

# Multidimensional Cheap Talk with Transparent Motives\*

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## Abstract

We consider how the transparency of an expert's motives affects the credibility and informativeness of multidimensional cheap talk such as coverage of different topics by a biased news network, or discussion of different product attributes by a biased salesperson. When the expert's motives are sufficiently transparent, we find that the expert can always reveal comparative information across dimensions. For linear preferences, which we show are a natural way to represent very large biases within and across dimensions, the expert can use comparative statements to reveal all information in all but one dimension. When motives are not transparent, communication possibilities contract. Using novel techniques, the model generates results on the informativeness of biased media, the implicit costs of negative advertising, the informational efficiency of voting rules, and the revenue gains from auction disclosure.

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# 1 Introduction

Experts are often biased. Political analysts are biased toward certain candidates, salespeople receive different commissions on different products, and media outlets benefit from emphasizing particular issues. Suspicion over the advice of a biased expert is clearly warranted, but if the expert’s biases are known it seems that a decision maker should be able to “see through” the biases and still obtain useful information. This idea that transparency facilitates communication has motivated the regulation of expert advice in a wide range of areas, including requirements that investment advisors reveal any conflicts of interest, that lobbyists reveal their clients, and that political advertisements contain statements of approval by candidates.<sup>1</sup> As the Federal Communications Commission has argued, “... the public is entitled to know by whom it is persuaded” (Coase, 1979).

Despite these efforts to increase transparency, doubts remain whether transparency can ensure adequate communication and many reforms go further to directly restrict the role of biased experts or change their incentives. For instance, investment banks are required to insulate their stock analysts from conflicting interests, and issue groups are restricted in their ability to directly advertise for or against political candidates.<sup>2</sup> This question of whether transparency alone is effective arises in almost every field where expert advice is important. For instance, while many medical journals now require authors to reveal any financial conflicts of interest, some journals go further to restrict publication of articles by authors with conflicting interests (Drazen and Curfman, 2002).

To investigate the effects of transparency on communication, we consider costless, unverifiable “cheap talk” by a potentially biased expert to a decision maker (Crawford and Sobel, 1982). We are interested in environments where the expert has multidimensional information, e.g., a news network has information on different political issues, or a lobbyist has information on different spending projects. With multidimensional information, even if the expert has a strict preference ordering over the decision maker’s actions in each dimension, e.g., always prefers the decision maker to take the highest action, the expert will not have a strict ordering over all action profiles if preferences are continuous. Therefore an expert might be able to credibly reveal information that trades off higher actions on one dimension for lower actions

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<sup>1</sup>These requirements follow respectively from the Securities Exchange Act of 1934, the Lobbying Disclosure Act of 1995, and the Bipartisan Campaign Reform Act of 2002.

<sup>2</sup>The former restriction is required by the Securities Exchange Act of 1934 and subsequent regulations, while the latter restriction is a contested provision of the Bipartisan Campaign Reform Act of 2002.

on another dimension. Chakraborty and Harbaugh (2007) show conditions under which this is possible when the expert is sufficiently unbiased across dimensions, e.g., a stock analyst with equal incentives to promote two stocks indicates which one is better.

We consider the credibility and informativeness of cheap talk when the expert can have arbitrarily large biases across dimensions and there might be uncertainty about these biases. For instance, is a news network concerned primarily with increasing viewership or does it also have a political bias towards one party and, if so, which one? We call situations without uncertainty about the expert’s “motives” (preferences over actions) the case of full transparency, and say that motives are less transparent the greater the number of motives that are considered possible. We look for cheap talk equilibria where the decision maker adjusts his interpretation of the expert’s statement to filter out the effect of possible biases across dimensions, and the expert rationally anticipates this adjustment.

We show that influential and informative cheap talk equilibria exist as long as the expert’s motives are sufficiently transparent and continuous. This result, which uses the Borsuk-Ulam Theorem, holds regardless of any biases across dimensions and any other asymmetries or correlations in priors. The equilibria we consider involve the expert partitioning the multidimensional space so as to create trade-offs between messages that eliminate the incentive to misreport. In equilibrium, the decision maker is less influenced by the expert on the dimensions that the expert is known to care more about, so the expert’s incentive to boost a favored dimension is eliminated.

