencies of Truthful Revelations on Dimension H by Senders 1			
Subject No.	(L, U)	(L, D)	(R, U)
1	1	0.33	1
2	0.9	0.42	1
3	1	0.11	1
4	1	1	1
5	0.91	1	1
11	0.75	0	0.91
12	0.78	1	0.89
13	0.78	0.91	0.9
14	1	0	1
15	0.57	0.55	1
21	1	0.75	0.92
22	1	1	1
23	1	1	1
24	1	0	0.92
25	1	0.92	0.82
26	1	1	1
33	0.83	0.06	0.88
34	1	0.83	1
35	1	0.9	1
36	1	0	0.88
37	1	0	0.91
38	1	0	1
Overall	0.93	0.54	0.96

Frequencies of Truthful Revelations on Dimension V by Senders 2			
Subject No.	(L, U)	(L, D)	(R, U)
6	0.88	0.67	0.3
7	1	1	0
8	1	1	0
9	1	1	1
10	0.82	1	0
16	1	0.82	0.14
17	1	0.88	0.4
18	1	1	1
19	1	0.93	0.09
20	1	1	0.69
27	0.92	0.67	0.08
28	1	1	1
29	1	1	0
30	1	1	1
31	1	1	1
32	1	1	0
39	1	1	0.1
40	1	1	0.27
41	1	1	0.91
42	0.91	0.9	0.33
43	1	0.93	0.78
44	1	0.92	1
Overall	0.98	0.94	0.46

The dichotomy of subjects motivates us to search for an alternative model to organize our experimental data. We consider a behavioral model with two behavioral types of senders, honest and strategic, and retain equilibrium as the solution concept. An honest sender always truthfully reveals the state subject to the availability of the messages and their literal meanings. A strategic sender best responds to maximize expected payoffs. A sender's behavioral

[34]The prevalence of honest senders is consistent with "lying aversion" documented in the experimental literature of communication games. See, for example, Gneezy (2005) and Sánchez-Pagés and Vorsatz (2007).

type is his private information. The common prior is that a sender is honest with probability $\lambda \in (0, 1)$. The standard strategic model is a limiting case when $\lambda \to 0$.[35]

We conclude our analysis by presenting a robust equilibrium of the behavioral model which, with appropriate choice of parameters, allows us to interpret findings from Game R in light of equilibrium behavior:

Proposition 5. *The following strategy profile constitutes a robust partially revealing equilibrium in the behavioral model of Game R for any $\lambda \in (0, 1)$: 1) strategic Sender 1 sends "left" in state (L, U) and "right" in both (R, U) and (L, D); 2) strategic Sender 2 sends "up" in state (L, U) and "down" in both (R, U) and (L, D); 3) the receiver takes (h, v) after receiving ("h", "v") unless ("h", "v") = ("right", "down") in which case she randomizes between (right, up) and (left, down) with respective probabilities α and $1 - \alpha$, $\alpha \in [0, 1]$.*

With $\alpha = \frac{1}{2}$, i.e., the receiver randomizes uniformly between (right, up) and (left, down) upon receiving ("right", "down"), the equilibrium captures reasonably well the observed aggregate behavior of the receivers (Figure 7(b)), which the strategic model falls short of doing. For the senders, with λ in the neighborhood of $\frac{1}{2}$, which is consistent with the classification using individual subject data, the equilibrium also results in distributions of messages that are consistent with the aggregate data on message uses (Figure 6).[36] The resulting reinterpretation of message uses is that in state (L, D) "left" is entirely sent by the honest Senders 1 and "right" by the strategic Senders 1, and in (R, U) "up" is sent by the honest Senders 2 and "down" by the strategic Senders 2. Fixing λ precisely at $\frac{1}{2}$, the equilibrium predicts probabilities of 67% for state-message-action alignments and 83% for state-action alignments, which are fairly close to the aggregate numbers reported in Table 3C (60% and 78% respectively). At the possible expense of introducing non-strategic players, the behavioral model allows us to retain equilibrium as the basis for interpreting observed behavior. Theoretically, since every message pair is expected in equilibrium so that there will be no out-of-equilibrium beliefs, the partially revealing equilibrium also has the advantage of being robust.[37]

[35] While motivated by the data, our model fits into the growing literature of introducing behavioral players into communication games. Through a level-k model, Crawford (2003) introduces honest senders and credulous receivers into games with communication of intentions. For communication of private information, Ottaviani and Squintani (2006) and Kartik et al. (2007) introduce credulous receiver into the Crawford and Sobel's (1982) setting. Chen (2011) further introduces honest sender. Sobel (1985) considers two types of strategic sender, where one shares the receiver's preference and thus behaves like an honest sender. Kartik et al. (2007) and Kartik (2009) introduces lying costs for the sender; when the cost is infinitely high, the strategic sender can be considered as honest sender. Finally, Jehiel and Koessler (2008) use an alternative equilibrium concept—analogy-based expectation equilibrium (Jehiel, 2005) in which players bundle states into analogy classes—to analyze communication in Crawford and Sobel's (1982) model.

[36] The strategy profiles of the strategic players in Proposition 5 also constitute a partially revealing equilibrium in the strategic model. The information partition in the equilibrium, $\{\{(L, U)\}, \{(L, D), (R, U)\}\}$, is, however, inconsistent with our findings in which the receivers do sometimes identify states (L, D) and (R, U).

[37] While our behavioral model is motivated by the *ad hoc* task of rationalizing the findings from Game R,

5 Concluding Remarks

In this study, we experimentally implement the fully revealing equilibrium first proposed by Battaglini (2002) for multidimensional cheap talk. We find, consistent with equilibrium predictions, that the frequency of fully revealing outcomes is significantly higher in two-sender games than in one-sender game. Guided by Battaglini's (2002) robustness criterion and the insight of Ambrus and Takahashi (2008) regarding the impact of restricted state space, we also investigate empirically the robustness of the fully revealing equilibrium. We obtain evidence that fully revealing equilibria supported by implausible out-of-equilibrium beliefs are unlikely to be implemented. Nevertheless, a behavioral equilibrium with a positive fraction of honest senders allows us to interpret the observed play with equilibrium behavior. As an initial experimental attempt to implement the fully revealing equilibrium in multidimensional cheap talk, our approach has been to give it a best chance by creating an environment as simple as possible, including a 2×2 state space and "dominance" for senders to truthfully reveal. We believe that exploring the limits of implementing the fully revealing equilibrium in the laboratory with different designs represent interesting and promising research for the future.

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it may allow us to interpret our entire findings under one general framework, especially since (strategically) truthful behavior is largely observed in Game T and Game T′. Proposition 6 in Appendix C shows that the respective classes of equilibria in the strategic model of Game S, Game T, and Game T′ do exist in the behavioral model (with any $\lambda \in (0, 1)$ for Game T/T′ and $\lambda \leq \frac{1}{2}$ for Game S).

