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

Ernest K. Lai† Wooyoung Lim‡ Joseph Tao-yi Wang§

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Abstract

We design experimental games that admit Battaglini's (2002) construction of fully revealing equilibrium in multidimensional cheap talk. Two senders transmit information to a receiver over a 2×2 state space. Despite overall misaligned interests, in equilibrium senders truthfully revealing on distinct dimensions provide each other with incentives to do so. Subjects behaved as prescribed by equilibrium when the ideal actions of each sender and the receiver, though misaligned, shared common dimensional components. Lower adherence was observed when such dimensional alignments of interests were removed for some states. Even in this case, restricting senders' access to messages, under which out-of-equilibrium messages never arise, substantially brought behavior back in line with equilibrium. When out-of-equilibrium messages could not be eliminated and the equilibrium required implausible supporting beliefs, however, restricting message spaces lost its effects. Our findings highlight the role of message space and its limit in facilitating laboratory success of fully revealing equilibrium.

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

JEL classification: C72; C92; D82; D83

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†Department of Economics, Lehigh University. Email: kwl409@lehigh.edu.

‡Department of Economics, The Hong Kong University of Science and Technology. Email: wooyoung@ust.hk.

§Department of Economics, National Taiwan University. Email: josephw@ntu.edu.tw.

1 Introduction

A defining hallmark of modern economies is the extensive specialization that occurs in both physical production and the more intangible domain of decision making and information provision. Comparative advantage not only dictates decision makers to delegate knowledge acquisition to experts, but also guides different experts to specialize in giving advice on separate areas. When conflicts of interests are present, strategic considerations may provide yet another reason for decision makers to consult different experts. In seeking advice from an interested advisor on the potential impacts of a bill, a legislator may obtain impartial advice only on certain areas, creating a need for her to consult another advisor who might be forthright in a different manner. In a seminal paper on multidimensional cheap talk, Battaglini (2002) provides a 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), the analysis renders a clear picture, which survives modeling variations within the single-sender-single-dimension environment: unless interests are perfectly aligned between the sender and the receiver, 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. In Battaglini's (2002) fully revealing equilibrium under a multidimensional (unbounded) state space, the receiver fully identifies the state even when the two senders with different directional preferences are otherwise arbitrarily biased.

The informational properties of equilibria represent only one disparity brought about by the departure from single-sender environment—robustness is another. With one sender, out-of-equilibrium belief arises only after unused messages, which can be disregarded without impact on equilibrium outcomes. With two senders, out-of-equilibrium belief arises when messages convey inconsistent information, bringing with it robustness implications. Battaglini (2002) points out that while fully revealing equilibrium also exists with two

[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 (Kőszegi, 2006).

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

senders under unidimensional state space, it requires support of implausible beliefs.[3] Even though in his equilibrium construction for multidimensional state space, the messages, concerning different dimensions, will never convey inconsistent information, Ambrus and Takahashi (2008) point out that out-of-equilibrium belief can still arise if the state space is bounded: after a deviation, the messages may point to a "state" outside the state space.[4] In multidimensional cheap talk with multiple senders, the robustness and plausibility of equilibrium are issues that cannot be sidestepped and have received close attention in the theoretical literature since the pioneering work of Battaglini (2002).[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, 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. One of our main findings 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. Our findings also highlight the role of message space and its limit in facilitating laboratory success of fully revealing equilibrium.

In our pivotal game, two senders, Sender 1 (he) and Sender 2 (he), send simultaneous messages to a receiver (she) regarding a 2 (horizontal dimension) $\times$ 2 (vertical dimension) state space. The receiver chooses among four actions, labeled in similar dimensional terms. Each sender has available four (two-dimensional) costless messages framed as non-binding

[3]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 receivers, see Farrell and Gibbons (1989) and Goltsman and Pavlov (2011).

[4]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.

[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 show that no fully revealing equilibrium in Levy and Razin (2007) survives.

action recommendations. Players' ideal actions differ. Yet, when senders' influences on the receiver are limited to distinct dimensions, horizontal for Sender 1 and vertical for Sender 2, each sender and the receiver share common ranking of the relevant actions. Such preference structure is exploited in a fully revealing equilibrium, in which using one sender's message to restrict the dimension of influence of the other allows more information to be extracted, even though interests are overall misaligned.

We consider a number of variations of the game. The more important one is a game with binary (one-dimensional) message spaces and three states. Inspired by Battaglini's (2002) consideration and Ambrus and Takahashi's (2008) extension, the game has exclusive out-of-equilibrium messages that point to the eliminated state. The corresponding fully revealing equilibrium is supported by out-of-equilibrium beliefs that are implausible according to the robustness criterion in Battaglini (2002). Other games include ones in which the overall misaligned ideal actions of each sender and the receiver share a common component on one dimension ("dimensional alignment of interests"), ones in which Sender 1 reveals between the diagonals of the 2×2 state space, and one-sender version of the games.

Our experimental findings are divided with respect to the sizes of message spaces. For games with two-dimensional messages, high adherence to fully revealing equilibrium was observed under dimensional alignments of interests, in which Sender 1s revealed on dimension H and randomized on dimension V, and vice versa for Sender 2s. Receivers filtered information accordingly, following senders' recommendations selectively on the separate dimensions they revealed, even when messages were inconsistent with each other. Overall, receivers identified true states more often with two senders than with one sender, although lower adherence to fully revealing equilibrium was observed when dimensional alignments were removed for some states. In those cases, senders complied especially less in states without dimensional alignment, and receivers commensurately followed recommendations less often, notably mainly to inconsistent messages that might have been sent as a result of deviations.

Findings from one-dimensional message games showed drastically higher adherence. With each sender restrained to recommend only on one dimension, which eliminated occurrence of inconsistent messages, receivers virtually always followed recommendations. Senders in turn followed the prescriptions of fully revealing equilibrium significantly more often. The power of restricting message spaces was especially highlighted by senders' adherence in states without dimensional alignment, in which a sharp contrast with the two-dimensional message games was observed. Lower adherence resurfaced under restricted state space. After messages that indicated deviation had occurred, receivers took the plausible responses that in theory do not support the equilibrium. The finding connected theoretical implausibility with empirical implausibility.

Our findings indicate that implementing the fully revealing equilibrium in the laboratory requires the aid of message spaces. Restricting message spaces, which in theory ensures that out-of-equilibrium beliefs will never arise, helps narrow the range of subjects' anticipations of others' behavior by reducing strategic uncertainty surrounding how messages may be interpreted. Message spaces, however, only facilitated and did not necessarily lead to adherence to equilibrium; when the strategic incentives are not right—when receivers' plausible responses invited deviations as reflected in the non-robust nature of the equilibrium—restricting message spaces lost its effects. Blume et al. (2008) also document that restricting message spaces expedites convergence in single-sender games with *a priori* meaningless messages. Our findings demonstrate the effects of message spaces when the challenge for communication originates not from absence of literal meanings but from how two exogenously meaningful messages are reconciled and interpreted.

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.[6] An independent study that is also motivated by Battaglini (2002) is Vespa and Wilson (2012). Their design represents the dimensions of state space with circles. The larger state space design complements our simple design by considering a richer environment; our simple design complements theirs by informing whether certain complementary, non-compliance findings they obtained were not due to, relative to ours, the more complex design. Our differences also reflect our different emphases; they adopt the circular design to avoid consideration of out-of-equilibrium beliefs, whereas part of our design is to address how the presence and absence of out-of-equilibrium beliefs affect laboratory behavior. The emphasis on message spaces is also unique to us. They find that whether information transmission takes place as predicted depends on receivers' ability to identify trustworthy source, and enlist level-k reasoning and analogy-based expectation to analyze non-compliance.[7] Their findings complement ours on receivers' different responses to

[6]Until recently, the experimental literature of communication games has focused on one sender and one receiver. Examples are Dickhaut et al. (1995), Blume, et al. (1998, 2001), Gneezy (2005), Cai and Wang (2006), Sánchez-Pagés and Vorsatz (2007, 2009), Kawagoe and Takizawa (2009), and Wang et al. (2010). See also Crawford (1998) for a survey on earlier studies. As the first experimental study that moves away from this on the receiver's side, Battaglini and Makarov (2014) design an experiment to test the prediction of Farrell and Gibbons (1989).

[7]See Crawford (2003) for pioneering theoretical work on applying level-k reasoning to communication

messages depending on whether they might have come from deviations.

Section 2 presents our experimental games and analyze their equilibria. Section 3 formulates experimental hypotheses and describes the experimental procedures. Section 4 reports our findings. Section 5 concludes. Proofs are relegated to Appendix A. Appendix B contains a sample of (translated) experimental instructions and Appendix C additional figures and tables. (Appendix D, not intended for publication, contains the original instructions in Chinese.)

2 Two-Dimensional Cheap-Talk Games

2.1 The Basic Game Structure

In all but one of our games, uncertainty is represented by a discrete state of the world with two dimensional components, each being a binary variable: $(H, V) \in \{L, R\} \times \{U, D\}$.[8] The common priors are that the four states are equally likely. Players are a receiver and one or two senders.

In the two-sender games, after observing the state, Sender i, $i = 1, 2$, sends a cheap-talk message, $m \in M_i$, to the receiver.[9] Messages are sent simultaneously, after which the receiver takes an action $a \in A = \{a_{LU}, a_{RU}, a_{LD}, a_{RD}\}$. A behavioral strategy of Sender i is $\sigma_i : \{L, R\} \times \{U, D\} \to \Delta M_i$ and that of the receiver is $\rho : M_1 \times M_2 \to \Delta A$. The receiver's belief function is $\mu : M_1 \times M_2 \to \Delta(\{L, R\} \times \{U, D\})$. Payoffs are determined by state and action. The solution concept is perfect Bayesian equilibrium, where strategies are optimal given beliefs and beliefs are derived from Bayes' rule whenever possible.

Battaglini's (2002) equilibrium construction leverages on the common interests shared between senders and receiver in a lower dimension, even though in a higher dimension

games. Analogy-based expectation equilibrium is developed by Jehiel (2005), and Jehiel and Koessler (2008) apply the alternative equilibrium concept to analyze communication in Crawford and Sobel's (1982) model.

[8]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.

[9]Theoretically, the size of the message spaces has no significance so long as it does not constrain the set of equilibrium outcomes. This will be the case for, for example, binary and quadruple message spaces, which will be covered in our experimental design.

interests are misaligned. In our games, the ideal action of the receiver in state (H, V) is a_{HV}, whereas those of the senders differ. Yet the following rankings of actions are in place which allow a fully revealing equilibrium to be constructed:

1. Sender 1 and the receiver:
   (a) Fixing $V = U$, both prefer a_{LU} to a_{RU} when $H = L$ and a_{RU} to a_{LU} when $H = R$.
   (b) Fixing $V = D$, both prefer a_{LD} to a_{RD} when $H = L$ and a_{RD} to a_{LD} when $H = R$.
2. Sender 2 and the receiver:
   (a) Fixing $H = L$, both prefer a_{LU} to a_{LD} when $V = U$ and a_{LD} to a_{LU} when $V = D$.
   (b) Fixing $H = R$, both prefer a_{RU} to a_{RD} when $V = U$ and a_{RD} to a_{RU} when $V = D$.

To illustrate how these conditionally aligned interests can be exploited for full revelation, suppose that (L, D) is realized and Sender 1 truthfully reveals (only) that $H = L$ (and the receiver believes him). This forces Sender 2 to choose between a_{LU} and a_{LD}, the respective actions that the receiver will take when she believes that the state is most likely (L, U) and (L, D). Since Sender 2 prefers a_{LD} to a_{LU} in state (L, D), he will prefer to tell that $V = D$. And given that Sender 2 truthfully reveals that $V = D$, Sender 1 will also, by a similar argument, prefer to tell that $H = L$. The true state (L, D) is thus revealed to the receiver. In effect, a sender truthfully reveals on a dimension to help align the interests of the other sender with the receiver's.

2.2 Five Games with Two-Dimensional Messages

We induce the above environment and its variants for experimentations. In this subsection, we describe and analyze games with two-dimensional messages, where a sender's message space contains four elements. Action labels (left, up) for a_{LU}, (right, up) for a_{RU}, (left, down) for a_{LD}, and (right, down) for a_{RD} were used in the experiments; from now on we use (h, v) to denote a generic action. We assign literal meaning to messages in accordance with the action labels, and the information transmission problem is framed as sender(s) providing action recommendations. Sender i's message space is: $M_i = \{$"(h, v)"$|$"(left, up)", "(right, up)", "(left, down)", "(right, down)"$\}$.[10]

Figure 11 in Appendix C provides the complete picture of our experimental design with eight games. Five out of our eight games have two-dimensional messages: the single-sender Games 1 and 1-DAL, and the two-sender Games 2, 2-LAB and 2-DAL. Figure 1 depicts the payoff profiles of the two-sender games. Each game is represented by four tables, each table corresponds to a state, and each cell in a table contains the payoffs received by Sender 1, Sender 2 and the receiver when an action, identified by column and row, is taken in the state.

Game 2 forms the pivot of our design; every other game is derived with essentially one or two properties away from it.[11] Game 1, not depicted, is obtained by omitting Sender 2. Game 2-LAB is Game 2 with relabeled states and actions; in each state the payoffs under actions (left, down) and (right, down) are interchanged and then the whole payoff profiles under states (L, D) and (R, D) are interchanged. Payoffs in Game 2-DAL follow partially different preference orders. The substantive difference with Game 2 lies in dimensional alignment; Sender 1's (Sender 2's) ideal action shares the same h (v) component with the receiver's in every state in Game 2-DAL, whereas in Game 2 Sender 1's [Sender 2's] ideal action does not share any common component with the receiver's in state (L, D) [(R, U)].[12] Game 1-DAL, again not depicted, is derived from Game 2-DAL by omitting also Sender 2.

We analyze the most informative equilibria of the games, which for two-sender games are fully revealing. We say that a sender truthfully reveals on dimension H (V) if he reveals whether the state consists of L or R (U or D); a sender is said to truthfully reveal between the diagonals if he reveals whether the state is in the major diagonal $\{(L, U), (R, D)\}$ or in the minor $\{(R, U), (L, D)\}$. We group all fully revealing equilibria with same information partition provided by each sender into a class; equilibria within a class thus differ only by different uses of messages to induce the unique information partitions.

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

[11]The game naming convention is that the number, 1 or 2, indicates the number of sender(s) and any suffix represents a manipulation relative to Game 2 or its derivative.

[12]The receiver's payoffs are also slightly different. Given receiver's ideal action (h^*, v^*), in Game 2-DAL, (h', v^*) and (h^*, v'), $h' \neq h^*$, $v' \neq v^*$, yield a payoff of zero, whereas (h', v') yields 20; in Game 2, (h', v') yields 0, whereas (h', v^*) and (h^*, v') yield 20 or 10. As will be shown below, the purpose of the differences is to obtain different equilibrium strategies for Sender 1's incarnations in the corresponding one-sender games. Note also that in Game 2-LAB, the appropriately redefined "diagonal alignment" is in place for Sender 1 in all states except (R, D), and for Sender 2 the dimensional alignment profile remains the same as that in Game 2.