How much information can be revealed in equilibrium? Even if the expert has a strong incentive to exaggerate within each of  $N$  dimensions, there is always an  $N - 1$  dimensional subspace over which the expert has no incentive to deceive the decision maker. Therefore, full revelation on these  $N - 1$  “dimensions of agreement” may be possible if the preference ordering is known, i.e., there is full transparency.<sup>3</sup> With linear preferences we show that this limit is always attainable even with arbitrary distributions and arbitrary biases across dimensions through repeated subdivision of the state space into smaller regions. Such communication, which can be either simultaneous or sequential, reveals detailed comparative information across dimensions. Similar detailed cheap talk is also possible for preferences that are strictly quasi-convex (or quasi-concave), typically by using mixed strategies over messages with a resultant

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<sup>3</sup>Full transparency implies that the expert’s preferences over actions are common knowledge / state-independent in that they do not depend on the private information of the expert about the state of the world. In the context of state-dependent preferences, the idea of a dimension of agreement is introduced by Battaglini (2002) and developed further in Levy and Razin (2007).

loss in information.

When the expert's motives are less transparent, communication possibilities contract. If  $T$  is the number of possible expert motives, then there is only an  $N - T$  dimensional subspace on which the decision-maker and the different expert types are sure to agree. For linear preferences, we show that the expert can reveal all information on these  $N - T$  dimensions of agreement. More generally, even if all information cannot be revealed, it is always possible to reveal some information as long as  $T < N$ . In particular, there always exists a two-message influential cheap talk equilibrium with actions on the dimensions of agreement in which each message is sent with probability at least  $1/(N + 1)$ , a bound that rises to  $1/e$  under a standard logconcavity distributional assumption, and that rises all the way to  $1/2$  if  $N - T > 1$ .

If the expert's motives are insufficiently transparent,  $T \geq N$ , there is no longer a shared dimension of agreement among all players so there does not in general exist an equilibrium where all types of the expert are informative. If the probability of the extra types is sufficiently low, under mild regularity conditions an equilibrium will still exist in which the low probability types are uninformative. More generally, additional restrictions on preferences and distributions will be required to ensure communication. This is the case in Chakraborty and Harbaugh (2007) who consider a multidimensional version of the Crawford-Sobel model in which the expert's preferences are supermodular in the state and the action, i.e., the expert wants a higher action in a dimension when the state is higher in that dimension. The expert's and decision maker's incentives are therefore aligned across dimensions as long as the environment is sufficiently symmetric, so communication is possible even though the sender's motives are different for every state of the world.<sup>4</sup>

Our model with a finite set of motives best fits situations where the expert has a strong incentive to exaggerate (upwards or downwards) in each dimension regardless of the true state of the world, so that the main uncertainty is whether the expert is biased across dimensions. In particular, linear preferences are the limiting case of standard Euclidean preferences as the bias in each dimension becomes large. Since there is always an equilibrium for linear preferences, this implies the existence of an informative cheap talk equilibrium *at* the limit of an infinitely biased expert with Euclidean preferences. Since the convergence is uniform, it also implies the existence of an approximate or  $\varepsilon$ -equilibrium (Radner, 1981) for Euclidean preferences with sufficiently large biases, i.e., communication is possible as long as there is any non-zero cost

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<sup>4</sup>Levy and Razin (2007) show that sufficient asymmetries in preferences and distributions can sometimes preclude communication even in environments where supermodularity is satisfied. We discuss their results further in Section 5.

to lying. Indeed, the set of such “ $\varepsilon$ –cheap talk equilibria” converges to the set of cheap talk equilibria for the corresponding linear preferences with the ratio of biases equal to the expert’s bias across dimensions.