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Appendix A - Proofs

Proof of Proposition 1. Let $\mu = (\mu_{LU}, \mu_{LD}, \mu_{RU}, \mu_{RD})$ be the receiver's beliefs, where μ_{HV} is the probability assigned to state $(H, V) \in \{L, R\} \times \{U, D\}$, and $U_R(a|\mu)$ be her expected payoff from taking action a given beliefs μ. Then, we have $U_R((\text{left, up})|\mu) = 50\mu_{LU} + 20\mu_{RD}$, $U_R((\text{right, up})|\mu) = 50\mu_{RU} + 20\mu_{LD}$, $U_R((\text{left, down})|\mu)) = 50\mu_{LD} + 20\mu_{RU}$, and $U_R((\text{right, down})|\mu) = 50\mu_{RD} + 20\mu_{LU}$. Accordingly, the receiver's best response to μ is

$$\text{(left, up) if } \mu_{LU} \geq \mu_{RD} \text{ and } 5\mu_{LU} + 2\mu_{RD} \geq 3\max\{\mu_{LD}, \mu_{RU}\} + 2(\mu_{LD} + \mu_{RU}); \quad \text{(A.1)}$$

$$\text{(left, down) if } \mu_{LD} \geq \mu_{RU} \text{ and } 5\mu_{LD} + 2\mu_{RU} \geq 3\max\{\mu_{LU}, \mu_{RD}\} + 2(\mu_{LU} + \mu_{RD}); \quad \text{(A.2)}$$

$$\text{(right, up) if } \mu_{RU} \geq \mu_{LD} \text{ and } 5\mu_{RU} + 2\mu_{LD} \geq 3\max\{\mu_{LU}, \mu_{RD}\} + 2(\mu_{LU} + \mu_{RD}); \quad \text{(A.3)}$$

$$\text{(right, down) if } \mu_{RD} \geq \mu_{LU} \text{ and } 5\mu_{RD} + 2\mu_{LU} \geq 3\max\{\mu_{LD}, \mu_{RU}\} + 2(\mu_{LD} + \mu_{RU}). \quad \text{(A.4)}$$

We first show the existence of the partially revealing equilibrium. Suppose that the sender truthfully reveals that the state is L on dimension H and babbles on dimension V. Given the uniform prior, the receiver's updated beliefs are $\mu_{LU} = \mu_{LD} = \frac{1}{2}$ and $\mu_{RU} = \mu_{RD} = 0$. (A.1) and (A.2) are satisfied, and randomizing between (left, up) and (left, down) with probabilities $(p, 1-p)$ is a best response of the receiver for any $p \in [0,1]$. Consider next that the sender truthfully reveals that the state is R on dimension H and babbles on dimension V. The receiver's updated beliefs are $\mu_{RU} = \mu_{RD} = \frac{1}{2}$ and $\mu_{LU} = \mu_{LD} = 0$. (A.3) and (A.4) are satisfied, and randomizing between (right, up) and (right, down) with probabilities $(q, 1-q)$ is a best response of the receiver for any $q \in [0,1]$. In state (L, U), we require that the sender has no incentive to reveal that the state consists of R, or $20p + 50(1-p) \geq 10(1-q)$, which is satisfied for all $p \in [0,1]$ and all $q \in [0,1]$. Similarly, it is straightforward that for all $p \in [0,1]$ and all $q \in [0,1]$, the sender has no incentive to deviate in states (R, U), (L, D) and (R, D).

We show that there exists no equilibrium in Game S in which the receiver receives information partitions other than $\{\{(L,U),(L,D)\},\{(R,U),(R,D)\}\}$. It is straightforward that the fully revealing partition $\{\{(L,U)\},\{(L,D)\},\{(R,U)\},\{(R,D)\}\}$ cannot be sustained as equilibrium. It suffices to consider state (L,U) in which the sender has an incentive to tell that it is (L,D) given that he will receive 50 rather than 20. We show next that information partitions where only one state is fully revealed (1-3 partitions) are not feasible in equilibrium. Consider the partition where only (L,U) is fully revealed. The receiver takes (left, up) when the state is (L,U). In all other three states, the receiver's updated beliefs are $\mu_{LD} = \mu_{RU} = \mu_{RD} = \frac{1}{3}$ and $\mu_{LU} = 0$. Only (A.2) and (A.3) are satisfied, and the receiver randomizes between (left, down) and (right, up) with probabilities $(p, 1-p)$, $p \in [0,1]$. This does not constitute an equilibrium, because in state (L,D) the receiver has an incentive to tell that it is (L,U) given that $50 > 20p + 10(1-p)$ for all $p \in [0,1]$. Similar arguments hold for all other 1-3 partitions.

We show next that other 2-2 partitions cannot constitute an equilibrium. Consider the partition where dimension V is fully revealed. When the true state consists of U, $\mu_{LU} = \mu_{RU} = \frac{1}{2}$ and $\mu_{LD} = \mu_{RD} = 0$. (A.1) and (A.3) are satisfied, and the receiver's best response is to randomize between (left, up) and (right, up) with probabilities $(p, 1-p)$ for some $p \in [0,1]$. When the true state consists of D, $\mu_{LU} = \mu_{RU} = 0$ and $\mu_{LD} = \mu_{RD} = \frac{1}{2}$. (A.2) and (A.4) are satisfied, and the receiver's best response is to randomize between (left, down) and (right, down) with probabilities $(q, 1-q)$ for some $q \in [0,1]$. To show that this does not constitute an equilibrium, it suffices to consider states (L,U) and (R,U). The requirements for no profitable deviation are, respectively, $20p \geq 50q + 10(1-q)$ and $20(1-p) \geq 10q + 50(1-q)$, which implies $20 \geq 60$, a contradiction. For the partition $\{\{(L,U),(R,D)\},\{(L,D),(R,U)\}\}$ in which the diagonal is revealed, a similar argument shows that in states (L,U) and (R,D), the absence of profitable deviations requires, respectively, $50q \leq 20p + 10(1-p)$ and $50(1-q) \leq 10p + 20(1-p)$, which leads to the contradiction of $50 \leq 30$.

We complete the proof by ruling out 1-1-2 partitions. There are six possible partitions in this category. By the same argument against the fully revealing partition, the two partitions in which H is fully revealed for fixed values of V cannot be sustained in equilibrium. The two other partitions in which V is fully revealed for fixed values of H are also not feasible in equilibrium, because the sender shares no common interest with the receiver along dimension V. This leaves two partitions, $\{\{(L,U),(R,D)\},\{(L,D)\},\{(R,U)\}\}$ and $\{\{(L,U)\},\{(R,D)\},\{(L,D),(R,U)\}\}$. Since when the state is one of the partially revealed ones the sender has an incentive to tell that it is one of the fully revealed ones, for this yields him a payoff of 50, they also cannot be feasible in equilibrium.

□

Proof of Proposition 2. We construct a fully revealing equilibrium. To economize on notations, we denote (h,v) to be the receiver's ideal action in state $(H,V) \in \{L,R\} \times \{U,D\}$. Consider the following strategy profiles of the senders: for all $(H,V) \in \{L,R\} \times \{U,D\}$,

$$\sum_{\tilde{v} \in \{\text{up, down}\}} \sigma_1(\text{``}(h,\tilde{v})\text{''}|(H,V)) = 1, \text{ and } \sum_{\tilde{h} \in \{\text{left, right}\}} \sigma_2(\text{``}(\tilde{h},v)\text{''}|(H,V)) = 1. \tag{A.5}$$