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

State: (R,U)						
Action	left			right		
up	0	15	20	20	20	50
down	10	60	0	50	0	10

State: (L,D)						
Action	left			right		
up	15	0	20	60	10	0
down	20	20	50	0	50	10

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

(a) Game 2 (Game 2-2/M)

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

State: (R,U)						
Action	left			right		
up	0	15	20	20	20	50
down	50	0	10	10	60	0

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

State: (R,D)						
Action	left			right		
up	15	0	20	60	10	0
down	0	50	10	20	20	50

(b) Game 2-LAB (Game 2-LAB-2/M)

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

(c) Game 2-DAL

Figure 1: Payoff Profiles of Games with Two Senders and Four States

Proposition 1. *There exists a fully revealing equilibrium in Games 2, 2-LAB, and 2-DAL. Between Games 2 and 2-LAB,*

1. *there is a class of fully revealing equilibria unique to Game 2, in which Sender 1 truthfully reveals only on dimension H and Sender 2 only on dimension V;*
2. *there is a class of fully revealing equilibria unique to Game 2-LAB, in which Sender 1 truthfully reveals only between the diagonals and Sender 2 only on dimension V; and,*
3. *there is a class of fully revealing equilibria common to both games, in which both Sender 1 and Sender 2 truthfully reveal all four states.*

All three classes of equilibria exist in Game 2-DAL, with another class unique to Game 2-DAL in which Sender 1 truthfully reveals only on dimension H and Sender 2 only between the diagonals.

The rationale behind the fully revealing equilibria in Game 2 follows from the discussion in Section 2.1. The *equilibrium-relevant dimension* is H for Sender 1 and V for Sender 2. The relabeling in Game 2-LAB effectively interchanges states (L, D) and (R, D) for Sender 1's revelation in the characteristic equilibrium. In Game 2-DAL, under all-state dimensional alignments and the fact that the receiver's ideal actions are the senders' second most preferred, the game admits equilibria not only with dimensional revelation but also with diagonal revelations.[13]

Other than equilibrium properties, strategic uncertainty will also inform our experimental hypotheses. For the dimensionally revealing equilibrium in Game 2-DAL, the all-state dimensional alignments, which are in agreement with the equilibrium-relevant dimensions, create some sort of "dominance." Conditioned on the receiver following the other sender's recommendation on the relevant dimension, regardless of whether it is truthful or not, a sender always prefers to truthfully reveal on his own dimension. No such property exists for the diagonally revealing equilibria; there exists a state in which a sender prefers to deviate from truthful revelation unless he believes that the other sender truthfully reveals

[13]The classes of fully revealing equilibria in Proposition 1 are meant to be representative but not exhaustive. There exist fully revealing equilibria with hybrid strategy profile in which, for example, Sender 1 truthfully reveals all four states and Sender 2 only on dimension V. For expositional convenience, from now on we use "equilibrium" unless the plural form is called for to convey specific points.

with probability $\frac{2}{3}$ or above. Similarly, a belief of at least $\frac{9}{13}$ is required for the equilibria in Games 2 and 2-LAB. In terms of less strategic uncertainty from the senders' side, the dimensionally revealing equilibrium in Game 2-DAL thus dominates not only the alternative diagonally revealing equilibrium, but also the equilibria in Games 2 and 2-LAB.

To set the stage for introducing additional games, we comment on the types of out-of-equilibrium messages in the two-sender games. In the equilibria in which each sender reveals all four states, out-of-equilibrium messages arise as *inconsistent message pairs*. In such equilibria, the receiver expects to receive messages that indicate the same (H, V). Out-of-equilibrium messages therefore arise when a message pair that indicates different entries for H, V, or both are received. For the equilibria with dimensional/diagonal revelations, the only out-of-equilibrium messages that may arise are *unused messages*. Since each sender reveals only a binary characteristic of the state, two messages suffice for each to separate, leaving other two messages potentially unused. Unused messages are, however, trivial in cheap-talk games; one can have all messages used by prescribing the senders to randomize. Without any out-of-equilibrium messages, inconsistent or unused, a fully revealing equilibrium where senders randomize on non-equilibrium-relevant dimensions is free of out-of-equilibrium beliefs.

In the single-sender games, partitional information is transmitted:

Proposition 2. *There exists a partially revealing equilibrium in Game 1 in which the single sender truthfully reveals (L, U) only. The corresponding information partition, $\{\{(L, U)\}, \{(R, U), (R, D), (L, D)\}\}$, is the unique informative equilibrium partition. There exists a partially revealing equilibrium in Game 1-DAL in which the single sender truthfully reveals only on dimension H. The corresponding information partition, $\{\{(L, U), (L, D)\}, \{(R, U), (R, D)\}\}$, is the unique informative equilibrium partition.*

While informative partitions are unique, the two games each has a continuum of equilibrium outcomes, depending on how the receiver randomizes over actions in response to the coarse information.[14] As cheap-talk games, there is also the inessential multiplicity of equilibria with different uses of messages supporting a given equilibrium outcome.

[14]For the equilibrium outcomes in Game 1, the receiver takes (left, up) in (L, U) and randomizes in the other three states between (right, up) and (right, down) with arbitrary probabilities, leaving out the strictly dominated (left, down). For Game 1-DAL, the receiver randomizes between (left, up) and (left, down) in (L, U) and (L, D), and between (right, up) and (right, down) in (R, U) and (R, D), both with arbitrary probabilities.

2.3 Three Games with One-Dimensional/Diagonal Messages

We restrict the message spaces in Games 2 and 2-LAB, creating Games 2-2/M and 2-LAB-2/M. Both games have binary message spaces. For Game 2-2/M, they are $M_1 = \{$"h"$|$"left", "right"$\}$ and $M_2 = \{$"v"$|$"up", "down"$\}$. For Game 2-LAB-2/M, while it remains for Sender 2 that $M_2 = \{$"v"$|$"up", "down"$\}$, Sender 1's message space is replaced by $M_1 = \{$"(h, v) or (h', v')"$|$"(left, up) or (right, down)", "(right, up) or (left, down)"$\}$. We turn to the equilibria:

Proposition 3. *There exists a unique class of fully revealing equilibria in Game 2-2/M in which Sender 1 truthfully reveals on dimension H and Sender 2 on dimension V. There exists a unique class of fully revealing equilibria in Game 2-LAB-2/M in which Sender 1 truthfully reveals between the diagonals and Sender 2 on dimension V. Any fully revealing equilibrium in the two games is free of out-of-equilibrium beliefs.*

Restricting message spaces serves two experimental purposes. It eliminates receiver's need to interpret inconsistent messages and thus minimizes strategic uncertainty thereon. It also serves as a step toward controlling the scenarios in which out-of-equilibrium belief arise by first eliminating them.

We introduce our last game in which out-of-equilibrium belief arises under specific scenarios that can be readily identified in the laboratory. Leveraging on Ambrus and Takahashi's (2008) insight on the cause of out-of-equilibrium messages under a restricted state space, we eliminate state (R, D) in Game 2-2/M, adjusting the prior so that the remaining three states are equally likely. The result is Game 2-2/M-3/S (Figure 2).

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

State: (R, U)						
Action	left			right		
up	0	15	20	20	20	50
down	10	60	0	50	0	10

State: (L, D)						
Action	left			right		
up	15	0	20	60	10	0
down	20	20	50	0	50	10

No State

Figure 2: Payoff Profile of Game 2-2/M-3/S

Fully revealing equilibrium also exists in Game 2-2/M-3/S, but now out-of-equilibrium belief, which can arise even under the binary message spaces, plays a crucial role. Consider a deviation by Sender 2 when the state is (R, U). In Game 2-2/M, the receiver, being told by the equilibrium-abided Sender 1 that the state consists of R and by the deviating Sender 2 that it consists of D, cannot detect the 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), action (right, down) is not as attractive as the equilibrium (right, up).

In Game 2-2/M-3/S, the same deviation creates an entirely different scenario. Given that (R, D) no longer exists, the receiver can detect that there is a deviation because under no circumstance will she receive such a message pair in equilibrium. The deviation does lead to the receipt of out-of-equilibrium messages. To register a difference from inconsistent message pairs, we call these out-of-equilibrium messages arisen due to restricted state space *irreconcilable message pairs*. The following proposition states the beliefs required to support the equilibrium:

Proposition 4. *There exists a unique class of fully revealing equilibria in Game 2-2/M-3/S in which Sender 1 truthfully reveals on dimension H and Sender 2 on dimension V. Any fully revealing equilibrium is supported by out-of-equilibrium beliefs that induce the receiver to take action (left, up) with probability at least $\frac{4}{5}$ after an irreconcilable message pair.*

With (R, D) omitted, action (right, down), which can otherwise deter deviations, is strictly dominated for the receiver. Accordingly, (left, up), undominated to receiver and second least preferred to senders' in (R, U) and (L, D), assumes the task of supporting the equilibrium.

2.4 Robustness Analysis

We analyze the robustness of the fully revealing equilibria in all two-sender games. Using Battaglini's (2002) criterion, 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, in which he observes a random state drawn from a probability distribution, g_i, that puts positive probability on all possible states. The resulting definition of robust equilibrium is:

Definition 1 (Battaglini, 2002)**.** *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 first apply the criterion to Game 2-2/M-3/S:

Corollary 1. *None of the fully revealing equilibria in Game 2-2/M-3/S is robust.*

Consider an equilibrium in which "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. In this equilibrium, ("right", "down") is the irreconcilable, out-of-equilibrium message pair. In an ε-perturbed game, the receiver considers to have received the message pair after at least one sender's observation of the state was erroneous. When ε is small, the event that both senders' observations of the state were erroneous is irrelevant; the receiver believes that one of the messages, "right" or "down", conveys information, and in the limit assigns zero probability to (L, U). In the original, unperturbed Game 2-2/M-3/S, the out-of-equilibrium belief required to support the fully revealing equilibrium has to, however, put positive probability on (L, U). The consistent belief requirement in Battaglini's (2002) criterion thus rules the equilibrium as non-robust.

In the games with two-dimensional messages, a fully revealing equilibrium with senders babbling by means of randomization is free of out-of-equilibrium beliefs, which makes the equilibrium necessarily robust. However, one can also construct non-robust equilibria, such as one where both senders truthfully reveal all four states.[15] We thus have:

Corollary 2. *Some, but not all, fully revealing equilibria in Games 2, 2-LAB, and 2-DAL are robust.*

In contrast, given that any fully revealing equilibrium in four-state games with binary messages is free of out-of-equilibrium beliefs, the robustness criterion is trivially satisfied:

Corollary 3. *All fully revealing equilibria in Games 2-2/M and 2-LAB-2/M are robust.*

[15] 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.

We conclude by explaining our choice of robustness criterion. Battaglini's (2002) use of perturbed state observations to impose restriction on out-of-equilibrium beliefs parallels the consistency requirement of sequential equilibrium, where trembles are introduced at the strategy level. However, the overarching mistake probability for all states renders Battaglini's (2002) criterion stronger than sequential equilibrium, at least for our games. Unless we also require the sequence of completely-mixed behavioral strategies to converge to the equilibrium strategies in identical or comparable rates across states, the fully revealing equilibrium in Game 2-2/M-3/S is sequential. Thus, even though our games are finite, using Battaglini's (2002) criterion originally devised for a game with infinite actions allows us to highlight the implausible aspect of the equilibrium in Game 2-2/M-3/S when sequential equilibrium *per se* has no bite.[16]

3 Experimental Hypotheses and Procedures

3.1 Treatments and Hypotheses

Table 1 summarizes the properties of the eight games, which constitute our experimental treatments. We hypothesize on how the treatment variables affect information revelation outcomes, i.e., how often receivers identify true states. The hypothesized effects are guided by equilibrium and other properties of the games. We first compare between games in which number of sender is the only treatment variable, informed by Propositions 2 and 1:

Hypothesis 1. ***Positive Effect of Additional Sender****: Receivers in Game 2 (2-DAL) identify true states more often than do receivers in Game 1 (1-DAL).*

Our second hypothesis addresses the treatment effects of dimensional alignments and relabeling. We deviate from pure (fully revealing) equilibrium consideration, which predicts no outcome difference among Games 2, 2-DAL, and 2-LAB. Our comparison between

[16]For sequences of completely-mixed strategy profiles in which Sender 1's perturbation probability is orders of magnitude higher in state (L, U) than in (L, D) and Sender 2's in (L, U) than in (R, U), the limit of the receiver's converging beliefs puts probability one on (L, U) after the message pair irreconcilable in equilibrium; the equilibrium is thus sequential. Note, however, that given the receiver's beliefs on and off the equilibrium path, Sender 1, for example, will stand to lose more by trembling in (L, U) (receiving payoff 0) than in (L, D) (receiving payoff 15). It therefore seems natural that the perturbation probability should be at least as high in (L, D) as in (L, U). Such consideration, which shares the spirit of lower mistake probabilities with costlier mistakes in Myerson's (1978) proper equilibrium, generates robustness conclusion for Game 2-2/M-3/S that is alternatively reached by Battaglini's (2002) criterion.

Table 1: Properties of the Games

Game/ Treatment	No. of Senders	Messages per Sender	No. of States	All-State Dim. Align.	Out-of-Eq. Messages	Fully Revealing Equilibrium (Dimensions) [Robust]
1	1	4	4	No	0–2	No
1-DAL	1	4	4	Yes	0–2	No
2	2	4	4	No	0–12	Yes ($H; V$) [Some]
2-DAL	2	4	4	Yes	0–12	Yes (Multiple) [Some]
2-LAB	2	4	4	No	0–12	Yes (Diagonal; V) [Some]
2-2/M	2	2	4	No	0	Yes ($H; V$) [All]
2-LAB-2/M	2	2	4	No	0	Yes (Diagonal; V) [All]
2-2/M-3/S	2	2	3	No	1	Yes ($H; V$) [None]

Note: "All-State Dim. Align." refers to whether each sender's ideal action and the receiver's share common dimensional component in all states. "Out-of-Equilibrium Messages" refer to the possible number of out-of-equilibrium messages per sender in any most informative equilibrium. "Dimensions" refer to the equilibrium-relevant dimensions of Sender 1 and Sender 2; "Multiple" means a sender revealing between the diagonals or on dimension H/V are both consistent with equilibrium. "Robust" refers to whether the fully revealing equilibria are robust or not according to Definition 1.