Since all information can be revealed on  $N - 1$  dimensions for linear preferences under perfect transparency, the same is true for the limiting case of Euclidean preferences with large but known biases. Similarly, if the biases are unknown and can take  $T < N$  possible values, then all information can be revealed in  $N - T$  dimensions for Euclidean preferences with large but unknown biases. These results provide a bridge between the assumption of our model that the expert’s preferences are (nearly) state-independent, and the more common assumption in the literature that preferences are (highly) state-dependent. More importantly, they confirm that the degree of transparency of the expert’s bias across dimensions is central to understanding communication in environments with large biases in each dimension.

The effect of transparency on communication in multidimensional environments is distinct from that in one-dimensional environments. In Crawford and Sobel’s canonical model the expert prefers an action that differs from the true state of the world by the expert’s bias, and informative cheap talk is only possible with a known bias if the bias is sufficiently small. Morgan and Stocken (2003) consider this model when the expert might be biased or not, Dimitrakas and Sarafidas (2004) allow for a continuum of possible biases, Li and Madarasz (2006) allow for the direction of the bias to be uncertain as well, and Gordon (2006) allows for the bias to be state-dependent.<sup>5</sup> Since knowledge of the bias helps or hurts communication depending on the size of the bias that is revealed, the overall effect of transparency about the bias need not be positive in these models. Our results differ from this literature because there is greater potential for communication in multidimensional environments and because our definition of transparency applies to the expert’s preferences over actions, not just to the expert’s biases.

Despite these benefits from transparency, the equilibria we consider do not fully reveal the expert’s information so there remains room for stronger policy measures that attempt to modify or eliminate biases. Similarly there remains room for other factors that we have not modeled to affect communication, e.g., multiple periods (Sobel, 1985; Benabou and Laroque, 1992; Morris, 2001; Gentzkow and Shapiro, 2006; Ottaviani and Sørensen, 2006) and multiple

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<sup>5</sup>Also in one-dimensional environments, Lyon and Maxwell (2004) analyze transparency of the expert’s bias in an environment with costly signals, Inderst and Ottaviani (2007) consider the transparency of a salesperson’s endogenous commission structure, and the central banking literature examines the transparency of central bank policy, e.g., Moscaroni (2007). Note that in the literature on decision making in committees, “transparency” refers to the separate issue of rules about the openness of committee deliberations, e.g., Levy (2007).

competing experts (Gilligan and Krehbiel, 1989; Austen-Smith, 1993; Krishna and Morgan, 2001; Battaglini, 2002; Mullainathan and Shleifer, 2006; Ambrus and Takahashi, 2006; Gick, 2006; Visser and Swank, 2007).

In Section 2 we provide two examples that illustrate the main results. In Section 3 we construct informative cheap talk equilibria for general continuous preferences. In Section 4 we use these results to construct highly informative equilibria for linear preferences. Section 5 then applies the linear preferences results to analyze  $\varepsilon$ -cheap talk equilibria for Euclidean preferences with large biases. Section 6 concludes while the Appendix contains all proofs.

## 2 Motivating Examples

We start with two motivating examples that illustrate the applicability of the analysis and provide insight into our three main propositions and related results. Further examples in Sections 3 and 4 show how the expert can benefit from cheap talk, how the results are robust to small uncertainties, and how the expert can use mixed messages to convey detailed information.

### Example 1 *Media Bias*

Consider a news network which reports on two political scandals. The network knows the seriousness of the scandals, represented by the random variables  $\theta_1$  and  $\theta_2$ , but the audience only knows the ex ante distributions which are uniform i.i.d. on  $[0, 1]$ . Audience estimates of the seriousness of the scandals given a message  $m$  are represented by “actions”  $a_1 = E[\theta_1|m]$  and  $a_2 = E[\theta_2|m]$ . To boost ratings the network might want to promote belief in the seriousness of either scandal, and for partisan reasons the network might want to exaggerate one of the scandals in particular.<sup>6</sup> We represent these possible preferences for the network by the utility function  $U = \lambda_1 a_1 + \lambda_2 a_2$  where the weights  $\lambda_i$  capture any partisan bias across dimensions.