Sender 1 truthfully reveals on dimension H but is not required to truthfully reveal on dimension V; Sender 2 does the exact opposite. Upon receiving the senders' messages, the receiver updates her beliefs using Bayes' rule: for any $w \in \{\text{up, down}\}$ and $k \in \{\text{left, right}\}$, we have

$$\begin{aligned} \mu_{HV}((\text{``}(h,w)\text{''}, \text{``}(k,v)\text{''})) &= \frac{\frac{1}{4}\sigma_1(\text{``}(h,w)\text{''}|(H,V))\sigma_2(\text{``}(k,v)\text{''}|(H,V))}{\sum_{(\tilde{H},\tilde{V}) \in \{L,R\} \times \{U,D\}} \frac{1}{4}\sigma_1(\text{``}(\tilde{h},w)\text{''}|(\tilde{H},\tilde{V}))\sigma_2(\text{``}(k,\tilde{v})\text{''}|(\tilde{H},\tilde{V}))} \\ &= \frac{\sigma_1(\text{``}(h,w)\text{''}|(H,V))\sigma_2(\text{``}(k,v)\text{''}|(H,V))}{\sigma_1(\text{``}(h,w)\text{''}|(H,V))\sigma_2(\text{``}(k,v)\text{''}|(H,V))} = 1, \end{aligned} \tag{A.6}$$

where the second equality follows from the fact that either $\sigma_1(\text{``}(h,w)\text{''}|(\tilde{H},\tilde{V})) = 0$ or $\sigma_2(\text{``}(k,v)\text{''}|(\tilde{H},\tilde{V})) = 0$ unless $(\tilde{H},\tilde{V}) = (H,V)$. Given the beliefs, the best responses of the receiver are to take her ideal actions: $\rho(\text{``}(h,w)\text{''}, \text{``}(k,v)\text{''}) = (h,v)$.

To verify that (A.5) constitutes an equilibrium, note that given the strategies of Sender 2 and the receiver, Sender 1 can only influence the receiver in the choice between (h,v) and $(\tilde{h},v)$, $h \neq \tilde{h}$; it is straightforward to verify that Sender 1 strictly prefers (h,v) over $(\tilde{h},v)$. Similarly, Sender 2, given the others' strategies, can only influence the receiver in the choice between (h,v) and $(h,\tilde{v})$ where he strictly prefers (h,v) over $(h,\tilde{v})$. Other than (A.5), there is no restriction on $\sigma_1(\text{``}(h,\text{up})\text{''}|(H,V))$, $\sigma_1(\text{``}(h,\text{down})\text{''}|(H,V))$, $\sigma_2(\text{``}(\text{left},v)\text{''}|(H,V))$

and σ_2("(right, v)"$|(H, V))$. If $\sigma_1(\text{“}(h, v)\text{”}|(H, V)) = \sigma_2(\text{“}(h, v)\text{”}|(H, V)) = 1$, we are in the first class of strategy profiles. The receiver's response after receiving an out-of-equilibrium inconsistent message pair can be assigned to be one of the equilibrium responses, which suffice to deter deviations by the senders. If $\sigma_1(\text{“}(h, \text{up})\text{”}|(H, V)) > 0$, $\sigma_1(\text{“}(h, \text{down})\text{”}|(H, V)) > 0$, $\sigma_2(\text{“}(\text{left}, v)\text{”}|(H, V)) > 0$ and $\sigma_2(\text{“}(\text{right}, v)\text{”}|(H, V)) > 0$, we are in the second class of strategy profiles, in which there is no out-of-equilibrium message pair.

□

Proof of Proposition 3. With the binary message spaces the senders' strategy profiles in (A.5) become $\sigma_1(\text{“}h\text{”}|(H, V)) = \sigma_2(\text{“}v\text{”}|(H, V)) = 1$. The receiver updates her beliefs in a similar fashion as in (A.6), and her best response is $\rho(\text{“}h\text{”}, \text{“}v\text{”}) = (h, v)$. Similar to the argument in the proof of Proposition 2, the senders' strategies also constitute best responses. There are two other classes of strategy profiles to achieve full revelation: 1) Sender 1 truthfully revealing on dimension V and Sender 2 on dimension H, and 2) one sender reveals whether the state is in $\{(L, U), (R, D)\}$ or in $\{(L, D), (R, U)\}$, and the other sender truthfully reveals on either dimension V or dimension H. It is straightforward to verify that neither of these strategy profile can constitute an equilibrium. Given that under the binary message spaces there is no out-of-equilibrium message pair for any fully revealing equilibrium, the receiver's beliefs are always derived from Bayes' rule.

□

Proof of Proposition 4. Consider, as in the proof of Proposition 3, $\sigma_1(\text{“}h\text{”}|(H, V)) = \sigma_2(\text{“}v\text{”}|(H, V)) = 1$, where the receiver's best response is $\rho(\text{“}h\text{”}, \text{“}v\text{”}) = (h, v)$. It carries over from Game T$'$ that in state (L, U) no sender has an incentive to deviate. To ensure that the senders' strategies are best responses, we specify the receiver's response after receiving an irreconcilable message pair, either in state (R, U) or (L, D). Given the receiver's beliefs $\mu = (\mu_{LU}, \mu_{LD}, \mu_{RU})$, her expected payoffs are $U_R((\text{left, up})|\mu) = 50\mu_{LU}$, $U_R((\text{right, down})|\mu) = 20\mu_{LU}$, $U_R((\text{right, up})|\mu) = 50\mu_{RU} + 20\mu_{LD}$, and $U_R((\text{left, down})|\mu)) = 50\mu_{LD} + 20\mu_{RU}$. For any μ, $U_R((\text{right, down})|\mu) < \frac{1}{2}U_R((\text{left, up})|\mu) + \frac{1}{4}U_R((\text{left, down})|\mu)) + \frac{1}{4}U_R((\text{right, up})|\mu)$. Thus, (right, down) is strictly dominated. Suppose that, after receiving an irreconcilable message pair, the receiver takes (left, up), (right, up) and (left, down) with respective probabilities p, q and $1 - p - q$. In state (L, D), in order for Sender 1 not to have an incentive to tell that the state consists of R, we require $20 \geq 15p + 30q + 20(1 - p - q)$ or $p \geq 2q$. In state (R, U), in order for Sender 2 not to have an incentive to tell that the state consists of D, we require that $20 \geq 15p + 20q + 30(1 - p - q)$ or $3p + 2q \geq 2$. Combining $p \geq 2q$ and $3p + 2q \geq 2$, we obtain $p \geq \frac{1}{2}$ as required. Similar to Game T$'$, other classes of strategy profiles to achieve full revelation cannot constitute an equilibrium so that $\sigma_1(\text{“}h\text{”}|(H, V)) = \sigma_2(\text{“}v\text{”}|(H, V)) = 1$

represent the unique strategy profiles that constitute a fully revealing equilibrium.

□

Proof of Corollary 1. To support the fully revealing equilibrium, the receiver's distribution of actions after an irreconcilable message pair needs to put probability of at least $\frac{1}{2}$ on (left, up), so the out-of-equilibrium beliefs have to assign positive probability on (L, U). We show that for any sequence ε^n converging to zero there exists no $g = (g_1, g_2)$ putting positive probabilities on all states so that the beliefs induced by equilibrium strategies $\sigma = (\sigma_1, \sigma_2)$ in an ε-perturbed game put positive probability on (L, U) as $\varepsilon^n \to 0$. In an ε-perturbed game, after receiving an irreconcilable message pair the receiver's belief that the state is (L, U) is

$$\mu_{LU}(\sigma, g, \varepsilon^n) = \frac{\frac{1}{3}\varepsilon_1^n g_1^{RU} \varepsilon_2^n g_2^{LD}}{\frac{1}{3}\varepsilon_1^n g_1^{RU} \varepsilon_2^n g_2^{LD} + \frac{1}{3}\varepsilon_2^n g_2^{LD} + \frac{1}{3}\varepsilon_1^n g_1^{RU}},$$

where g_i^{HV} is the probability that Sender i observes state (H, V) in the event of mistake. For $g_1^{RU} > 0$ and $g_2^{LD} > 0$, $\mu_{LU}(\sigma, g, \varepsilon^n) \to 0$ as $\varepsilon^n \to 0$ for any ε^n converging to zero.