Games 2 and 2-DAL is first informed by the implicit hypothesis that within Game 2-DAL the diagonally revealing equilibria surrender to the dimensionally revealing equilibrium under the latter's minimal strategic uncertainty; the same minimal uncertainty in turn serves to inform that the dimensionally revealing equilibrium in Game 2-DAL outperforms the equilibrium in Game 2 as more empirically plausible. For Games 2 and 2-LAB, we hypothesize that, despite comparable degrees of strategic uncertainty from the senders' side, the diagonally revealing equilibrium in Game 2-LAB is nevertheless less focal than the dimensionally revealing equilibrium in Game 2. We thus have:

Hypothesis 2a. ***Positive Effect of Dimensional Alignments****: Receivers in Game 2-DAL identify true states more often than do receivers in Game 2.*

Hypothesis 2b. ***Positive Effect of Focality of Revelation Dimensions****: Receivers in Game 2-LAB (2-LAB-2/M) identify true states less often than do receivers in Game 2 (2-2/M).*

We next compare between games in which message spaces are the only treatment variable. Fully revealing equilibrium again predicts no difference in revelation outcomes between Games 2 (2-LAB) and 2-2/M (2-LAB-2/M). Yet, under the binary message spaces, the equilibria in the latter set of games are free of out-of-equilibrium beliefs and thus robust, while there exist equilibrium in the former that is not. This differentiation informs our next hypothesis:

Hypothesis 3. ***Positive Effect of Restricting Message Spaces***: *Receivers in Game 2-2/M (2-LAB-2/M) identify true states more often than do receivers in Game 2 (2-LAB).*

Finally, we compare between Games 2-2/M and 2-2/M-3/S, in which number of states is the only treatment variable. The robustness analysis again informs our hypothesis. In Game 2-2/M-3/S, each sender has a distinct state to unilaterally effect out-of-equilibrium, irreconcilable messages. To deter deviations, however, the receiver has to virtually believe that both senders have deviated. Such "implausible" belief, reflected formally in the non-robust equilibrium, suggests that responses that invite deviation are more plausible. In translating theoretical (im)plausibility to empirical (im)plausibility, we hypothesize that a plausible response is also a likely response, predicting a lower adherence to fully revealing equilibrium in Game 2-2/M-3/S:

Hypothesis 4. ***Negative Effect of Restricting State Space***: *Receivers in Game 2-2/M-3/S identify true state less often than do receivers in Game 2-2/M.*

3.2 Procedures

The experiments were conducted in Chinese using z-Tree (Fishchbacher, 2007) at the Taiwan Social Sciences Experimental Laboratory (TASSEL) of National Taiwan University. Four sessions were conducted for each game using a *between-subject* design. Each session involved five to seven groups of three (two-sender games) or five to nine groups of two (one-sender games), with 492 subjects participated in 32 sessions. Eight sessions were conducted in May 2011 and 24 sessions between June 2012 and January 2013.[17] Subjects had no prior experience in our experiments and were recruited from the undergraduate/graduate student population of the university.

Upon arrival at the laboratory, subjects were instructed to sit at separate computer terminals. Each was given a copy of the experimental instructions. To strive for inducing the instructions as common knowledge, they were read aloud, supplemented by slide illustrations. In each session, subjects first participated in three rounds of practice and then 50

[17] We set a minimum of five groups per session, with upper bound set by the capacity of TASSEL. Two sessions of Game 1 were conducted in five groups, one in six and one in seven (46 subjects). Two sessions of Game 1-DAL were conducted in seven groups, one in five and one in nine (56 subjects). One session of Game 2 was conducted in seven groups and three in five (66 subjects). For each of Game 2-LAB and Game 2-2/M, one session was conducted in six groups and three in five (63 subjects per each game). All four sessions of Game 2-DAL and Game 2-LAB-2/M were conducted in, respectively, six groups (72 subjects) and five groups (60 subjects). Two sessions of Game 2-2/M-3/S were conducted in six groups and two in five (66 subjects).

official rounds. A *random matching* protocol with *fixed roles* was used (repeating partners were allowed).

We illustrate the instructions for two-sender games with two-dimensional messages. Subjects formed groups of three: Member A (Sender 1), Member B (Sender 2), and Member C (receiver). The roles were randomly assigned at the beginning of a session and maintained throughout. At the beginning of each round, the computer would randomly draw one of (L, U), (R, U), (L, D) or (R, D). The draws were independent across groups and rounds. The drawn outcome would be revealed on the screens of Member A and Member B; they then privately input their recommendation for Member C. Each sender's recommendation was input in two steps. Member A input "left"/"right" first, followed by "up"/"down". The opposite order was used for Member B. After the recommendation, each sender would be asked to make a point prediction about the other's recommendation. The belief elicitation was mildly incentivized with two payoff points for a correct prediction of each dimensional component of the other's recommendation.[18]

The four recommendation inputs, two by each sender, were then revealed to Member C in one step. Member C's screen would show, for example, that "Member A recommends left; Member A recommends up; Member B recommends right; Member B recommends up." Member C then concluded the round by choosing (left, up), (right, up), (left, down) or (right, down). In every decision step, the corresponding payoff profiles in Figure 1 were shown on each subject's screen.[19] At the end of each round, subjects were provided with the current round history (the draw, Members A's and B's recommendations, Member C's action, and subject's own payoff). At the end of the last round, all members were asked to make a point prediction of the state when recommendations "(right, up)" was received from Member A and "(left, down)" from Member B. These pre-specified messages for prediction were made known to them only at this time. We randomly drew one instance among all groups in the last 30 rounds when these recommendations were observed and rewarded 100 payoff points to subjects with correct prediction.[20]

[18] This belief elicitation was conducted for all games except Games 1-DAL and 2-DAL. In games with one-dimensional messages, subjects were rewarded with four payoff points for a correct prediction of the other sender's recommendation. Thus, in games with one-dimensional and two-dimensional messages, the maximum payoff points a subject could receive from making prediction in a round were standardized to be four. The simple elicitation with mild incentives was adopted to minimize interference with the major decision tasks.

[19] Refer to Appendix B for an English translation (by the authors) of the experimental instructions for Game 2. While the original instructions are in Chinese (Appendix D), the notation for the state, (L, U), (R, U), (L, D) and (R, D), was used.

[20] This belief elicitation was conducted for all games except Games 1-DAL and 2-DAL. In Games 2-2/M

Ten payoff points converted into a real payment of NT$5. A subject was paid his or her sum of rewards from all 50 rounds, including the payoff points from making predictions, plus a NT$100 show-up fee. Subjects earned on average NT$801.78 ($\approx$US$28.06), ranging from NT$435 ($\approx$US$15.23) to NT$1,360 ($\approx$US$47.60).

4 Experimental Findings

Section 4.1 covers findings from two-dimensional message games. Sections 4.2 and 4.3 cover one-dimensional message games. Each subsection consists of one main result on quantitative comparisons of revelation outcomes, with sub-results on key qualitative findings on strategies.

4.1 Additional Sender, Dimensional Alignments, and Focality

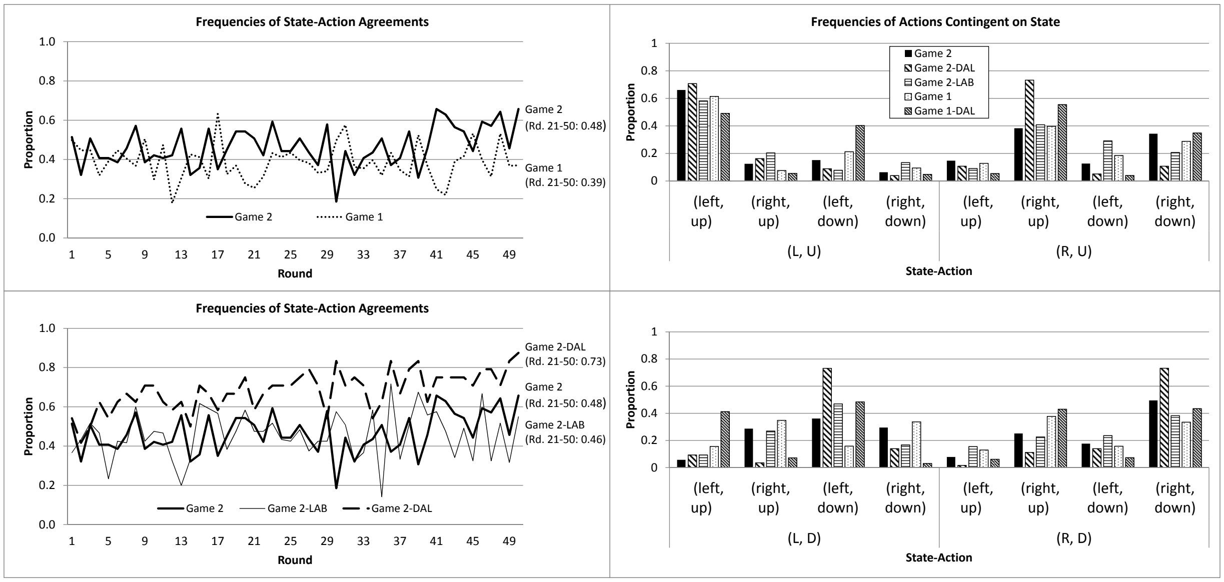
Result 1 (**Outcomes**).

- ***Positive Effect of Additional Sender****: Receivers in Game 2 (2-DAL) identified true states significantly more often than did receivers in Game 1 (1-DAL).*
- ***Positive Effect of Dimensional Alignments****: Receivers in Game 2-DAL identified true states significantly more often than did receivers in Game 2.*
- ***No Effect of Focality of Revelation Dimensions****: Receivers in Game 2-LAB identified true states as often as did receivers in Game 2.*

Figure 3(a) presents the frequencies of state-action agreements, with which we measure how often receivers identified true states by recording instances in which their ideal actions were taken. The frequency aggregated across last 30 rounds of all sessions was 48% (73%) in Game 2 (2-DAL), significantly higher than the 39% (45%) in Game 1 (1-DAL), confirming Hypothesis 1 ($p \leqslant 0.0147$, Mann-Whitney tests).[21] All were significantly higher than 25% ($p = 0.0625$, Wilcoxon signed-rank tests), the benchmark for no information transmis-

and 2-2/M-3/S, the prediction was for the state when Member A recommended "right" and Member B "down"; in Games 2-LAB-2/M, Member A's recommendation was "(right, up) or (left, down)".

[21] Refer to Figure 12 in Appendix C for the frequency comparison between Games 2-DAL and 1-DAL.



(a) Frequencies of State-Action Agreements (b) Frequencies of Actions Contingent on State

Figure 3: Information Revelation Outcomes in Games 2, 2-DAL, 2-LAB, 1, and 1-DAL

sion with ideal actions taken out of random guess.[22] Information transmission facilitated receivers' identifications of true states and, to varying degrees with respect to dimensional alignments, two senders served better than one.

The frequency in Game 2-DAL was in turn significantly higher than that in Game 2, confirming Hypothesis 2a ($p \leqslant 0.0571$, Mann-Whitney tests). There was, however, no significant difference between Games 2 and 2-LAB, rejecting Hypothesis 2b (two-sided $p = 0.4857$, Mann-Whitney test). Figure 3(b) breakdowns the frequencies for each state. Between Games 2 and 2-DAL, dimensional alignments improved revelation outcomes through, naturally, (L, D) and (R, U), in which no alignment is in place for, respectively, Sender 1 and Sender 2 in Game 2, although "positive spillover" to other states was also observed, especially for (R, D). The less focal revelation dimensions in Game 2-LAB did not, however, adversely affect revelation outcomes, although compared to Game 2 lower degree of

[22] All our statistical tests use aggregate data from last 30 rounds of each session as an independent observation. Further convergence in varying degrees across games, which deepens the comparisons in favor of our hypotheses, was typically observed after the 30th round. (In Game 2, for example, the agreement frequency in the last 10 rounds was 10% higher at 58%.) The 30-round cutoff, though rather arbitrary, is adopted with a view to balancing conservativeness with convergence. Table 3 in Appendix C contains statistics under three different aggregations (first 20, last 30, and last 10 rounds). From now on, all frequencies reported and referred to are from last 30 rounds. We consider a difference as statistically significant if and only if one-sided $p \leqslant 0.0571$ for the Mann-Whitney test and $p = 0.0625$ (the lowest possible for four observations) for the Wilcoxon signed-rank test.

convergence was observed.[23]

For Games 1 and 2, the more frequent state-action agreements in the two-sender game originated from (L, D) and (R, D). On the other hand, for Games 1-DAL and 2-DAL, the more frequent agreements in the latter were observed throughout all states. The qualitative nature of such "difference-in-difference" suggests that the addition of Sender 2 influenced behavior differently with or without all-state dimensional alignments, which is in line with the fact that the equilibrium strategy of the single-sender is different between Games 1 and 1-DAL.

Result 1a (Strategies in Two-Sender Games).

- *Senders in two-sender games with two-dimensional messages, Games 2, 2-DAL, and 2-LAB, revealed on their equilibrium-relevant dimensions and randomized on the other, except for the states without dimensional alignment in Games 2 and 2-LAB.*

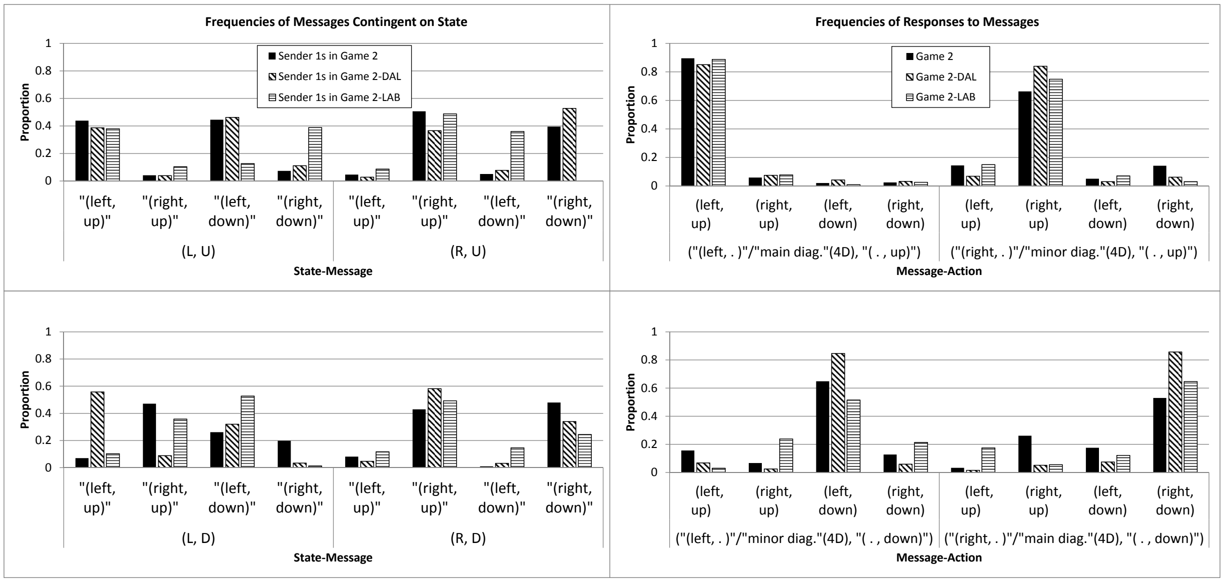
- *Receivers in Game 2-DAL followed recommendations according to equilibrium-relevant dimensions. Receivers in Games 2 and 2-LAB followed less often for messages that might have come from states without dimensional alignment, unless two senders recommended the same.*

Figure 4(a) presents message uses in each state, in which for clarity we include Sender 1s only. Figure 4(b) presents receivers' responses to messages.[24] Consider message uses in (L, U), a representative state with dimensional alignment. Messages "(left, up)" and "(left, down)" constituted 85% or more of Sender 1s' messages in Games 2 (44% and 45%) and 2-DAL (39% and 46%); "(left, up)" and "(right, down)" constituted 77% of Sender 1s' messages in Game 2-LAB (38% and 39%). For Sender 2s' messages, "(left, up)" and "(right, up)" were used at least 78% of the time in Games 2 (35% and 45%), 2-DAL (45% and 47%), and 2-LAB (37% and 41%). Senders' behavior in states with dimensional alignments was consistent with the prescriptions of fully revealing equilibrium, in which, using the literal recommendations, they revealed only on their equilibrium-relevant dimensions, including the diagonals in Game 2-LAB.[25]

[23]The state-action agreement frequencies in the last 10 rounds indicate further convergence in Game 2 (58%) but not in Game 2-LAB (46%), with the former significantly higher ($p = 0.0143$, Mann-Whitney test). Our no-effect conclusion rejecting Hypothesis 2b is drawn in adherence to the criterion of last 30 round data commonly applied to all other comparisons.