When only the ratings bias is present,  $\lambda_1 = \lambda_2$ , if the network “plays up” one of the scandals the audience has no reason to doubt that the scandal is more serious. To see how communication is still credible even with an extreme partisan bias that is transparent, consider the left panel of Figure 1 which shows the network’s indifference curves for different action pairs over the state/action space when  $U = 4a_1 + a_2$ , i.e., the network particularly wants to exaggerate the first scandal. We are interested in a cheap talk equilibrium where the space is

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<sup>6</sup>According to a 2005 survey by the Pew Research Center, most respondents believe that news organizations care more about “Attracting biggest audience” than “Keeping public informed,” and that they “Favor one side in politics.”

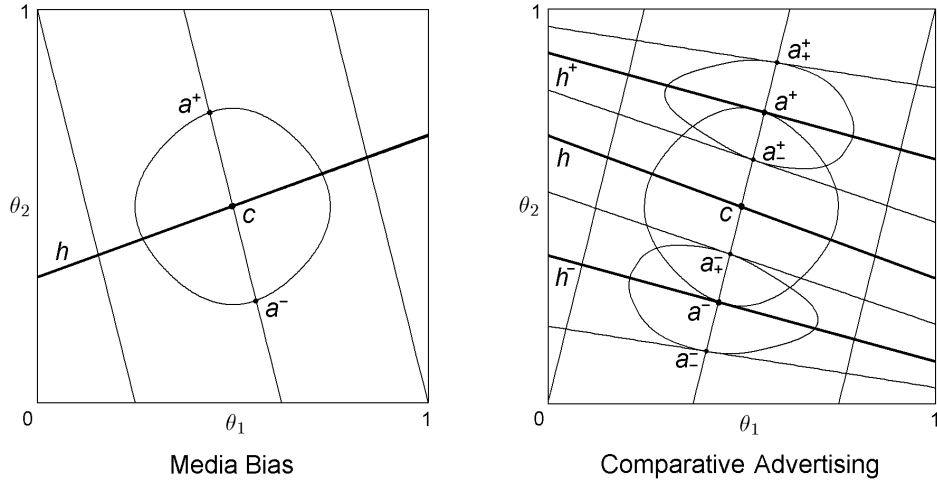


Figure 1: Cheap talk equilibria.

partitioned into two regions with an “announcement line”  $h$  and the network’s message  $m^+$  or  $m^-$  indicates which region the variables fall in. When  $h$  is such that the pairs of expected values  $a^+ = (E[\theta_1|m^+], E[\theta_2|m^+])$  and  $a^- = (E[\theta_1|m^-], E[\theta_2|m^-])$  for the two regions are on the same indifference curve the network has no incentive to lie about which region  $\theta$  falls in, so the announcement line is an equilibrium.

As the announcement line is spun around  $c = (\frac{1}{2}, \frac{1}{2})$  from vertical to vertical again, the actions for the two regions trace out the “circular” path shown in the figure.<sup>7</sup> Since the actions reverse themselves as the announcement line is rotated continuously, and since preferences are continuous, at some intermediate point the actions must fall on the same indifference curve, i.e., an equilibrium must exist. In equilibrium, the messages balance out the network’s incentives on each dimension so that any incentive to lie is eliminated. Clearly this result depends on the audience knowing the network’s bias. Theorem 1 uses the Borsuk-Ulam theorem (a multidimensional version of the intermediate value theorem)<sup>8</sup> to show how this construction

<sup>7</sup>For instance, with a vertical announcement line and message  $m^+$  corresponding to the left region and  $m^-$  to the right region, the actions are  $a^+ = (E[\theta_1|\theta_1 < \frac{1}{2}], E[\theta_2]) = (\frac{1}{4}, \frac{1}{2})$  and  $a^- = (E[\theta_1|\theta_1 \geq \frac{1}{2}], E[\theta_2]) = (\frac{3}{4}, \frac{1}{2})$ . When the announcement line is rotated to the 45 degree line the actions are  $a^+ = (E[\theta_1|\theta_1 < \theta_2], E[\theta_2|\theta_1 < \theta_2]) = (\frac{1}{3}, \frac{2}{3})$  and  $a^- = (E[\theta_1|\theta_1 \geq \theta_2], E[\theta_2|\theta_1 \geq \theta_2]) = (\frac{2}{3}, \frac{1}{3})$ .