□

Proof of Corollary 2. Since one can construct equilibria that are free of out-of-equilibrium beliefs, they are also robust. We provide an example of non-robust fully revealing equilibrium. Consider an equilibrium in which each sender sends "(left, up)" for state (L, U), "(right, up)" for (R, U), "(left, down)" for (L, D) and "(right, down)" for (R, D). It suffices to consider one inconsistent message pair. Suppose the equilibrium is supported by out-of-equilibrium beliefs that assign probability one to (L, U) after message pair ("(right, down)", "(right, up)"); the receiver takes action (left, up), which deters deviations by Sender 1 in state (R, U) and by Sender 2 in state (R, D). Upon receiving ("(right, down)", "(right, up)") in the corresponding equilibrium in an ε-perturbed game, the receiver's beliefs that the state is (L, U) is

$$\mu_{LU}(\sigma, g, \varepsilon^n) = \frac{\frac{1}{4}\varepsilon_1^n g_1^{RD} \varepsilon_2^n g_2^{RU}}{\frac{1}{4}\varepsilon_1^n g_1^{RD} \varepsilon_2^n g_2^{RU} + \frac{1}{4}\varepsilon_1^n g_1^{RD} + \frac{1}{4}\varepsilon_1^n g_1^{RD} \varepsilon_2^n g_2^{RU} + \frac{1}{4}\varepsilon_2^n g_2^{RU}}.$$

For $g_1^{RD} > 0$ and $g_2^{RU} > 0$, $\mu_{LU}(\sigma, g, \varepsilon^n) \to 0$ as $\varepsilon^n \to 0$ for any ε^n converging to zero.

□

Proof of Corollary 3. The corollary follows immediately from the fact that any fully revealing equilibrium in Game T$'$ is free of out-of-equilibrium beliefs.

□

Proof of Proposition 5. We first show that Sender 1's strategy in 1) is a best response to 2) and 3); the case for Sender 2 is symmetric and will be omitted. In state (L, U), given that Sender 2, honest or strategic, sends "up", Sender 1 receives 20 from sending the prescribed "left". He has no incentive to deviate to send "right" since the receiver will then take (right, up), which yields him a payoff of 0. Consider next state (R, U) and that Sender 1 sends "right". With probability λ, Sender 2 is honest, in which case the receiver takes (right, up). With probability $1-\lambda$, Sender 2 is strategic and sends "down", in which case the receiver takes (right, up) and (left, down) with respective probabilities α and $1-\alpha$. Sender 1's expected payoff from sending "right" is thus $20\lambda+[20\alpha+10(1-\alpha)](1-\lambda)$. If Sender 1 sends "left", with probability λ the receiver takes (left, up) and with probability $1-\lambda$ the receiver takes (left, down). Sender 1 thus receives $10(1-\lambda)$. Given that $20\lambda+[20\alpha+10(1-\alpha)](1-\lambda) \geq 10(1-\lambda)$ for all $\lambda \in (0,1)$ and all $\alpha \in [0,1]$, Sender 1 has no incentive to deviate to send "left". In state (L, D), the receiver will take (left, down) if Sender 1 sends "left", yielding him a payoff of 20. By sending "right", Sender 1 contributes to induce the receiver to randomize between (right, up) and (left, down), which brings him an expected payoff of $30\alpha + 20(1-\alpha)$. Given that $30\alpha + 20(1-\alpha) \geq 20$ for all $\alpha \in [0,1]$, Sender 1 has no incentive to deviate to send "left".

We verify next that the receiver's strategy in 3) constitutes a best response given 1) and 2). Since the message pair ("left", "up") is sent only in state (L, U) when the senders are either honest or strategic, the receiver's updated beliefs put probability one on (L, U), and she takes action (left, up). The message pair ("right", "up) is sent only in state (R, U) when Sender 2 is honest and Sender 1 is either honest or strategic. Updating beliefs accordingly, the receiver takes (right, up). Similarly, the receiver takes (left, down) after receiving ("left", "down"), for it is sent only in state (L, D) when Sender 1 is honest and Sender 2 is either honest or strategic. Upon receiving ("right", "down"), which can only be sent in either state (R, U) or (L, D), the receiver updates her beliefs that $\mu_{RU}((\text{“right”}, \text{“down”})) = [\frac{1}{3}(1-\lambda)]/[\frac{1}{3}(1-\lambda) + \frac{1}{3}(1-\lambda)] = \frac{1}{2}$ and is indifferent between (right, up) and (left, down). The receiver is thus willing to randomize with any $\alpha \in [0,1]$. Finally, since every message pair is expected in equilibrium, the partially revealing equilibrium constituted by the above strategies is robust.

□

Appendix B - Translated Instruction for Game T

TASSEL EXPERIMENTAL INSTRUCTION

Experimental Payment

At the end of the experiment, you will receive a show-up fee of NT$100 plus the NTD converted from the "Standard Currency Units" you have earned in the experiment. ("Standard Currency Units" are the experimental currency units used in the experiment.) The amount of "Standard Currency Units" you will receive, which will be different for each participant, depends on your decision, the decision of others and some random factor. All earnings are paid in private and you are not obligated to tell others how much you have earned.

Note: The exchange rate between "Standard Currency Units" and NTD is $2:1$**. (**2 **Standard Currency Units = NT$1.)**

Experimental Instructions

This is an experiment on group decisions among three individuals. There are 3 practice rounds and 50 official rounds. Each group consists of three members, Member A, B and C. At the beginning of the experiment, you will be randomly assigned by the computer to be either A, B, or C. Once decided, your role remains the same throughout the experiment. However, at the beginning of each round, the computer will randomly rematch participants to form new groups; thus, members in your group are not the same each round.

At the beginning of each round, the computer will randomly select the current state out of four possibilities: (L, U), (R, U), (L, D) and (R, D). Member A and Member B will be informed about the selected current state (displayed on their screens) but not Member C. In each round, Member C will have to make a decision, choosing (left, up), (right, up), (left, down) or (right, down).

Before Member C makes the decision, Member A and Member B will both recommend "left" or "right" and "up" or "down". Member A will first recommend "left" or "right" and then "up" or "down"; Member B will recommend "up" or "down" and then "left" or "right". Recommendations will be displayed on Member C's screen only after all the recommendations have been made by both Member A and Member B, after which Member C makes the decision. For example, the decision screen of Member C is displayed here, in which Member A has recommended "left", "down" and Member B has recommended "right", "up".[38]

In each round, each member's earnings depend on the current state and Member C's decision, as in the table displayed on the screen. Your earnings are bold in blue and those of the other two members are in black (italic or underlined). If you are Member A and Member B, the current state will further be highlighted in red. There are four regions in the table, the top-left region shows the earnings when the current state is (L, U), and the top-right shows

[38] The experimental instruction is accompanied by slide illustrations showing screen shot 3 in Appendix C.

the earnings when the current state is (R, U). Similarly, the bottom-left and the bottom-right regions show the respective earnings for (L, D) and (R, D). In each of the regions, there are four cells showing each member's respective earnings when Member C chooses (left,up), (right, up), (left, down) or (right, down).