[24]Figure 13(a) in Appendix C presents Sender 2s' message uses. For Game 2-LAB in Figure 4(b), "main diagonal" refers to either "(left, up)" or "(right, down)" and "minor diagonal" to "(right, up)" or "(left, down)".

[25]Corresponding to the fact that meanings in cheap-talk games are determined in equilibrium, it is the



(a) Frequencies of Messages Contingent on State (Sender 1s)

(b) Frequencies of Responses to Message Pairs

Figure 4: Strategies in Games 2, 2-DAL, and 2-LAB

Different behavioral patterns were observed in states without dimensional alignment. The three most frequently used messages were truthful recommendation and two messages that deviate from equilibrium-relevant dimensions in light of literal meanings and message uses in states with alignments. In Game 2, for instance, Sender 1s' messages in (L, D) concentrate on "(left, down)", "(right, up)", and "(right, down)" (26%, 47%, and 20%). Consider the most frequent "(right, up)", which is recommendation for Sender 1's own ideal action.[26] With Sender 2s' messages concentrated on "(left, down)" and "(right, down)" (43% and 45%) in (L, D), which was accurately anticipated by Sender 1s, Sender 1s' self-serving recommendation induced ("(right, up)","(left, down)") or ("(right, up)","(right, down)").[27] Whether Sender 1s' deviation prompting for own ideal action would be rewarded

observed uses of messages that determine how meanings should be assigned in our findings. As an anchoring point of interpreting observed behavior, we nevertheless presume that subjects transmit information using the literal meanings of recommendations, in which "recommend (h, v)" is considered to mean "it is in your best interest to take (h, v)." Deviations are interpreted accordingly.

[26]Similar patterns were observed in other states without alignment. Messages "(right, down)", "(right, up)", and "(left, down)" constituted 88% of Sender 1s' messages in (R, D) in Game 2-LAB. For Sender 2s in (R, U), "(right, up)", "(left, down)", and "(right, down)" constituted 88% of messages in Game 2 and 89% in Game 2-LAB. In each case, the most frequent messages were recommendations of the senders' own ideal actions.

[27]Sender 1s' predicted frequencies of Sender 2s' messages in (L, D) were 55% for "(left, down)" and 41% for "(right, down)". Overall, senders' prediction of the other senders' messages was consistent with actual message uses. Figure 14(a) in Appendix C presents the predictions in Games 2 and 2-LAB.

or punished depended on how receivers would interpret these inconsistent messages.

Table 2: Receivers' Responses to All Message Pairs

$m_1 \backslash m_2$	"(left, up)"	"(right, up)"	"(left, down)"	"(right, down)"
		A. Game 2		
"(left, up)"	(**0.88**, 0.12, 0.00, 0.00)	(**0.89**, 0.03, 0.03, 0.05)	(0.20, 0.10, **0.45**, 0.25)	(0.39, 0.00, **0.43**, 0.17)
"(right, up)"	(0.29, **0.29**, 0.04, 0.38)	(0.08, **0.92**, 0.00, 0.00)	(0.07, 0.33, 0.08, **0.52**)	(0.02, 0.08, 0.47, **0.43**)
"(left, down)"	(**1.00**, 0.00, 0.00, 0.00)	(**0.83**, 0.10, 0.03, 0.03)	(0.00, 0.03, **0.97**, 0.00)	(0.07, 0.14, **0.64**, 0.14)
"(right, down)"	(0.19, **0.50**, 0.06, 0.25)	(0.09, **0.73**, 0.09, 0.09)	(0.01, 0.62, 0.04, **0.33**)	(0.01, 0.03, 0.06, **0.90**)
		B. Game 2-DAL		
"(left, up)"	(**0.97**, 0.00, 0.03, 0.00)	(**0.92**, 0.00, 0.05, 0.03)	(0.08, 0.00, **0.83**, 0.10)	(0.06, 0.03, **0.87**, 0.04)
"(right, up)"	(0.02, **0.89**, 0.02, 0.07)	(0.03, **0.90**, 0.03, 0.03)	(0.00, 0.08, 0.12, **0.80**)	(0.04, 0.11, 0.04, **0.80**)
"(left, down)"	(**0.76**, 0.13, 0.04, 0.07)	(**0.83**, 0.12, 0.04, 0.02)	(0.03, 0.03, **0.95**, 0.00)	(0.06, 0.03, **0.85**, 0.06)
"(right, down)"	(0.11, **0.75**, 0.05, 0.09)	(0.10, **0.82**, 0.02, 0.06)	(0.00, 0.03, 0.15, **0.82**)	(0.03, 0.00, 0.00, **0.97**)
		C. Game 2-LAB		
"(left, up)"	(**0.97**, 0.03, 0.00, 0.00)	(**0.89**, 0.11, 0.00, 0.00)	(0.32, 0.08, 0.20, **0.40**)	(0.27, 0.12, 0.19, **0.42**)
"(right, up)"	(0.32, **0.40**, 0.20, 0.08)	(0.13, **0.85**, 0.00, 0.03)	(0.01, 0.09, **0.43**, 0.47)	(0.07, 0.29, **0.46**, 0.18)
"(left, down)"	(0.22, **0.57**, 0.17, 0.04)	(0.03, **0.94**, 0.03, 0.00)	(0.00, 0.02, **0.91**, 0.07)	(0.02, 0.55, **0.30**, 0.14)
"(right, down)"	(**0.96**, 0.04, 0.00, 0.00)	(**0.77**, 0.10, 0.03, 0.10)	(0.14, 0.03, 0.14, **0.69**)	(0.00, 0.00, 0.00, **1.00**)

Note: Each array of numbers represents the frequencies of (left, up), (right, up), (left, down), (right, down). The numbers in **bold** refer to the cases when receivers follow Sender 1s' recommendation (m_1) on dimension H (diagonals) and Sender 2s' recommendation (m_2) on dimension V.

Had receivers sorted them through by following "right" from Sender 1s and "down" from Sender 2s, as was frequently observed in Game 2-DAL (86%), the deviation would have been confronted with a severe punishment of zero payoff. In Game 2, however, receivers responded to ("(right, .)","(. , down)") with "(right, down)" not as often (53%). In return, for the two particular inconsistent message pairs, ("(right, up)","(left, down)") and ("(right, up)","(right, down)"), receivers' responses put substantial frequencies on Sender 1's ideal (right, up) (33%) after one, and on the harmless (left, down) (47%) after the other (Table 2). Despite incongruence with the prescriptions of fully revealing equilibrium, senders' behavior in states without dimensional alignment reflected receivers' less severely punishing and at times rewarding responses to inconsistent messages.[28]

It was not just for ("(right, .)","(. , down)"); receivers in Game 2-DAL in general took (h, v) with frequencies at least 75% when ("$(h, .)$","$(. , v)$") were received, even when

[28]The other less frequent message that deviates from equilibrium-relevant dimension, "(right, down)", induced a mixture of higher rewards and more severe punishments. Overall, the three frequently sent messages in a given state without dimensional alignment gave senders comparable expected payoffs (calculated based on observed strategies of other senders and receivers), with sometimes even higher payoffs for the deviating messages. For Sender 1s in (L, D), expected payoffs from "(left, down)", "(right, up)", and "(right, down)" were 21.33, 21.22, and 22.95 in Game 2; for Sender 1s in (R, D), payoffs from "(right, down)", "(right, up)", and "(left, down)" were 19.06, 22.33, and 26.08 in Game 2-LAB; for Sender 2s in (R, U), payoffs from "(right, up)", "(left, down)", and "(right, down)" were 19.97, 16.6, and 20.66 in Game 2 and 18.19, 31.52 and 33.45 in Game 2-LAB.

the two messages are totally inconsistent. Subjects in Game 2-DAL exhibited sophistication in filtering information in message pairs according to senders' equilibrium-relevant dimensions, consistent theoretically with the equilibrium construction and empirically with actual message uses.

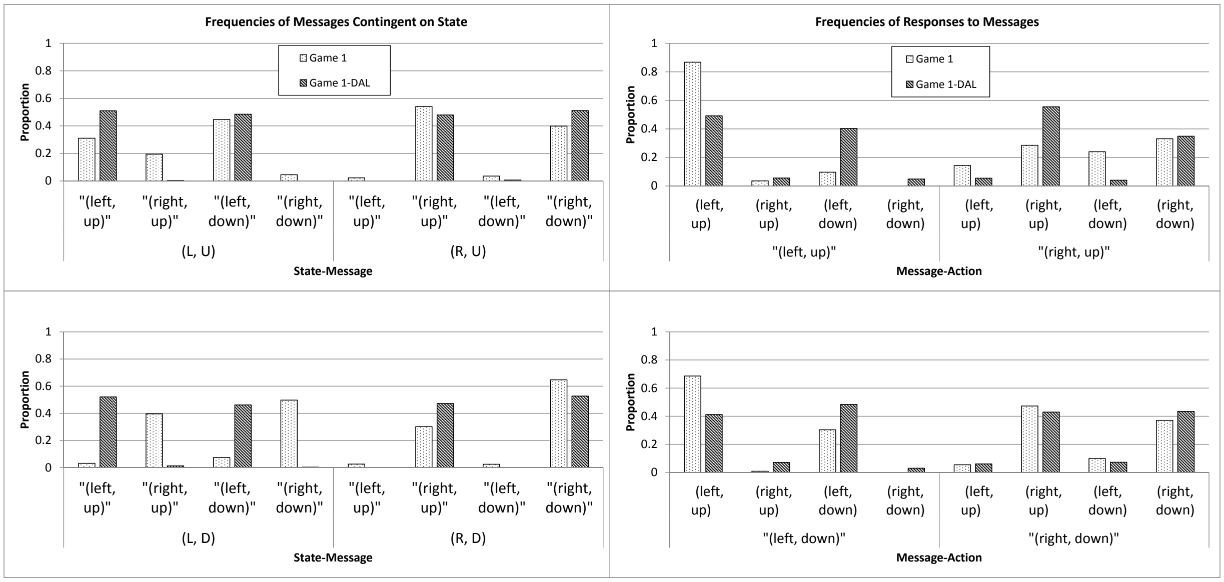
With senders' deviations in states without alignments, receivers in Games 2 and 2-LAB behaved differently from those in Game 2-DAL. Receivers' responses in Game 2 when (right, up) was received from Sender 1s provide a representative example. Receivers took (right, up) with 29% frequency if "(left, up)" was received from Sender 2s; (right, down) with 52% frequency if "(left, down)" was received from Sender 2s; (right, down) with 43% frequency if "(right, down)" was received from Sender 2s; and "(right, up)" with frequency 92% if "(right, up)" was also received from Sender 2s. By contrast, when cases in ("(left, .)", "(. , up)") were received, (left, up) was taken with $83\% - 100\%$ frequencies. Such observed behavior can be organized by a response rule in which messages are filtered in two different ways: receivers followed senders on equilibrium-relevant dimensions when no message that might have come from states without alignment was received; when one was received, receivers followed the relevant dimensions less often unless the message was endorsed by an identical message from the other sender.

In the two-dimensional message environment, how receivers responded to inconsistent messages was crucial to the laboratory success of fully revealing equilibrium. In Game 2-DAL, the all-state dimensional alignments presented receivers with minimal strategic uncertainty on how to interpret inconsistent messages, which in turn fostered senders' adherence to reveal according to the equilibrium-relevant dimensions. In Games 2 and 2-LAB, where senders' ideal actions lie across equilibrium-relevant dimensions in states without alignments, receivers were not as predictable with inconsistent messages, which in turn made deviations more justifiable. As will be covered in Section 4.2, restricting senders' access to messages, which eliminates occurrences of inconsistent messages, significantly brought their behavior back in line with the prescriptions of fully revealing equilibrium, notably even for states without dimensional alignment.

Result 1b (Strategies in One-Sender Games).

- *Senders in Game 1-DAL revealed on dimension H as did Sender 1s in Game 2-DAL; Senders in Game 1 behaved differently from Sender 1s in Game 2, consistent with the partially revealing equilibrium in which only (L, U) is revealed.*

- *Receivers in Game 1-DAL followed senders' message only on dimension H; receivers' responses in Game 1 reflected senders' revelations of (L, U).*



(a) Frequencies of Messages Contingent on State (b) Frequencies of Responses to Messages

Figure 5: Strategies in Games 1 and 1-DAL

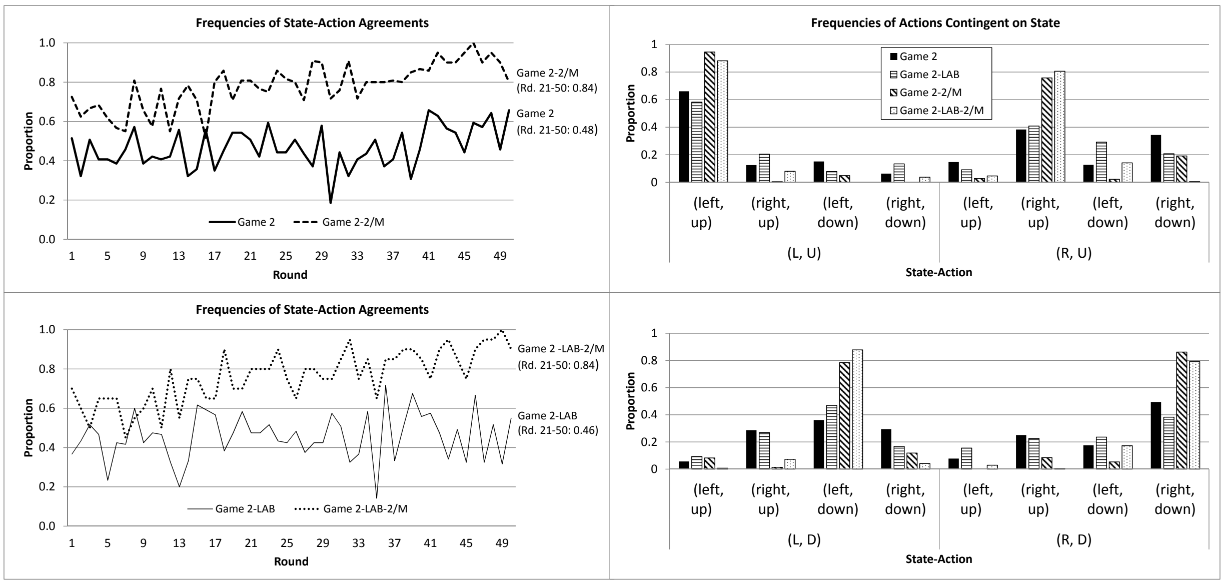
Figure 5 presents message uses and responses in the two one-sender games. Same as Sender 1s in Game 2-DAL, senders in Game 1-DAL revealed on dimension H. In Game 1, the combined frequency of "(left, up)" and "(left, down)" was 76% in (L, U) and never exceeded 10% in the other three states, across which the uses of "(right, up)" and "(right, down)" were fairly uniform. Such message uses resulted in the revelation of (L, U), with slight or no information provided for the other three states, consistent with the partially revealing equilibrium.[29]

In Game 1-DAL, receivers listened to senders on dimension H, mostly ignoring the part of messages on dimension V. In Game 1, receivers' responses to "(left, up)" and "(left, down)" were most often (left, up), largely consistent with the finding that the two messages were used to reveal (L, U), a pattern not seen in Game 1-DAL.