<sup>8</sup>Most famously, in three dimensions the theorem implies that there are two antipodal points on the globe where both temperature and barometric pressure are identical if both variables vary continuously over the earth’s surface. The theorem also implies Brouwer’s fixed point theorem and the Ham-Sandwich theorem (Matousek, 2003).

depends on the transparency of preferences and to generalize it to more dimensions and to all continuous preferences and well-behaved distributions.  $\square$

**Example 2** *Comparative Advertising*

Now consider how this analysis can be applied to a cheap talk model of advertising,<sup>9</sup> and in particular how the above equilibrium can be used as a building block to reveal detailed information. Let  $p(a)$  be the probability that a product is purchased and assume that an advertiser wants to maximize this probability,  $U = p(a)$ . The right panel of Figure 1 shows preferences  $U = p(a) = 4a_1 - a_2$ , e.g., to maximize sales, an advertiser wants to raise consumer impressions of the quality of its product and to lower consumer estimates of the quality of a competing product.<sup>10</sup> The announcement line  $h$  is for a single comparative message corresponding to the upper and lower regions with equilibrium actions  $a^+$  and  $a^-$ . To reveal more information we can follow the same procedure for the upper region to spin a new announcement line  $h^+$  around  $a^+$ , and also follow the same procedure for the lower region to spin a new announcement line  $h^-$  around  $a^-$ . The resulting actions for the top region are then  $a_+^+$  and  $a_-^+$ , and for the lower region are  $a_+^-$  and  $a_-^-$ . Clearly we can continue to follow the same procedure to further subdivide each new region without limit (the figure shows one additional set of subdivisions), so that the space can be divided into arbitrarily fine slices corresponding to distinct messages.

In equilibrium the actions for each message, i.e., the expected values of  $\theta$  for each slice, must be on the same indifference curve. This is the case in the figure and Theorem 2 shows generally that, if preferences are linear and transparent, it is always possible to use this construction to ensure that this condition holds. The indifference curves are upward sloping in this example, so the equilibrium condition implies that “positive advertising” about the advertiser’s product improves consumer impressions of both products, while “negative advertising” about the competing product worsens consumer impressions of both products. This pattern has been observed empirically in political advertising (Lau et al., 1999) and consumer product advertising (Jain 1993; Jain and Posovac, 2004).

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<sup>9</sup>This cheap talk model is distinguished from signaling models of advertising where the credibility of advertising depends on its cost, and from disclosure/persuasion game models where any information revealed is verifiable (Anderson and Renault, 2006; Polborn and Yi, 2006).

<sup>10</sup>Alternatively the dimensions could represent different attributes, positive or negative, of the advertiser’s product. The linear purchase probability function used in this example is standard in the marketing literature on multi-attribute attitudes, e.g., Green and Srinivasan (1978). As shown in related contexts in Examples 3 and 4, heterogeneity in consumer preferences can create non-linearities.

This example assumes that the advertiser’s preferences are linear. A natural interpretation of linear preferences is that the expert has a strong bias toward exaggerating (favorably or unfavorably) in each dimension without regard for the truth. Theorem 3 confirms this interpretation by showing that linear preferences are the limiting case of standard Euclidean preferences as the biases within each dimension become arbitrarily large.  $\square$

### 3 Informative Cheap Talk

A sender (a.k.a. expert) is privately informed about the ideal actions  $\theta \in \Theta$  of a receiver (a.k.a. decision maker) where  $\Theta$  is a compact convex subset of  $\mathbb{R}^N$  with a non-empty interior  $\text{int}(\Theta)$  and  $N \geq 2$ .<sup>11</sup> She sends advice in the form of a cheap talk message  $m$  from an arbitrary set  $\mathbf{M}$  to an uninformed receiver whose prior beliefs about  $\theta$  are summarized by a joint distribution  $F$ . The distribution is well-behaved in that it admits a continuous density  $f$  that has full support on  $\Theta$ . The receiver then chooses actions  $a \in \mathbf{A} \equiv \Theta$  equal to  $E[\theta|m]$ , the expected value of  $\theta$  given his priors and the sender’s message  $m$ . This standard behavioral assumption for the receiver reflects underlying preferences for estimating the state  $\theta$  as precisely as possible.