For example, suppose the current state is selected to be (L, U). If Member C's decision is (left, up), then she will receive 50 Standard Currency Units, while the other two members will each receive 20 (top-left cell). On the other hand, if Member C's decision is (left, down), then this will only bring her 10 Standard Currency Units, while Member A receives 50 and Member B receives 0 (bottom-left cell). If Member C chooses (right, up) instead, herself and Member A will both receive 0, while Member B will receive 50 (top-right cell). Finally, if Member C chooses (right, down), she will receiver 20 Standard Currency Units, while both Member A and Member B will receive 10 (bottom-right cell). Similarly for other three states.

At the end of each round, the computer will display results of the round, including the current staten, Member A's and Member B's recommendations, Member C's decision and your earnings. Click "Confirm" to proceed to the next round.

Practice Rounds

There are three practice rounds, where the objective is to get you familiar with the computer interface and the earnings calculation. **Please note that the practice rounds are entirely for this purpose, and any earnings in the practice rounds will not contribute to your final payment at all.** Once the practice rounds are over, the experimenter will announce "The official experiment begins now!" after which the official experiment starts.

If you have any questions, please raise your hand. The experimenter will answer your question individually.

The Official Experiment Begins

The official experiment begins now. There are in total 50 rounds. The Standard Currency Units you earn in all 50 rounds will be converted into NTD and paid to you according to the $2 : 1$ exchange rate (2 Standard Currency Units = NT\$1). So, please make your decisions carefully.

Appendix C - Behavioral Model for Other Games and Additional Tables/Figures (Not Intended for Publication)

C.1 Behavioral Model for Game S, Game T, and Game T′

We show that our behavioral model admits equilibria that have the same informational properties as the partially/fully revealing equilibria in the strategic model of Game S, Game T and Game T′. We say that two equilibria are information-equivalent if they result in the same information partition.

Proposition 6. *An equilibrium information-equivalent to all partially revealing equilibria in the strategic model of Game S exists in the behavioral model for any $\lambda \in (0, \frac{1}{2}]$. An equilibrium information-equivalent to all fully revealing equilibria in the strategic model of Game T (Game T′) exists in the behavioral model for any $\lambda \in (0, 1)$.*

Proof. The proofs for Game T and Game T′ are straightforward and omitted. We show that the following constitutes an equilibrium in the behavioral model of Game S for $\lambda \in (0, \frac{1}{2}]$, in which the receiver receives $\{\{(L, U), (L, D)\}, \{(R, U), (R, D)\}\}$: 1) the strategic sender randomizes between "(left, up)" and "(left, down)" with probabilities $(1 - \frac{1}{2(1-\lambda)}, \frac{1}{2(1-\lambda)})$ in state (L, U) and $(\frac{1}{2(1-\lambda)}, 1-\frac{1}{2(1-\lambda)})$ in (L, D) and randomizes between "(right, up)" and "(right, down)" with probabilities $(1 - \frac{1}{2(1-\lambda)}, \frac{1}{2(1-\lambda)})$ in (R, U) and $(\frac{1}{2(1-\lambda)}, 1 - \frac{1}{2(1-\lambda)})$ in (R, D); and 2) the receiver randomizes between (left, up) and (left, down) with probabilities $(p, 1 - p)$ for some $p \in [0, 1]$ after receiving "(left, up)" and "(left, down)" and between (right, up) and (right, down) with probabilities $(q, 1 - q)$ for some $q \in [0, 1]$ after receiving "(right, up)" and "(right, down)".

Upon receiving "(left, up)", the receiver's beliefs put zero probability on both states (R, U) and (R, D) because "(left, up)" is not sent in either state. For state (L, U), we have

$$\mu_{LU}(\text{“(left, up)”}) = \frac{\frac{1}{4}(\lambda + (1 - \lambda)(1 - \frac{1}{2(1-\lambda)}))}{\frac{1}{4}(\lambda + (1 - \lambda)(1 - \frac{1}{2(1-\lambda)})) + \frac{1}{4}((1 - \lambda)\frac{1}{2(1-\lambda)})} = \frac{1}{2}.$$

Similarly, upon receiving "(left, down)", $\mu_{LU}(\text{“(left, down)”}) = \mu_{LD}(\text{“(left, down)”}) = \frac{1}{2}$. By a similar argument, upon receiving "(right, up)" or "(right, down)", the receiver's beliefs put zero probability on (L, U) and (L, D) and probability of $\frac{1}{2}$ on each of (R, U) and (R, D). Given these beliefs, the receiver is indifferent between the relevant actions and is thus willing to randomize with any probabilities $p \in [0, 1]$ and $q \in [0, 1]$. It follows from the argument in the proof of Proposition 1 that the prescribed randomization for the sender above also constitutes a best response. The requirement that $\frac{1}{2(1-\lambda)} \leq 1$ gives $\lambda \leq \frac{1}{2}$.

□

The results for Game T and Game T′ are straightforward. Under the fully revealing strategy profile in which literal recommendations are sent, the behavior of a strategic sender is exactly the same as his honest counterpart. The receiver's best responses will not change with the presence of honest senders, and so neither will the strategic senders' best responses. The key of the equilibrium construction for Game S is that the strategic sender randomizes on dimension V in a way that provides information "counter-balancing" that provided by the honest sender, leaving the receiver indifferent between (left, up) and (left, down) and between (right, up) and (right, down) as in the partially revealing equilibrium of the strategic model. The randomization probability that achieves this imposes restriction that $\lambda \leq \frac{1}{2}$.[39]

Given that our findings from Game S, Game T and Game T′ are highly consistent with the respective equilibria of the strategic model, Proposition 6 suggests that the behavioral model can also explain our findings when $\lambda \in (0, \frac{1}{2}]$. Together with the analysis for Game R Section 4.3, a behavioral model with parameter $\lambda = \frac{1}{2}$ provides a unifying framework for interpreting our entire findings.

[39] An equilibrium information-equivalent to all fully revealing equilibria in the strategic model of Game R also exists in the behavioral model for any $\lambda \in (0, 1)$. Also, for all games, the robustness properties of the equilibria carry over to the behavioral model.

C.2 Tables and Figures

Table 6: Random Effect MLE Regressions: Action on Message (top: dimension H; bottom: dimension V)

	(1)	(2)	(3)	(4)	
	h_{it}	h_{it}	h_{it}	h_{it}	
"h_{it}" (Sender 1)	0.978***	0.975***	0.979***	–	
	(0.00695)	(0.00887)	(0.0128)		
"h_{it}" × D_{it}^{GameS} (Sender 1)	–	0.00196	-0.0301	–	
		(0.0103)	(0.0165)		
"h_{it}" × D_{it}^{GameT} (Sender 1)	–	–	-0.0293	–	
			(0.0167)		
"h_{it}" × D_{it}^{GameR} (Sender 1)	–	–	-0.144***	–	
			(0.0177)		
"h_{it}" (Sender 2)	–	–	–	-0.0159	
				(0.0383)	
	(1)	(2)		(4)	(5)
	v_{it}	v_{it}		v_{it}	v_{it}
"v_{it}" (Sender 1)	0.101**	-0.0845*		–	–
	(0.0360)	(0.0379)			
"v_{it}" × D_{it}^{GameS} (Sender 1)	–	0.178***		–	–
		(0.0506)			
"v_{it}" (Sender 2)	–	–		0.974***	0.974***
				(0.0127)	(0.0134)
"v_{it}" × D_{it}^{GameT} (Sender 2)	–	–		–	-0.0235
					(0.0174)
"v_{it}" × D_{it}^{GameR} (Sender 2)	–	–		–	-0.141***
					(0.0184)
Game	Game S	Games S, T	All	Game T	Game T T′, R
Round	Last 30	Last 30	Last 30	Last 30	Last 30
No. of Observations	840	1560	2880	720	2040
No. of Groups	28	52	96	24	68

Note: Standard errors in parentheses; *** for p <0.001, ** for p <0.01, * for p <0.05.