[29] The frequencies of (L, U) contingent on "(left, up)" and "(left, down)" were, respectively, 81% and 78%. Contingent on "(right, up)", the frequency of (R, U) was higher than that of (R, D) (38% vs. 19%), and vice versa for "(right, down)" (27% vs. 38%), while the two frequencies of (L, D) were very close (28% and 31%). Refer to Figure 13(b) in Appendix C for the conditional distributions of states implied by message uses.

4.2 Restricted Message Spaces

Result 2 (**Outcomes**). ***Positive Effect of Restricting Message Spaces**: Receivers in Game 2-2/M (2-LAB-2/M) identified true states significantly more often than did receivers in Game 2 (Game 2-LAB).*



(a) Frequencies of State-Action Agreements (b) Frequencies of Actions Contingent on State

Figure 6: Information Revelation Outcomes in Games 2, 2-LAB, 2-2/M, and 2-LAB-2/M

Figure 6 presents information revelation outcomes in the two one-dimensional message games, along with their four-message counterparts for comparisons. The frequency of state-action agreements in Game 2-2/M (Game 2-LAB-2/M) was 84% (84%), significantly higher than the 48% (46%) in Game 2 (Game 2-LAB), confirming Hypothesis 3 ($p = 0.0143$, Mann-Whitney tests). Restricting message spaces increased overall agreement frequencies by as high as 80%.[30]

Under the binary message spaces, high frequencies of state identifications ($76\% - 95\%$) were observed for all states. The states without dimensional/diagonal alignments were still discernable; as in Games 2 and 2-LAB, state identifications in Games 2-2/M and 2-LAB-2/M were more frequent in states with alignments than without. However, it was in the states with no alignment that restricting message spaces showed a slightly stronger

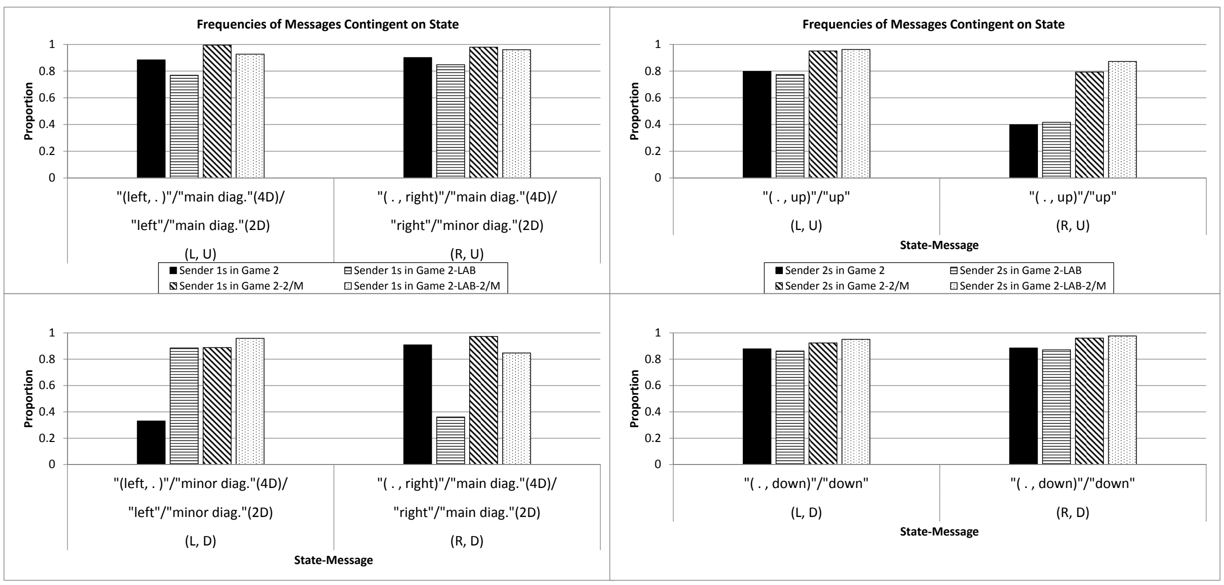
[30]The less focal revelation dimensions had virtually zero effect when message spaces were restricted. The part of Hypothesis 2b comparing Games 2-2/M and Game 2-LAB-2/M is rejected with an extreme two-sided $p = 1$ from Mann Whitney test.

effect.[31] Overall, restricting message spaces substantially brought observed outcomes in line with the prediction of fully revealing equilibrium, especially through its working on states without alignments.

Result 2a (Strategies).

- *Senders in two-sender games with one-dimensional messages, Games 2-2/M and 2-LAB-2/M, behaved in high accord with the prescriptions of fully revealing equilibrium, even for states without dimensional/diagonal alignment.*

- *Receivers in the two games virtually always followed senders' recommendations.*



(a) Frequencies of Messages Contingent on State: Sender 1s

(b) Frequencies of Messages Contingent on State: Sender 2s

Figure 7: Senders' Strategies in Games 2, 2-LAB, 2-2/M, and 2-LAB-2/M

Figure 7 presents message uses in Games 2-2/M and 2-2/M-LAB.[32] Message uses consistent with the prescriptions of fully revealing equilibrium were observed with $92\% - 99\%$ frequencies in states with alignments. In states without alignments, adherence was observed with $79\% - 89\%$ frequencies, compared to $33\% - 43\%$ when four messages were

[31] The positive differences of Game 2-2/M over Game 2 in state identifications were 42% and 38% for (L, D) and (R, U) and 37% and 29% for (R, D) and (L, U). For Games 2-LAB-2/M and 2-LAB, the differences were 41% and 40% for (R, D) and (R, U) and 41% and 30% for (L, D) and (L, U).

[32] Given that messages are binary, for each state we present only the frequencies of one message (truthful dimensional recommendation). For the two-dimensional message games included for comparisons, we condense the message cases accordingly. For Game 2-LAB-2/M, "main diagonal" refers to message "(left, up) or (right, down)" and "minor diagonal" to "(right, up) or (left, down)".

available. Under the binary message environment, senders' recommendations prompting for own ideal action in states without alignment could only be made on one dimension, and was very likely to be severely punished given that the other sender was recommending truthfully on the other dimension.

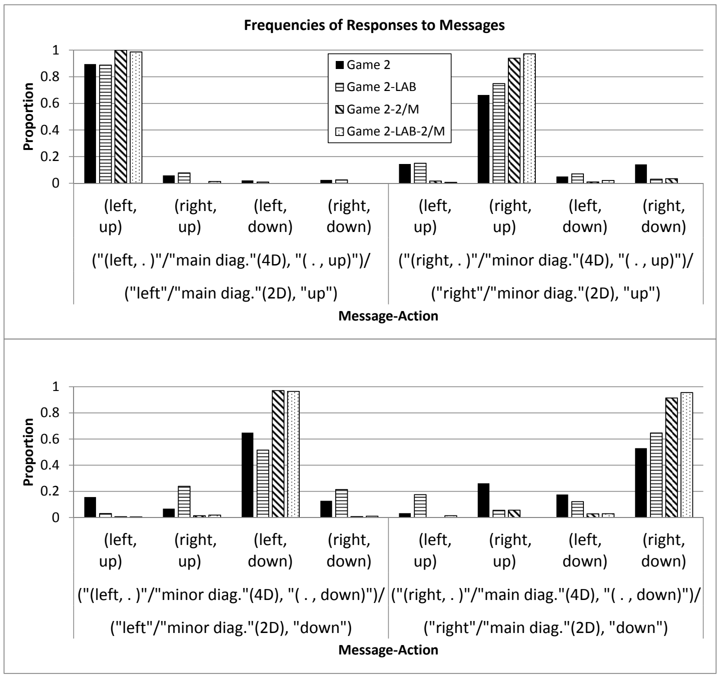


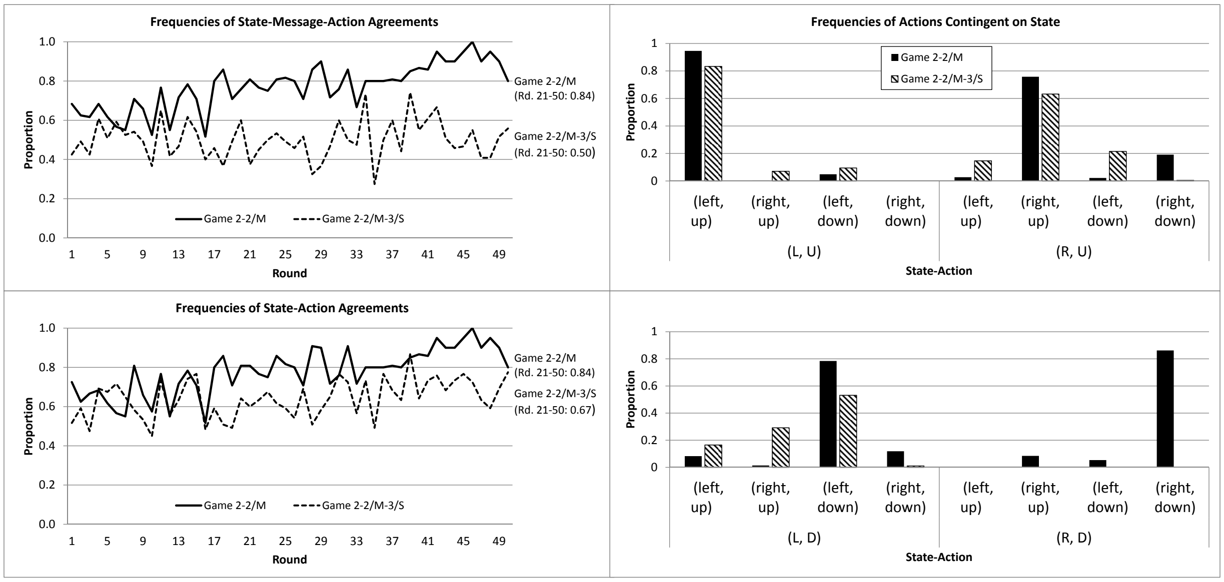
Figure 8: Receivers' Responses in Games 2, 2-LAB, 2-2/M, and 2-LAB-2/M

Figure 8 substantiates that receivers' responses were highly predictable under the binary message environment. The frequencies of following senders' recommendations were at least 91% and as high as 100%. The manners in which message pairs are combined are different for Games 2-2/M and 2-LAB-2/M. In Game 2-LAB-2/M, guided by Sender 2s' dimensional messages, receivers eliminate an irrelevant component from Sender 1s' diagonal messages. In Game 2-2/M, with dimensional messages from both senders, only a simple combination of messages is required. We illustrate with our last set of findings that even such apparently simple tasks of receivers were backed by considerations of senders' incentives.

4.3 Restricted State Space: Theoretical and Empirical Implausibility

Result 3 (Outcomes). ***Negative Effect of Restricting State Space****: Receivers in Game 2-2/M-3/S identified true states significantly less often than did receivers in Game*

2-2/M.



(a) Frequencies of State-(Message)-Action Agreements

(b) Frequencies of Actions Contingent on State

Figure 9: Information Revelation Outcomes in Games 2-2/M and 2-2/M-3/S

Figure 9(a), upper panel, presents the frequencies of state-message-action agreements, an alternative measure we use for comparing the revelation outcomes in Game 2-2/M-3/S with those in Game 2-2/M.[33] The frequency in Game 2-2/M-3/S was 50%, significantly lower than the 84% in Game 2-2/M, confirming Hypothesis 4 ($p = 0.0143$, Mann-Whitney test).[34] Figure 9(b) shows that less frequent state identifications were observed in all three states. The omission of a state, with its robustness implication for the fully revealing equilibrium in Game 2-2/M-3/S, significantly reduced the instances receivers identify true states.

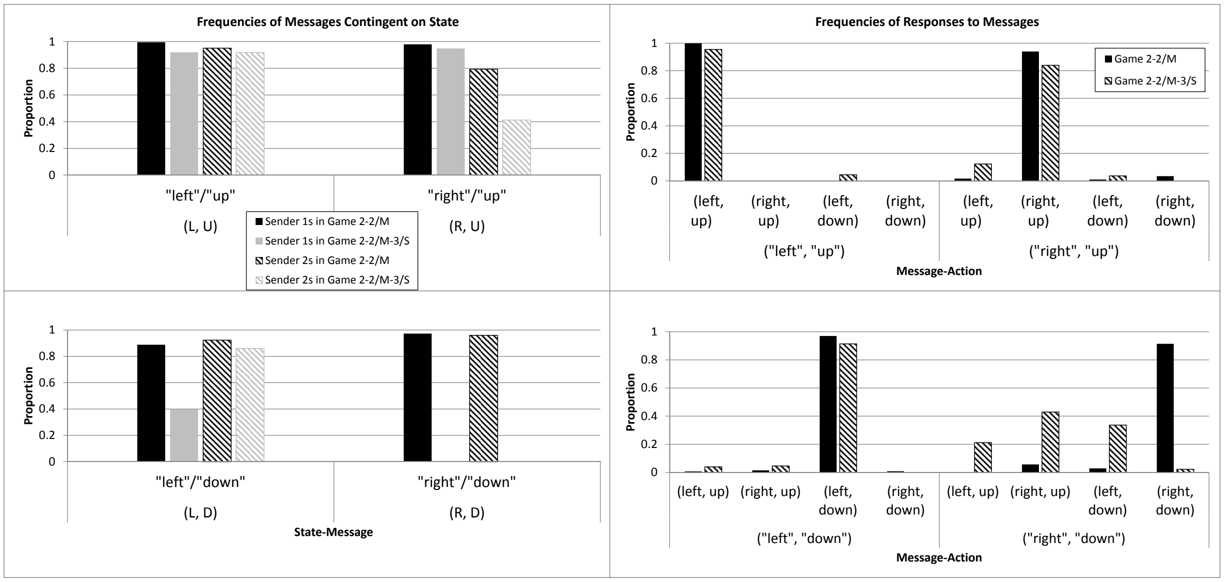
Result 3a (Strategies).

- *Senders in Game 2-2/M-3/S deviated in states without dimensional alignment from the message uses observed in Game 2-2/M.*

[33]The measure using state-action agreements, which is presented in the lower panel, does not provide a common ground for comparing a three-state game with a four-state, in which the probability of receivers taking ideal actions out of random guess is higher in Game 2-2/M-3/S. A condition for the validity of the new measure is that the literal meanings of recommendations are used, which was observed in Game 2-2/M.

[34]Same qualitative difference with statistical significance was also observed using state-action agreements, even though it favors Game 2-2/M-3/S. The frequency is 84% in Game 2-2/M, significantly higher than the 67% in Game 2-2/M-3/S ($p = 0.0571$, Mann-Whitney test).