The sender’s motives (i.e., preferences over receiver actions  $a$ ), are described by a continuous utility function  $U(\cdot; t) : \mathbf{A} \rightarrow \mathbb{R}$ , where  $t \in \mathbf{T}$  indexes the privately known sender type. In most of the literature on cheap talk games it is assumed that  $\mathbf{T} = \Theta$ . In contrast, we find it useful to draw a distinction between  $t$  and  $\theta$ , i.e., between uncertainty about the sender’s motives and uncertainty about the receiver’s ideal course of action.<sup>12</sup> We focus on the case where  $\mathbf{T}$  is a finite set with  $T \geq 1$  elements. In the case  $T = 1$ , the sender’s preferences are known by the receiver with certainty so her motives are perfectly transparent.<sup>13</sup> In contrast, when  $T > 1$ , the sender’s motives are imperfectly transparent, and possibly correlated with or a function of the state  $\theta$ .

An (announcement) strategy for a sender with motives  $t$  specifies a probability distribution over messages in  $\mathbf{M}$  as a function of the state  $\theta$ . An announcement strategy is *partitional* if

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<sup>11</sup>The compactness assumption is not used in Theorem 1 nor the first half of Theorem 2. It is necessary for the second half of Theorem 2 and it simplifies the statement and proof of Theorem 3.

<sup>12</sup>Relatedly, in one-dimensional models, Sobel (1985), Benabou and Laroque (1992), Morris (2001), Morgan and Stocken (2003), Dimitrakis and Sarafidis (2004), Li and Madarasz (2006), and Gordon (2006) consider cases where there is uncertainty about the sender’s bias in addition to uncertainty over the receiver’s ideal course of action. We differ in that in our paper a sender’s type fully specifies the sender’s preferences over actions.

<sup>13</sup>This corresponds to the case of known, state-independent sender preferences, and is particularly salient in view of our applications.

the inverse image of messages used with positive probability constitutes a partition of  $\Theta$  (e.g., any pure strategy). Such a partition is convex if each element of the partition is a convex set. In this paper we focus, for the most part, on convex partitional announcement strategies for the sender.<sup>14</sup> Such a strategy is created by “straight line cuts”, i.e., by the intersections of half-spaces created by hyperplanes and  $\Theta$ .

Given the specification of receiver behavior, a (perfect Bayesian) equilibrium of the cheap talk game is fully specified by an announcement strategy for each sender type.<sup>15</sup> We say that the sender with motives  $t$  induces an action  $a = E[\theta|m]$  in equilibrium if her announcement strategy chooses the message  $m$  with positive probability. In any equilibrium, every action induced by the sender with motives  $t$  must maximize  $U(\cdot; t)$ .

An equilibrium is influential if there are at least two different actions chosen by the receiver with strictly positive (ex-ante) probability, i.e., the sender uses at least two different messages with distinct (equilibrium) meanings. We use the term  $k$ -message equilibrium to refer to the case where the receiver chooses  $k$  different actions, i.e., the sender uses messages with  $k$  distinct equilibrium meanings.

We concentrate on equilibria where the sender uses the same partition of  $\Theta$ , regardless of her motives  $t$ . Such equilibria are independent of the prior beliefs of the receiver about the conditional distribution of  $t$  on  $\theta$ . This last fact allows us to think about transparency entirely in terms of  $T$ , the cardinality of the set of possible sender motives.