Table 7: Random Effect MLE Regressions: Action and Messages on State (top panel: dimension H; bottom panel: dimension V)

	(1) h_{it}	(2) h_{it}	(3) h_{it}	(4) h_{it}	(5) "h_{it}" of Sender 1	(6) "h_{it}" of Sender 1	(7) "h_{it}" of Sender 1	(8) "h_{it}" of Sender 1	(9) "h_{it}" of Sender 2	(10)
H_{it}	0.979***	0.747***	0.733***	0.772***	1.001***	0.940***	0.814***	0.861***	-0.0403	
	(0.00709)	(0.0294)	(0.0220)	(0.0222)	(0.00169)	(0.00986)	(0.0210)	(0.0204)	(0.0383)	
$H_{it} \times D_{it}^{GameS}$	–	0.0957**	0.0234	-0.0149	–	0.0584***	0.177***	0.130***	–	
		(0.0315)	(0.0288)	(0.0288)		(0.0133)	(0.0274)	(0.0266)		
$H_{it} \times D_{it}^{GameT}$	–	–	-0.0732*	-0.111***	–	–	-0.00103	-0.0485	–	
			(0.0305)	(0.0305)			(0.0278)	(0.0271)		
$H_{it} \times D_{it}^{GameT} \times D_{it}^{1-20}$	–	–	-0.0400**	-0.0400**	–	–	–	–	–	
			(0.0140)	(0.0138)						
$H_{it} \times D_{it}^{GameR}$	–	–	-0.179***	-0.217***	–	–	-0.0777**	-0.125***	–	
			(0.0315)	(0.0314)			(0.0295)	(0.0291)		
	(1) v_{it}	(2) v_{it}	(3) v_{it}	(4) v_{it}	(5) "v_{it}" of Sender 1	(6) "v_{it}" of Sender 1	(7)	(8)	(9) "v_{it}" of Sender 2	(10) "v_{it}" of Sender 2
V_{it}	0.0380	0.747***	0.820***	0.822***	0.0393	-0.197***			0.983***	0.949***
	(0.0359)	(0.0324)	(0.0240)	(0.0246)	(0.0360)	(0.0380)			(0.0103)	(0.0199)
$V_{it} \times D_{it}^{GameS}$	–	-0.697***	-0.771***	-0.772***	–	0.228***			–	–
		(0.0445)	(0.0324)	(0.0329)		(0.0507)				
$V_{it} \times D_{it}^{GameT}$	–	–	-0.117***	-0.119***	–	–			–	-0.0516
			(0.0337)	(0.0342)						(0.0276)
$V_{it} \times D_{it}^{GameT} \times D_{it}^{1-20}$	–	–	-0.00551	-0.00551	–	–			–	–
			(0.0152)	(0.0152)						
$V_{it} \times D_{it}^{GameR}$	–	–	-0.240***	-0.242***	–	–			–	-0.245***
			(0.0349)	(0.0354)						(0.0307)
Game	Game S	Games S, T	All	All (no outlier)	Game S	Games S, T	All	All (no outlier)	Game T	Games T, T′, R
Round	Last 30	Last 30	All 50	All 50	Last 30	Last 30	Last 30	Last 30	Last 30	Last 30
No. of Observations	840	1560	4800	4750	840	1560	2880	2850	720	2040
No. of Groups	28	52	96	96 (unbal.)	28	52	96	95	24	68

Note: Standard errors in parentheses; *** for p <0.001, ** for p <0.01, * for p <0.05. Results in Table 4 are reproduced in Columns (1), (2), (5), (6) and (9) for comparison. Column (10) is empty for dimension H because "h_{it}" is not sent by Sender 2 in Game T′ and Game R under the binary message spaces. Similarly, Columns (7) and (8) for dimension V are empty because "v_{it}" is not sent by Sender 1 in Game T′ and Game R.

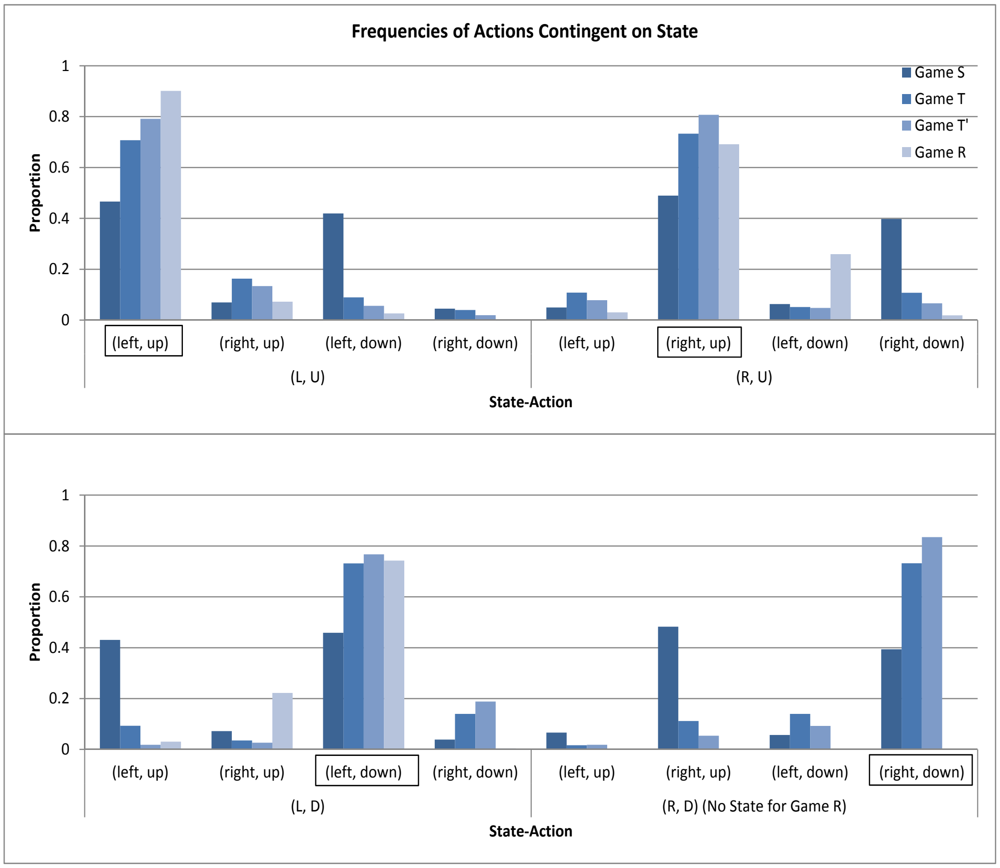
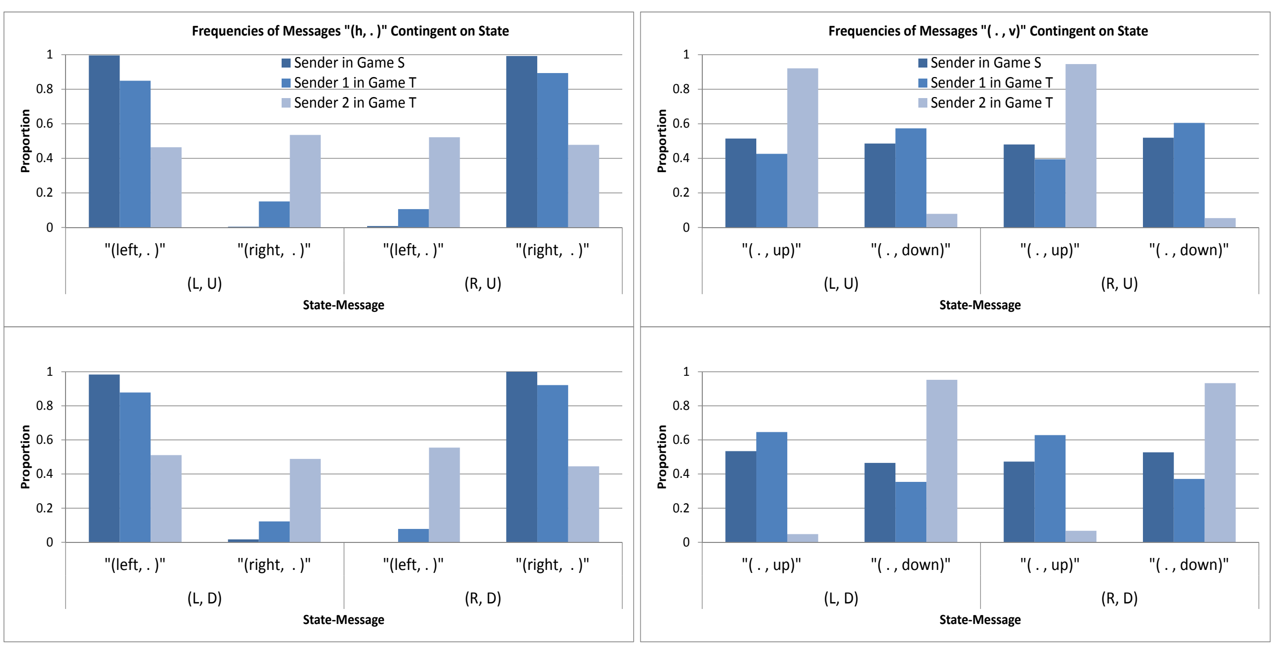