- *Receivers in Game 2-2/M-3/S tended to follow senders' recommendations less often, and their responses to irreconcilable messages justified senders' deviations.*



(a) Frequencies of Messages Contingent on State (b) Frequencies of Actions Contingent on Messages

Figure 10: Strategies in Games 2-2/M and 2-2/M-3/S

Figure 10 presents senders' message uses and receivers' responses in the two games. For Sender 1s in (L, D), the frequency of "left" decreased from 89% in Game 2-2/M to 40% in Game 2-2/M-3/S; for Sender 2s in (R, U), the frequency of "up" decreased from 79% to 41%.[35] Even with binary messages, the kind of deviations observed in Game 2 resurfaced in Game 2-2/M-3/S.[36] Obtained under the tight control of what messages may be received in a given instance, the finding adds force to the idea that uncertainty surrounding how receivers interpret messages that indicated inconsistency, in this case the irreconcilable ("right", "down"), was crucial to senders' adherence. It also suggests that the high adherence observed in Game 2-2/M was a result of senders getting behind the veils of message frames and acting on incentives; when receivers were likely to respond to deviating messages with attractive actions, senders deviated despite the fact that messages were framed according to the equilibrium-relevant dimensions.

[35] The decreases were statistically significant for the former ($p = 0.0143$, Mann-Whitney test) but not for the latter ($p = 0.1714$, Mann-Whitney test). The insignificance was accounted for by an outlier session in Game 2-2/M-3/S; the frequencies of "up" by Sender 2s in (R, U) were 20%, 25%, 30%, and 90% in the four sessions.

[36] A sender's deviation was accurately anticipated by the other sender. Figure 14(b) in Appendix C presents senders' predictions of the other's messages in Game 2-2/M-3/S as well as in Games 2-2/M and 2-LAB-2/M.

Although for message pairs ("left","up"), ("right","up"), and ("left","down") receivers in Game 2-2/M-3/S still combined and followed recommendations with high frequencies, the deviations by senders did leave a noticeable trace on receivers' responses, in which the frequencies were $4\% - 10\%$ lower than those in Game 2-2/M. Receivers' responses to ("right","down") indeed presented profitable opportunities for senders to deviate. The plausible, deviation inviting responses, (right, up) and (left, down), were observed with frequencies 43% and 34%, while the implausible, deviation deterring (left, up) were observed less often with 21%, significantly lower than the threshold of 80% required to support the equilibrium ($p = 0.0625$, Wilcoxon signed-rank test). Receivers' elicited beliefs further confirmed the implausibility of the supporting out-of-equilibrium beliefs. In the final round predictions of state, receivers in Game 2-2/M-3/S never predicted that the state was (L, U) when ("right","down") was received.[37] The theoretical implausibility of the fully revealing equilibrium in Game 2-2/M-3/S translated into a lower adherence in the laboratory, where observed behavior and elicited beliefs were consistent with the intuition behind why the equilibrium is implausible.

5 Concluding Remarks

Battaglini (2002) provides a pioneering equilibrium solution for how, facing experts with diverging interests, a decision maker can extract full information through cheap talk by selectively listening to them on different issues. We experiment on a series of simple games capturing Battaglini's (2002) equilibrium construction. We find, consistent with the 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 multidimensional 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. We further obtain the findings that, in moving away from the stringent requirement inherent in the notion of equilibrium, message spaces play an important role for full revelation.

Our findings suggest policy implications regarding institutions for eliciting information: in a multidimensional environment with multiple experts, even when talk is otherwise cheap and cannot be verified, decision makers may still effectively elicit information if

[37] Figure 15 in Appendix C presents the receivers' predictions in all games.

institutions are in place to restrict what experts can say on what issues. Extrapolated from this is that decision makers' opportunity to commit to what to listen to and from whom, while theoretically having no impact in light of Battaglini's (2002) equilibrium, may have an effect in practice. As one of the first experimental studies on this topic, we use a parsimonious design which allows us to, among others, identify in a stark setting the effects of message spaces in information aggregation.

Before experimentalists can "whisper in the ears of Princes" (Roth, 1995) with a more comprehensive picture on the issue, more experimental efforts will be needed; we hope that we have provided a simple setting capturing the multi-sender multidimensional cheap talk environment that will prove to be useful for future experimental research on this important topic.

References

[1] Ambrus, A., and S. E. Lu (2010): "Robust Almost Fully Revealing Equilibria in Multi-Sender Cheap Talk." *Mimeo.*

[2] Ambrus, A., and S. Takahashi (2008): "Multi-Sender Cheap Talk with Restricted State Spaces." *Theoretical Economics*, 3, 1–27.

[3] Austen-Smith, D (1993): "Interested Experts and Policy Advice: Multiple Referrals under Open Rule." *Games and Economic Behavior*, 5, 3–43.

[4] Battaglini, M (2002): "Multiple Referrals and Multidimensional Cheap Talk." *Econometrica*, 50, 1431–1451.

[5] Battaglini, M (2004): "Policy Advice with Imperfectly Informed Experts." *Advances in Theoretical Economics*, 4, Article 1.

[6] Battaglini, M., and U. Makarov (2011): "Cheap Talk with Multiple Audiences: An Experimental Analysis." *Games and Economic Behavior*, 83, 147–164.

[7] Binmore, K. (1999): "Why Experiment in Economics?" *Economic Journal*, 109, F16–F24.

[8] Blume, A., D. V. DeJong, and G. B. Sprinkle (2008): "The Effect of Message Space Size on Learning and Outcomes in Sender-Receiver Games." *Handbook of Experimental Economics Results*, Elsevier.

[9] Blume, A., D. V. Dejong, Y.-G. Kim, and G. B. Sprinkle (1998): "Experimental Evidence on the Evolution of the Meaning of Messages in Sender-Recevier Games." *American Economic Review*, 88, 1323–1340.

[10] Blume, A., D. V. Dejong, Y.-G. Kim, and G. B. Sprinkle (2001): "Evolution of Communication with Partial Common Interest." *Games and Economic Behavior*, 37, 79–120.

[11] Blume, A., O. J. Board, and K. Kawamura (2007): "Noisy Talk." *Theoretical Economics*, 2, 395–440.

[12] Cai, H., and J. T.-Y. Wang (2006): "Overcommunication in Strategic Information Transmission Games." *Games and Economic Behavior*, 56, 7–36.

[13] Chakraborty, A., and R. Harbaugh (2007): "Comparative Cheap Talk." *Journal of Economic Theory*, 132, 70–94.

[14] Chakraborty, A., and R. Harbaugh (2010): "Persuasion by Cheap Talk." *American Economic Review*, 100: 2361–382.

[15] Crawford, V. P. (1998): "A Survey of Experiments on Communication via Cheap Talk." *Journal of Economic Theory*, 78, 286–298.

[16] Crawford, V. P. (2003): "Lying for Strategic Advantage: Rational and Boundedly Rational Mispresentation of Intentions." *American Economic Review*, 93, 133–149.

[17] Crawford, V. P., and J. Sobel (1982): "Strategic Information Transmission." *Econometrica*, 50, 1431–1451.

[18] Dickhaut, J., K. McCabe, and A.t Mukherji (1995): "An Experimental Study of Strategic Information Transmission." *Economic Theory*, 6, 389-403.

[19] Farrell, J., and R. Gibbons (1989): "Cheap Talk with Two Audiences." *American Economic Review*, 79, 1214–1223.

[20] Fischbacher, U. (2007): "z-Tree: Zurich Toolbox for Ready-made Economic Experiments." *Experimental Economics*, 10, 171–178.

[21] Gilligan, T. W., and K. Krehbiel (1989): "Asymmetric Information and Legislative Rules with a Heterogeneous Committee." *American Journal of Political Science*, 33, 459–490.

[22] Gneezy, U. (2005): "Deception: The Role of Consequences." *American Economic Review*, 95, 384–394.

[23] Goltsman, M., J. H., G. Pavlov, and Francesco Squintani (2009): "Mediation, Arbitration and Negotiation." *Journal of Economic Theory*, 144, 1397–1420.

[24] Goltsman, M., and G. Pavlov (2011): "How to Talk to Multiple Audiences." *Games and Economic Behavior*, 72, 100–122.

[25] Ivanov, M. (2010): "Communication via a Strategic Mediator." *Journal of Economic Theory*, 145, 869–884.

[26] Jehiel, P. (2005): "Analogy-Based Expectation Equilibrium." *Journal of Economic Theory*, 123, 81–104.

[27] Jehiel, P., and F. Koessler (2008): "Revisiting Games of Incomplete Information with Analogy-Based Expectations." *Games and Economic Behavior*, 62, 533–557.

[28] Kawagoe, T., and H. Takizawa (2009): "Equilibrium Refinement vs. Level-k Analysis: An Experimental Study of Cheap-Talk Games with Private Information." *Games and Economic Behavior*, 66, 238–255.

[29] Kim, C. (2010), "Non-robustness of Fully Revealing Equilibria in Cheap Talk Games." *Mimeo*, University of California, San Diego.

[30] Kőszegi, B. (2006): "Emotional Agency." *Quarterly Journal of Economics*, 121, 121–155.

[31] Krishna, V., and J. Morgan (2001a): "A Model of Expertise." *Quarterly Journal of Economics*, 116, 747–775.

[32] Krishna, V., and J. Morgan (2001b): "Asymmetric Information and Legislative Rules: Some Amendments." *American Political Science Review*, 95, 435–452.

[33] Krishna, V., and J. Morgan (2004): "The Art of Conversation: Eliciting Information from Experts Through Multi-Stage Communication." *Journal of Economic Theory*, 117, 147–179.

[34] Levy, G., and R. Razin (2007): "On the Limits of Communication in Multidimensional Cheap Talk: A Comment." *Econometrica*, 75, 885–893.

[35] Lu, S. E. (2011): "Coordination-Free Equilibria in Cheap Talk Games." *Mimeo.*

[36] Minozzi, W., and J. Woon (2011): "Competition, Preference Uncertainty, and Jamming: A Strategic Communication Experiment." *Mimeo.*

[37] Morgan, J., and P. C. Stocken (2003): "An Analysis of Stock Recommendations." *Rand Journal of Economics*, 34, 183–203.

[38] Myerson, R. (1978): "Refinements of the Nash Equilibrium Concept." *International Journal of Game Theory*, 7, 73–80.

[39] Roth, A. E. (1995): "Introduction to Experimental Economics." in J. H. Kagel and A. E. Roth, eds., *Handbook of Experimental Economics*, Princteon, NJ: Princeton University Press, 3–109.

[40] Sánchez-Pagés, S., and M. Vorsatz (2007): "An Experimental Study of Truth-Telling in Sender-Receiver Game." *Games and Economic Behavior*, 61, 86–112.

[41] Sánchez-Pagés, S., and M. Vorsatz (2009): "Enjoy the Silence: An Experiment on Truth-Telling." *Experimental Economics*, 12, 220–241.

Coordination Failure in Average Opinion Games", *Quarterly Journal of Economics*, 106, 885–910.

[42] Vespa, E., and A. J. Wilson (2012): "Communication With Multiple Senders: An Experiment." *Mimeo.*

[43] Wang, J. T.-Y., M. Spezio and, C. F. Camerer (2010): "Pinocchio's Pupil: Using Eyetracking and Pupil Dilation To Understand Truth Telling and Deception in Sender-Receiver Games." *American Economic Review*, 100, 984–1007.

Appendix A - Proofs

Proof of Proposition 2. *Game 1.* Let $\mu = (\mu_{LU}, \mu_{RU}, \mu_{LD}, \mu_{RD})$ be the receiver's beliefs, where μ_{HV} is the probability assigned to $(H, V) \in \{L, R\} \times \{U, D\}$, and $U_R(a|\mu)$ be her expected payoff from action a given beliefs μ. We have that $U_R((\text{left, up})|\mu) = 50\mu_{LU}+20\mu_{RU}+20\mu_{LD}$, $U_R((\text{right, up})|\mu) = 20\mu_{LU}+50\mu_{RU}+20\mu_{RD}$, $U_R((\text{left, down})|\mu)) = 10\mu_{LU} + 50\mu_{LD} + 10\mu_{RD}$, and $U_R((\text{right, down})|\mu) = 10\mu_{RU} + 10\mu_{LD} + 50\mu_{RD}$. We first show that there exists a partially revealing equilibrium in which only (L, U) is revealed.

The receiver takes (left, up) when the state is (L, U). In all other three states, the receiver's beliefs are $\mu_{RU} = \mu_{LD} = \mu_{RD} = \frac{1}{3}$ and $\mu_{LU} = 0$. The receiver's best response is to randomize between (right, up) and (right, down) with probabilities $(p, 1-p)$, $p \in [0,1]$. In order for the sender not to deviate, we require $20 \geqslant 10(1-p)$, $20p + 50(1-p) \geqslant 0$ and $50p + 20(1-p) \geqslant 10$ respectively in state (L, U), (R, U) and (R, D), which are satisfied for all $p \in [0,1]$. In (L, D) we require $60p \geqslant 15$, which is satisfied for any $p \geqslant \frac{1}{4}$. We show that other $1-3$ partitions are not consistent with equilibrium. Consider that only $(H, V) \neq (L, U)$ is fully revealed. The receiver takes $(h,\, v)$ when the state is (H, V). In all other three states, the receiver's updated beliefs are $\mu_{\tilde{H}V} = \mu_{\tilde{H}\tilde{V}} = \mu_{H\tilde{V}} = \frac{1}{3}$ and $\mu_{HV} = 0$ for $\tilde{H} \neq H$, $\tilde{V} \neq V$. When $(H, V) = (R, U)$, the receiver's best response to the 3-state partition is to randomize between (left, up) and (left, down) with probabilities $(p, 1-p)$, $p \in [0,1]$, so a sender in state (L, D) has an incentive to tell that it is (R, U) given that $60 > 15p + 20(1-p)$ for all $p \in [0,1]$. When $(H, V) = (L, D)$, the receiver's best response to the 3-state partition is to take (right, up), so a sender in state (L, D) has an incentive to tell that the state is in $\{(L, U), (R, U), (R, D)\}$ given that $60 > 20$. When $(H, V) = (R, D)$, the receiver's best response to the 3-state partition is to take (left, up), so a sender in state (R, U) has an incentive to tell that the state is (R, D) given that $50 > 0$.

We next show that all $2-2$ partitions cannot constitute an equilibrium. First, consider an equilibrium in which only dimension H is revealed. When $H = L$ is revealed, the receiver's best response to the updated beliefs $\mu_{LU} = \mu_{LD} = \frac{1}{2}$ and $\mu_{RU} = \mu_{RD} = 0$ is to take (left, up). When $H = R$ is revealed, the receivers's best response to $\mu_{RU} = \mu_{RD} = \frac{1}{2}$ and $\mu_{LU} = \mu_{LD} = 0$ is (right, up). For a sender in (L, D), equilibrium requires $15 \geqslant 60$, which is not satisfied. Next, consider an equilibrium in which only dimension V is revealed. When $V = U$ is revealed, the receiver's best response to the updated beliefs $\mu_{LU} = \mu_{RU} = \frac{1}{2}$ and $\mu_{LD} = \mu_{RD} = 0$ is to randomize between (left, up) and (right, up) with probabilities $(p, 1-p)$ for any $p \in [0,1]$. When $V = D$ is revealed, the receiver's best response to $\mu_{LU} = \mu_{RU} = 0$ and $\mu_{LD} = \mu_{RD} = \frac{1}{2}$ is to randomize between (left, down) and (right, down) with probabilities $(q, 1-q)$ for any $q \in [0,1]$. For senders in states (L, U) and (R, U), equilibrium requires, respectively, $20p \geqslant 50q + 10(1-q)$ and $20(1-p) \geqslant 10q + 50(1-q)$, which implies $20 \geqslant 60$, a contradiction. Finally, we show that the diagonal partition $\{\{(L, U), (R, D)\},\ \{(R, U), (L, D)\}\}$ is not consistent with equilibrium. When the main diagonal $\{(L, U), (R, D)\}$ is revealed, the receiver's best response to $\mu_{LU} = \mu_{RD} = \frac{1}{2}$ and $\mu_{RU} = \mu_{LD} = 0$ is to randomize between (left, up) and (right, down) with probabilities $(p, 1-p)$ for any $p \in [0,1]$. When the minor diagonal $\{(R, U), (L, D)\}$ is revealed, the receiver's best response to $\mu_{LU} = \mu_{RD} = 0$ and $\mu_{RU} = \mu_{LD} = \frac{1}{2}$ is to randomize between (right, up) and (left, down) with probabilities $(q, 1-q)$ for any $q \in [0, 1]$. For senders in states (L, U) and (R, D), equilibrium requires, respectively, $20p + 10(1-p) \geqslant 50(1-q)$ and $10p + 20(1-p) \geqslant 50q$, which implies $30 \geqslant 50$, a contradiction.