**Theorem 1** *Suppose  $T < N$ . An influential cheap talk equilibrium exists for all  $U$  and all  $F$ .*

We prove Theorem 1 by considering a partition created by a single hyperplane  $h$  passing through any point  $c \in \text{int}(\Theta)$  that divides  $\Theta$  into two non-empty convex regions,  $R^+(h)$  and  $R^-(h)$ . We identify the orientation of such an announcement hyperplane by  $s$ , a point on the unit sphere  $\mathbb{S}^{N-1}$ . Since the expected values of  $\theta$  for each of the two regions vary continuously with  $s$ , whenever  $T < N$  we can use the Borsuk-Ulam theorem to find a hyperplane  $h^*$  through  $c$ , and corresponding actions  $a^+ = E[\theta|\theta \in R^+(h^*)]$  and  $a^- = E[\theta|\theta \in R^-(h^*)]$ ,  $a^+ \neq a^-$ , such that  $U(a^+, t) = U(a^-, t)$  for each  $t$ . Each sender type induces each of the two actions in any such equilibrium, and the sender’s message can be interpreted to be disclosing in which direction ( $s$  or  $-s$ ) the true state  $\theta$  stands in relation to the reference state  $c$ .

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<sup>14</sup>Lemma 1 in Crawford and Sobel (1982) shows that all equilibria are partitional, a fact that does not extend to our setup.

<sup>15</sup>We assume that all messages in  $\mathbf{M}$  are used in equilibrium, and accordingly avoid specifying off-the-path beliefs. This is without loss of generality in any cheap talk game.

The simplest case of perfect transparency provides the clearest intuition. In this case, if  $N = 1$  and  $\Theta$  is an interval,  $h$  would just be a point that divides the interval into two regions. If preferences are continuous then the intermediate value theorem implies an equilibrium exists if and only if the expert switches which of the two actions associated with each region is preferred as  $h$  varies over the interval. Such a “switching condition” cannot be satisfied, for example, by monotonic preferences.<sup>16</sup> In contrast, in our case with  $N > 1$ , the announcement hyperplane can be spun around in a continuous manner so that the actions reverse themselves, implying that the switching condition is always satisfied if preferences are continuous. As the number of dimensions  $N$  increases the number of different ways that the announcement hyperplane can be rotated increases, and the Borsuk-Ulam theorem implies it is possible to find a hyperplane that simultaneously keeps multiple types indifferent provided only that the number of equations is not more than the number of unknowns, i.e.,  $T < N$ .

Theorem 1 formalizes the intuition that influential cheap talk is easier to sustain whenever the sender’s motives are sufficiently transparent relative to the richness of her information, i.e., whenever  $T < N$ . Indeed, if one considers two instances of the model that differ only in the set of possible sender motives  $\mathbf{T}$  and  $\mathbf{T}'$  with  $\mathbf{T}' \subset \mathbf{T}$ , then every equilibrium characterized by Theorem 1 when there are  $T$  possible motives is also an equilibrium when there are  $T' < T$  possible motives, but not the converse. In this sense, greater transparency facilitates influential communication, independently of the precise specification of these motives and regardless of asymmetries and correlations.

Since the regions are convex, the equilibrium actions are contained in each region and therefore distinct,  $a^+ \neq a^-$ , and the equilibrium is influential. The value of cheap talk is still limited if only one of the messages is typically ever sent, implying the equilibrium is not informative. This is not an issue because, for any  $f$ , if  $c = E[\theta]$  then the probability mass of each half-space is at least  $1/(N + 1)$  (Grunbaum, 1960), so each equilibrium action is chosen with at least this probability. For logconcave  $f$  this lower bound can be raised considerably to  $1/e$  for any  $N$  (Caplin and Nalebuff, 1991). If  $N - T > 1$ , then there is extra freedom to choose an equilibrium hyperplane so as to maximize informativeness. In particular, it can be shown by the Borsuk-Ulam theorem that, for any  $c$ , an influential cheap talk equilibrium exists in which each equilibrium action is chosen with ex ante probability of  $1/2$ .

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<sup>16</sup>In the standard version of Crawford and Sobel (1982), this switching condition is generated by a sufficiently small conflict of interest (or bias) parameter, implying that for sufficiently low states the sender prefers a lower action to a higher action, and vice versa for sufficiently high states. Since  $\mathbf{T} = \Theta$ , a single-crossing condition is also required to ensure that non-indifferent types have the right incentives.