Figure 8: Frequencies of Actions Contingent on State (Last 30 Rounds)



(a) Messages "h" (b) Messages "v"

Figure 9: Frequencies of Messages Contingent on State: Game S and Game T (Last 30 Rounds)

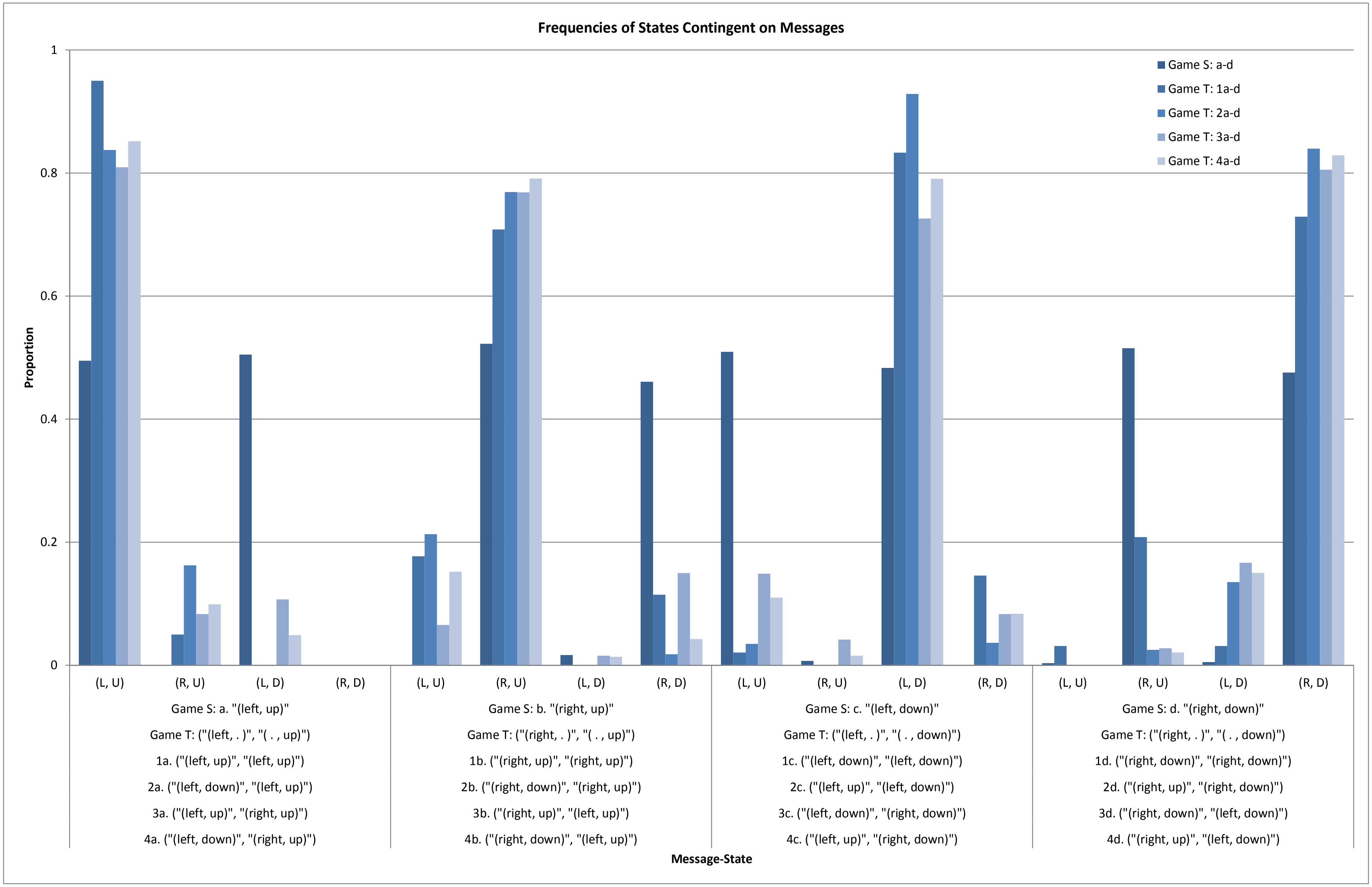


Figure 10: Frequencies of States Contingent on Message: Game S and Game T (Last 30 Rounds)