We show 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. To complete the proof, we rule out the $1-1-2$ partitions. There are six possible partitions here. The two 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. For each of the remaining four partitions, 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 a payoff of 50 or 60), they also cannot be feasible in equilibrium.

Game 1-DAL. We have that $U_R((\text{left, up})|\mu) = 50\mu_{LU} + 20\mu_{RD}$, $U_R((\text{right, up})|\mu) = 50\mu_{RU} + 20\mu_{LD}$, $U_R((\text{left, down})|\mu)) = 50\mu_{LD} + 20\mu_{RU}$, and $U_R((\text{right, down})|\mu) = 50\mu_{RD} + 20\mu_{LU}$. We first show the existence of the partially revealing equilibrium. Suppose the sender truthfully reveals $H = L$ and babbles on dimension V. The receiver's best response to her updated beliefs $\mu_{LU} = \mu_{LD} = \frac{1}{2}$ and $\mu_{RU} = \mu_{RD} = 0$ (from the uniform prior) is to randomize between (left, up) and (left, down) with probabilities $(p, 1-p)$, $p \in [0, 1]$. Consider next that the sender truthfully reveals $H = R$ and babbles on dimension V. The receiver's best response to the updated beliefs $\mu_{RU} = \mu_{RD} = \frac{1}{2}$ and $\mu_{LU} = \mu_{LD} = 0$ is to randomize between (right, up) and (right, down) with probabilities $(q, 1-q)$, $q \in [0, 1]$. In state (L, U), we require that the sender has no incentive to tell that the state consists of R, or $20p + 50(1-p) \geqslant 10(1-q)$, 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 1-DAL with other information partitions. First, $\{\{(L, U)\}, \{(L, D)\}, \{(R, U)\}, \{(R, D)\}\}$ cannot be sustained as equilibrium, for a sender in state (L, U) would have an incentive to tell that it is (L, D) given that he will receive 50 rather than 20. Consider next the $1-3$ partition where only (L, U) is fully revealed. In all other states, the receiver's best response to beliefs $\mu_{LD} = \mu_{RU} = \mu_{RD} = \frac{1}{3}$ and $\mu_{LU} = 0$ is to randomize between (left, down) and (right, up) with probabilities $(p, 1-p)$, $p \in [0, 1]$. This does not constitute an equilibrium, because a sender in state (L, D) has an incentive to tell that it is (L, U) so the receiver takes (left, up), 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 $V = U$ is revealed, the receiver's best response to the updated beliefs $\mu_{LU} = \mu_{RU} = \frac{1}{2}$ and $\mu_{LD} = \mu_{RD} = 0$ is to randomize between (left, up) and (right, up) with probabilities $(p, 1-p)$ for some $p \in [0,1]$. When $V = D$ is revealed, The receiver's best response to the updated beliefs $\mu_{LU} = \mu_{RU} = 0$ and $\mu_{LD} = \mu_{RD} = \frac{1}{2}$ is to randomize between (left, down) and (right, down) with probabilities $(q, 1-q)$ for some $q \in [0,1]$. For senders in states (L, U) and (R, U), equilibrium requires, respectively, $20p \geqslant 50q + 10(1-q)$ and $20(1-p) \geqslant 10q + 50(1-q)$, which implies $20 \geqslant 60$, a contradiction. For the partition $\{\{(L,U),(R,D)\},\{(L,D),(R,U)\}\}$ in which the diagonal is revealed, a similar argument shows that for senders in states (L,U) and (R,D), equilibrium requires, respectively, $50q \leqslant 20p + 10(1-p)$ and $50(1-q) \leqslant 10p + 20(1-p)$, which leads to the contradiction of $50 \leqslant 30$.

We complete the proof by ruling out the six 1-1-2 partitions. 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 partitions $\{\{(L,U),(R,D)\},\{(L,D)\},\{(R,U)\}\}$ and $\{\{(L,U)\},\{(R,D)\},\{(L,D),(R,U)\}\}$. However, senders in one of two partially revealed states have an incentive to tell that it is the fully revealed state that yields him a payoff of 50.

$\square$

Proof of Proposition 1. *Game 2 and 2-DAL existence.* We construct a fully revealing equilibrium in which Sender 1 truthfully reveals on dimension H and Sender 2 on dimension V. 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 senders' strategy profiles

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

for all $(H, V) \in \{L, R\} \times \{U, D\}$, in which Sender 1 truthfully reveals on dimension H but is not required to truthfully reveal on dimension V and Sender 2 does the exact opposite. The receiver's best responses are her ideal actions $\rho(\text{“}(h^*, v')\text{”}, \text{“}(h', v^*)\text{”}) = (h^*, v^*)$, because her updated beliefs (using Bayes' rule) are: For any $v' \in \{\text{up, down}\}$ and $h' \in \{\text{left, right}\}$,

$$\begin{aligned}\mu_{HV}((\text{``}(h^*, v')\text{''}, \text{``}(h', v^*)\text{''})) &= \frac{\frac{1}{4}\sigma_1(\text{``}(h^*, v')\text{''}|(H,V))\sigma_2(\text{``}(h', v^*)\text{''}|(H,V))}{\sum_{(\tilde{H},\tilde{V})\in\{L,R\}\times\{U,D\}} \frac{1}{4}\sigma_1(\text{``}(\tilde{h}^*, v')\text{''}|(\tilde{H},\tilde{V}))\sigma_2(\text{``}(h', \tilde{v}^*)\text{''}|(\tilde{H},\tilde{V}))} \\ &= \frac{\sigma_1(\text{``}(h^*, v')\text{''}|(H,V))\sigma_2(\text{``}(h', v^*)\text{''}|(H,V))}{\sigma_1(\text{``}(h^*, v')\text{''}|(H,V))\sigma_2(\text{``}(h', v^*)\text{''}|(H,V))} = 1,\end{aligned} \tag{A.2}$$

since either $\sigma_1(\text{``}(h^*, v')\text{''}|(\tilde{H},\tilde{V})) = 0$ or $\sigma_2(\text{``}(h', v^*)\text{''}|(\tilde{H},\tilde{V})) = 0$ unless $(\tilde{H},\tilde{V}) = (H,V)$.

To verify that (A.1) 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 that Sender 1 strictly prefers (h^*, v^*) over $(\tilde{h}, v^*)$. Similarly, Sender 2 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.1), 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 $\sigma_2(\text{``}(\text{right}, v^*)\text{''}|(H,V))$. If $\sigma_1(\text{``}(h^*, v^*)\text{''}|(H,V)) = \sigma_2(\text{``}(h^*, v^*)\text{''}|(H,V)) = 1$, we obtain the third class of equilibrium. 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. 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 obtain the first class of equilibrium, in which there is no out-of-equilibrium message pair.

Game 2 non-diagonal. Here we prove the non-existence of diagonal fully revealing equilibria for Game 2. If Sender 1 reveals partition $\{\{(L,U),(R,D)\},\{(R,U),(L,D)\}\}$, Sender 2 in state (R,U) has an incentive to tell that the state consists of D to induce action (left, down). If Sender 2 reveals partition $\{\{(L,U),(R,D)\},\{(R,U),(L,D)\}\}$, Sender 1 in state (L,D) has an incentive to tell that the state consists of U to induce (right, up).

Game 2-LAB existence & non-diagonal. Omitted as it is a relabeling of Game 2.

Game 2-DAL diagonal. For the second class of fully revealing equilibrium in which Sender 1 reveals between diagonals and Sender 2 reveals on dimension V, the receiver's best response (to the updated beliefs) is to take her ideal action $\rho(\text{``}(h^*, v^*) \text{ or } (\tilde{h}, \tilde{v})\text{''}, \text{``}(h', v^*)\text{''}) = (h^*, v^*)$ for $h^* \neq \tilde{h}$ and $v^* \neq \tilde{v}$. Given the strategies of Sender 1 and the receiver, Sender 2 can only influence the receiver in the choice between (h^*, v^*) and $(\tilde{h}, \tilde{v})$, but he strictly prefers (h^*, v^*) over $(\tilde{h}, \tilde{v})$. Similarly, Sender 1, given the others' strategies, can only influence the receiver in the choice between (h^*, v^*) and $(\tilde{h}, v^*)$ where he strictly prefers (h^*, v^*)

over $(\tilde{h}, v^*)$. For the last class of fully revealing equilibrium in which Sender 1 reveals on dimension H and Sender 2 reveals between diagonals, the receiver's best response (to the updated beliefs) is to take her ideal action $\rho(\text{“}(h^*, v')\text{”}, \text{“}(h^*, v^*) \text{ or } (\tilde{h}, \tilde{v})\text{”}) = (h^*, v^*)$ for $h^* \neq \tilde{h}$ and $v^* \neq \tilde{v}$. Given the strategies of Sender 1 and the receiver, Sender 2 can only influence the receiver in the choice between (h^*, v^*) and $(h^*, \tilde{v})$, $v^* \neq \tilde{v}$, but he strictly prefers (h^*, v^*) over $(h^*, \tilde{v})$. Similarly, Sender 1, given the others' strategies, can only influence the receiver in the choice between (h^*, v^*) and $(\tilde{h}, \tilde{v})$, $h^* \neq \tilde{h}$ and $v^* \neq \tilde{v}$, where he strictly prefers (h^*, v^*) over $(\tilde{h}, \tilde{v})$.

□

Proof of Proposition 3. With the binary message spaces the senders' strategy profiles in (A.1) become $\sigma_1(\text{“}h\text{”}|(H, V)) = \sigma_2(\text{“}v\text{”}|(H, V)) = 1$. The receiver updates her beliefs as in (A.2), and her best response is $\rho(\text{“}h\text{”}, \text{“}v\text{”}) = (h, v)$. Similar to the argument in the proof of Proposition 1, 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 truthfuly reveals on the diagonal, and the other sender 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 $\sigma_1(\text{“}h\text{”}|(H, V)) = \sigma_2(\text{“}v\text{”}|(H, V)) = 1$, where the receiver's best response is $\rho(\text{“}h\text{”}, \text{“}v\text{”}) = (h, v)$. It is straightforward that in state (L, U) no sender has an incentive to deviate, so we specify the receiver's response to an irreconcilable message pair to ensure non-deviation in states (R, U) and (L, D). Given $\mu = (\mu_{LU}, \mu_{LD}, \mu_{RU})$, the receiver's expected payoffs are $U_R((\text{left, up})|\mu) = 50\mu_{LU} + 20(\mu_{RU} + \mu_{LD})$, $U_R((\text{right, up})|\mu) = 20\mu_{LU} + 50\mu_{RU}$, $U_R((\text{left, down})|\mu)) = 10\mu_{LU} + 50\mu_{LD}$, and $U_R((\text{right, down})|\mu) = 10(\mu_{RU} + \mu_{LD})$. For any μ, $U_R((\text{right, down})|\mu) < U_R((\text{left, up})|\mu)$. Thus, (right, down) is strictly dominated. Let the receiver take (left, up), (right, up) and (left, down) with respective probabilities p, q and $1 - p - q$ after an irreconcilable message pair. Then, Sender 1 in state (L, D) will have no incentive to tell that the state consists of R only if $20 \geqslant 15p + 60q + 20(1 - p - q)$ or $p \geqslant 8q$. Sender 2 in state (R, U) will have no incentive to tell that the state consists of D only if $20 \geqslant 15p + 20q + 60(1 - p - q)$ or $9p + 8q \geqslant 8$. Combining $p \geqslant 8q$ and $9p + 8q \geqslant 8$, we obtain $p \geqslant \frac{4}{5}$ as required. Similar to Game 2-2/M, other classes of strategy profiles cannot constitute an equilibrium so that $\sigma_1(``h"|(H,V)) = \sigma_2(``v"|(H,V)) = 1$ represent the unique strategy profiles that does.

$\square$

Proof of Corollary 1. To support the fully revealing equilibrium, the receiver's strategy after an irreconcilable message pair needs to put probability of at least $\frac{4}{5}$ on (left, up), so the out-of-equilibrium beliefs have to assign positive probability on (L,U). In an ε-perturbed game, after 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. Hence, there exists no $g = (g_1, g_2)$ 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 $\varepsilon^n \to 0$.

$\square$

Proof of Corollary 2. Since the first two class of fully revealing equilibria are free of out-of-equilibrium beliefs, they are robust. We provide an example of non-robust (third class) equilibrium in which both sender send "(h,v)" for state (H,V). It suffices to consider one inconsistent message pair. Let the equilibrium be supported by out-of-equilibrium beliefs that assign probability one to (L,U) after ("(right, down)", "(right, up)"); the receiver takes action (left, up) to deter deviations by Sender 1 in state (R,U) and 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.

$\square$

Proof of Corollary 3. All fully revealing equilibria are free of out-of-equilibrium beliefs.

$\square$

Appendix B - Translated Instruction for Game 2 (for Online Only; Not Intended for Publication)

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 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, she will receive 20, while Member A will receive 0 and Member B will receive 50 (top-right cell). Finally, if Member C chooses (right, down), she will receiver 0 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 state, Member A’s and Member B’s recommendations, Member C’s decision and your earnings. Click “Confirm” to proceed to the next round.

In addition, in some rounds you will be asked to make some “predictions.” Please follow the instructions on the screen. If you have any questions, please raise your hand, and the experimenter will come to answer.

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.

[38]The experimental instructions were accompanied by slide illustrations showing screen shots in Appendix D.