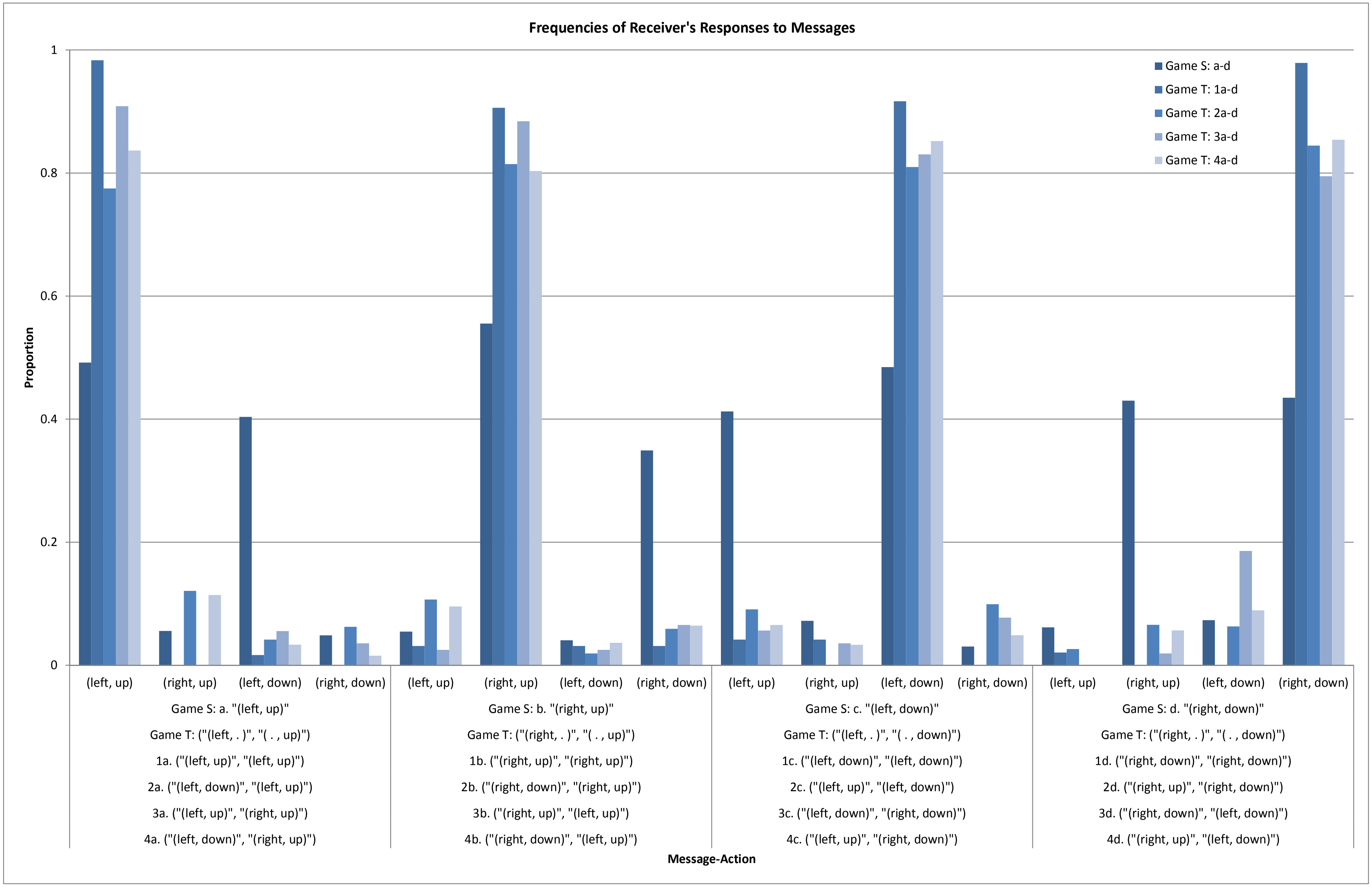


Figure 11: Frequencies of Receiver's Responses to Messages: Game S and Game T (Last 30 Rounds)

Appendix D (for Online Only; Not Intended for Publication)

TASSEL 實驗說明 p.1

實驗報酬

本實驗結束後，你將得到定額車馬費新台幣 100 元，以及你在實驗中獲得的「法幣」所兌換成之新台幣。（「法幣」為本實驗的實驗貨幣單位。）你在實驗中能獲得的「法幣」會根據你所做的決策、別人的決策，以及隨機亂數決定，每個人都不同。每個人都會個別獨自領取報酬，你沒有義務告訴其他人你的報酬多寡。**請注意：本實驗中的「法幣」與新台幣兌換匯率為 2:1。**(法幣 2 元=新台幣 1 元)

實驗說明

本實驗為三人一組的共同決策實驗，共有三個練習回合與五十回合的正式實驗。每組有成員甲、成員乙、成員丙三人。在實驗一開始時，電腦會隨機決定你是成員甲、成員乙還是成員丙。一旦決定之後，你的成員身份在實驗中不會再變動。然而，每回合一開始時，電腦會將所有人打散重新隨機分組，因此，每次你遇到的成員並非相同。

每回合一開始時，電腦會從下列四種可能性，隨機選取本回合的狀態：（Ｌ，Ｕ），（Ｒ，Ｕ），（Ｌ，Ｄ）和（Ｒ，Ｄ）。電腦會告知成員甲和成員乙每回合的狀態（顯示在螢幕上），但不會告知成員丙。每回合成員丙都必須做一個決定：「左上」、「右上」、「左下」或「右下」。

在成員丙做決定之前，成員甲和成員乙要分別**建議**選擇**「左」或「右」**與**「上」或「下」**。成員甲會先建議「左」或「右」，然後才建議「上」或「下」，成員乙則會先建議「上」或「下」，然後才建議「左」或「右」。當成員甲和成員乙的所有建議都完成之後，才會一次全部顯示在成員丙的螢幕上，然後成員丙才做決定。舉例來說，螢幕上顯示的是成員丙做決定的畫面，成員甲建議了「左」、「下」，成員乙建議了「右」、「上」。

每個成員的報酬取決於本回合的狀態與成員丙的決定，如螢幕上的附表所顯示。其中，你的報酬顯示為藍色粗體，其他成員的報酬則顯示為黑色斜體或黑色加底線。如果你是成員甲或成員乙，本回合的狀態會以紅色字體標示。表上有四個區域，左上的區域顯示狀態為（Ｌ，Ｕ）時的報酬表。右上的區域則顯示狀態為（Ｒ，Ｕ）時的報酬表。同理，左下和右下區域分別顯示狀態為（Ｌ，Ｄ）和（Ｒ，Ｄ）的報酬表。在每個區域的報酬表中均有四個方格，對應到的是該狀態下，當成員丙選取「左上」、「右上」、「左下」或「右下」的時候，每位成員各自的報酬。

TASSEL 實驗說明 p.2

舉例來說，當本回合的狀態為（L，U）時，成員丙的決定如果是「左上」，他自己會得到法幣 50 元的報酬，另外兩位成員則各得法幣 20 元（左上方格）。但是若成員丙的決定是「左下」，則只能帶給他自己法幣 10 元的報酬，成員甲則獲得法幣 50 元，成員乙獲得法幣 0 元（左下方格）。相反地，若成員丙的決定是「右上」，他自己和成員甲均會得到法幣 0 元，成員乙則獲得法幣 50 元（右上方格）。最後，成員丙的決定若是「右下」，他自己能獲得法幣 20 元，成員甲與成員乙則各獲得法幣 10 元（右下方格）。其他狀態依此類推。

每回合結束後，螢幕上會顯示這回合的實驗結果，包括本回合的狀態、成員甲和成員乙的建議選擇、成員丙的決定，以及你所獲得的報酬。按「確認」進入下一回合。

練習階段

此階段共有三回合，目的為幫助您熟悉正式實驗的操作介面及計分方式。請注意，**練習階段的得分僅供您熟悉本實驗的進行方式，與您最後的現金報酬無關。**練習結束後，實驗者會宣佈「實驗正式開始！」，然後才進入正式實驗。

如果您對本實驗有任何疑問，請在此時舉手。實驗者會過來解答。

實驗正式開始

現在實驗正式開始，一共有五十回合！在正式實驗中所獲得的「法幣」都會在實驗結束後，按照 2:1 的匯率 (法幣 2 元=新台幣 1 元) 兌換成新台幣付給您。因此請慎重選擇、慎重決定。

Screen Shot 1: Game T - Sender 1 Recommending L/R

Screen Shot 2: Game T - Sender 1 Recommending U/D

Screen Shot 3: Game T – Receiver

Screen Shot 4: Game T – Results