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 - Tables and Figures (for Online Only; Not Intended for Publication)

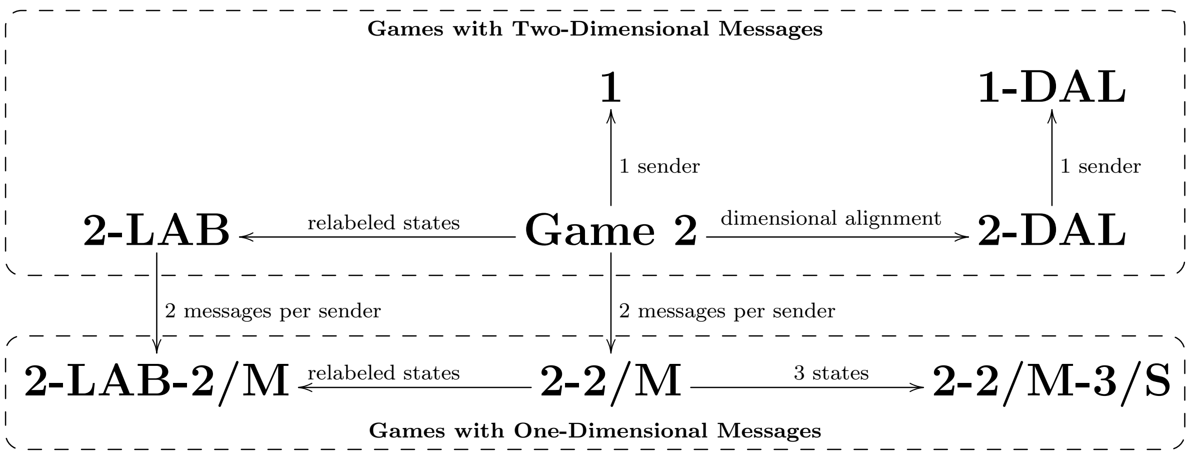


Figure 11: Experimental Design

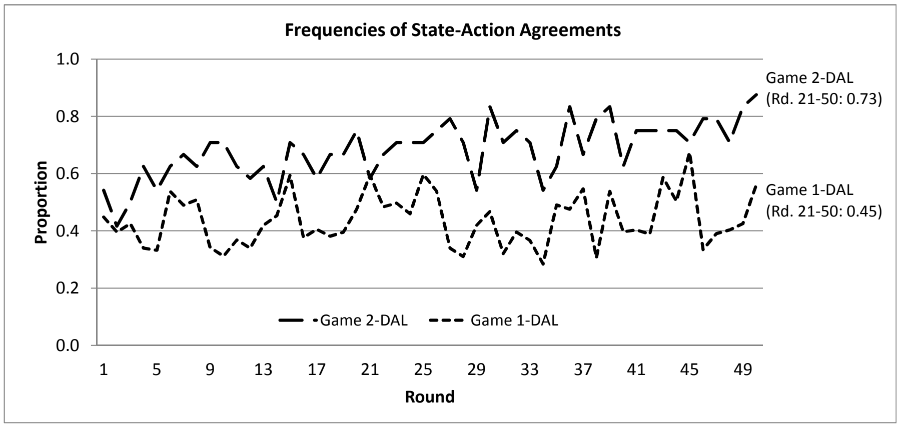
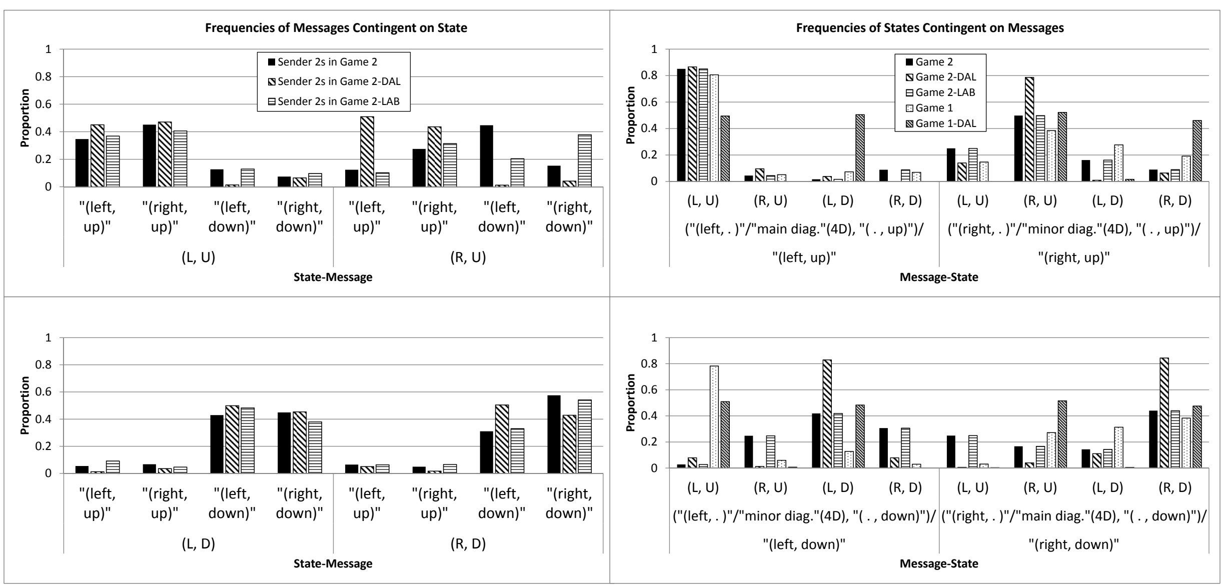


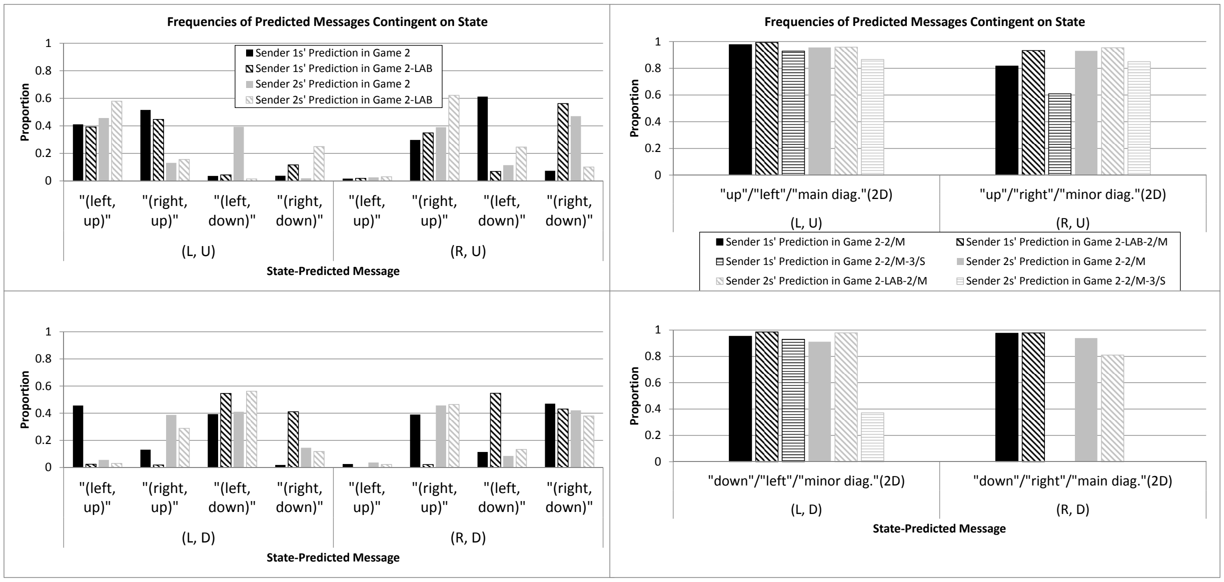
Figure 12: Frequencies of State-Action Agreements: Games 2-DAL and 1-DAL



(a) Frequencies of Messages Contingent on State (Sender 2s)

(b) Frequencies of States Contingent on Message Pairs

Figure 13: Sender 2s' Strategies in Games 2, 2-DAL, and 2-LAB, and Conditional Distributions of States Implied by Message Uses in All Two-Dimensional Message Games



(a) Frequencies of Predicted Messages Contingent on State: Games 2 and 2-LAB

(b) Frequencies of Predicted Messages Contingent on State: Games 2-2/M, 2-LAB-2/M, and 2-2/M-3/S

Figure 14: Senders' Predictions of the Other Sender's Messages

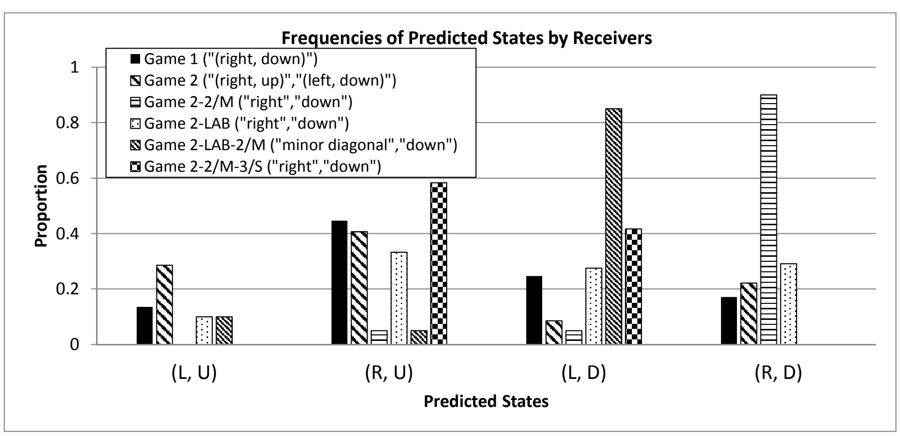


Figure 15: Receivers' Predictions of State Contingent on Messages

Table 3: Summary Statistics

		Rounds	(1) Game 1	(2) Game 1-DAL	(3) Game 2	(4) Game 2-DAL	(5) Game 2-2/M	(6) Game 2-2/M-3/S	(7) Game 2-LAB	(8) Game 2-LAB-2/M
	A. Frequencies of State-Message Agreements									
(1)	Sender 1 State-Message $(H,.) \rightleftarrows$ "$(h,.)$"	$1-20$	0.76	**0.95**	**0.72**	**0.87**	**0.88**	**0.77**	0.61	–
		$21-50$	0.69	**0.99**	**0.77**	**0.89**	**0.96**	**0.77**	0.60	–
		$41-50$	0.69	**0.99**	**0.83**	**0.93**	**0.99**	**0.77**	0.55	–
(2)	Sender 1 State-Message $(.,V) \rightleftarrows$ "$(.,v)$"	$1-20$	0.48	0.45	0.53	0.49	–	–	0.49	–
		$21-50$	0.58	0.50	0.50	0.39	–	–	0.50	–
		$41-50$	0.62	0.44	0.51	0.35	–	–	0.43	–
(3)	Sender 1 State-Message $(H,V)\nwarrow\searrow$"(h,v)"	$1-20$	–	–	0.52	0.53	–	–	**0.68**	**0.88**
		$21-50$	–	–	0.59	0.44	–	–	**0.72**	**0.92**
		$41-50$	–	–	0.62	0.38	–	–	**0.70**	**0.94**
(4)	Sender 2 State-Message $(H,.) \rightleftarrows$ "$(h,.)$"	$1-20$	–	–	0.61	0.45	–	–	0.56	–
		$21-50$	–	–	0.51	0.47	–	–	0.60	–
		$41-50$	–	–	0.47	0.50	–	–	0.62	–
(5)	Sender 2 State-Message $(.,V) \rightleftarrows$ "$(.,v)$"	$1-20$	–	–	**0.78**	**0.89**	**0.83**	**0.75**	**0.78**	**0.83**
		$21-50$	–	–	**0.75**	**0.94**	**0.91**	**0.72**	**0.73**	**0.94**
		$41-50$	–	–	**0.75**	**0.93**	**0.94**	**0.73**	**0.74**	**0.96**
	B. Frequencies of Message-Action Agreements									
(1)	Sender 1 Message-Action $(H,.) \rightleftarrows$ "$(h,.)$"	$1-20$	0.85	**0.86**	**0.75**	**0.85**	**0.96**	**0.77**	0.61	–
		$21-50$	0.79	**0.89**	**0.82**	**0.91**	**0.98**	**0.78**	0.56	–
		$41-50$	0.78	**0.92**	**0.83**	**0.93**	**0.99**	**0.77**	0.54	–
(2)	Sender 1 Message-Action $(.,V) \rightleftarrows$ "$(.,v)$"	$1-20$	0.45	0.58	0.47	0.51	–	–	0.47	–
		$21-50$	0.48	0.54	0.50	0.43	–	–	0.52	–
		$41-50$	0.48	0.62	0.51	0.42	–	–	0.49	–
(3)	Sender 1 Message-Action $(H,V)\nwarrow\searrow$"(h,v)"	$1-20$	–	–	0.53	0.53	–	–	**0.76**	**0.90**
		$21-50$	–	–	0.56	0.47	–	–	**0.80**	**0.97**
		$41-50$	–	–	0.58	0.45	–	–	**0.83**	**0.99**
(4)	Sender 2 Message-Action $(H,.) \rightleftarrows$ "$(h,.)$"	$1-20$	–	–	0.48	0.50	–	–	0.57	–
		$21-50$	–	–	0.48	0.48	–	–	0.62	–
		$41-50$	–	–	0.46	0.48	–	–	0.62	–
(5)	Sender 2 Message-Action $(.,V) \rightleftarrows$ "$(.,v)$"	$1-20$	–	–	**0.76**	**0.89**	**0.94**	**0.75**	**0.75**	**0.93**
		$21-50$	–	–	**0.78**	**0.92**	**0.97**	**0.74**	**0.80**	**0.99**
		$41-50$	–	–	**0.83**	**0.92**	**0.98**	**0.74**	**0.78**	**1.00**
	C. Frequencies of State-Action/State-Message-Action Agreements									
(1)	State-Action $(H,.) \rightleftarrows (h,.)$	$1-20$	0.71	0.82	0.63	0.76	0.85	0.71	0.58	0.69
		$21-50$	0.64	0.89	0.69	0.83	0.94	0.75	0.61	0.84
		$41-50$	0.64	0.91	0.76	0.88	0.98	0.78	0.62	0.89
(2)	State-Action $(.,V) \rightleftarrows (.,v)$	$1-20$	0.55	0.51	0.68	0.81	0.79	0.72	0.67	0.77
		$21-50$	0.56	0.50	0.66	0.86	0.89	0.75	0.64	0.93
		$41-50$	0.51	0.50	0.72	0.87	0.92	0.77	0.65	0.96
(3)	State-Action $(H,V) \rightleftarrows (h,v)$	$1-20$	0.39	0.42	0.44	0.62	0.68	0.60	0.45	0.65
		$21-50$	0.39	0.45	0.48	0.73	0.84	0.67	0.46	0.84
		$41-50$	0.38	0.47	0.58	0.77	0.91	0.71	0.46	0.89
(4)	State-Message-Action $(H,V) \rightleftarrows (h,v)$ ("$(h,.)$", "$(.,v)$")	$1-20$	–	–	0.35	0.59	0.67	0.50	–	–
		$21-50$	–	–	0.39	0.71	0.84	0.50	–	–
		$41-50$	–	–	0.47	0.76	0.91	0.52	–	–

Note: For Game 2-2/M and 2-2/M-3/S, "$(h,.)$" is used for "h" and "$(.,v)$" for "v". $(H,V)\nwarrow\searrow$"(h,v)" represents diagonal agreements. The numbers in **bold** indicate equilibrium-relevant dimensions.

Appendix D - Original Instructions in Chinese and Screen Shots (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」，他自己會得到法幣 20 元的報酬，成員甲獲得到法幣 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 0 元，成員甲獲得法幣 10 元，成員乙則獲得法幣 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。

另外，某些回合會請你做一些「預測」，請按照螢幕上的指示去做。如果有問題，請當場舉手，實驗者會過來解答。

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。

Figure 16: Sender 1 in Game 2 recommending left/right when the true state is (L, U)

Figure 17: Receiver in Game 2 choosing action after Sender 1 recommends (left, down) and Sender 2 (right, up)