The receiver always benefits from communication because he can make a more accurate estimate of  $\theta$ . The next two examples show how the sender can benefit as well.

**Example 3** *Persuading Voters*

In the equilibrium of Theorem 1, the messages induce a mean-preserving spread in the actions  $a_i$  relative to remaining silent or “babbling”.<sup>17</sup> It follows that the expert gains (loses) from communication if  $U$  is a quasi-convex (quasi-concave) function of  $a$ . In some situations quasi-concavity/quasi-convexity emerges naturally from the structure of the problem. Consider a President addressing Congress prior to a vote on a bill to authorize, say, a war. Suppose that  $N = 2$  and that  $\theta_1$  and  $\theta_2$  are two different arguments in favor of the bill, each of which is more likely to convince a different voting bloc or faction, with  $a_i = E[\theta_i|m]$  the probability that bloc  $i = 1, 2$  will vote in favor in some non-cooperative voting game to follow the President’s speech. Let  $p(a)$  be the probability that the bill is passed. Assume that  $T = 1$  and  $U = p(a)$ , so that the President wants to maximize the probability of obtaining approval from Congress regardless of the merits  $\theta$  of the bill.

We contrast two different scenarios. In the *Or* scenario, the President needs the support of either bloc to win so the probability of passage is given by the quasi-convex function  $p(a) = a_1 + a_2 - a_1a_2$ , implying the President benefits from communication. In the *And* scenario, the President needs the support of both blocs to win so the probability of passage is given by the quasi-concave function  $p(a) = a_1a_2$ , implying the President prefers to not reveal which argument is stronger, i.e., prefers the babbling equilibrium. The differences in the scenarios can arise from such factors as differences in the President’s political strength in Congress, whether or not a simple or super majority is enough for passage and whether or not the bill needs bipartisan support. The left panel of Figure 2 shows the superimposed *Or* and *And* indifference curves for the symmetric i.i.d. uniform case and the actions corresponding to the announcement line for the two-message equilibrium. Theorem 1 shows that an influential equilibrium exists more generally, e.g., when one bloc is larger than another or there are more than two blocs.

More generally, this example sheds light on the effect of voting rules on information disclosure distinct from that previously considered in the literature. For instance, the unanimity rule for jury convictions has been criticized for discouraging information flows among informed

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<sup>17</sup>A babbling equilibrium in which the sender’s messages convey no information exists in any standard cheap talk game.

jurors and in particular for increasing the chance of a mistaken conviction (Feddersen and Pesendorfer, 1998). In our context of information flows from a third party to voters with heterogeneous interests, unanimity decreases (increases) the incentive to disclose if the informed party wants a positive (negative) vote. Therefore it encourages the defense to provide information in the form of a comparative statement that weakens the defendant's case in one dimension but strengthens it in another dimension, in the hope that at least one member of the jury will be persuaded to vote for acquittal. By the same token it discourages the prosecution from being informative, so unanimity benefits the defense. Moreover, if the defense is more likely than the prosecution to have private information, this also implies that the unanimity rule leads to more accurate decisions by the jury.  $\square$

**Example 4** *Persuading Bidders*

To see how Theorem 1 applies to a market environment, suppose a seller with information on  $N = 2$  attributes of a product communicates to  $n \geq 2$  potential buyers prior to holding a second-price auction. Buyers have correlated private values,  $v_j = \lambda_{j1}a_1 + \lambda_{j2}a_2$  where  $a_i = E[\theta_i]$  is the expected value of each attribute of the product and  $\lambda_{ji}$  represents the weight buyer  $j = 1, \dots, n$  attaches to attribute  $i$ . The seller knows the relevant attributes  $\theta$  of the object and, since buyers bid their expected values  $v_j$ , seeks to maximize the second-highest bid,  $U = 2^{nd} \max_j \{v_j\}$ . Since  $U$  is continuous in  $a$ , Theorem 1 implies the seller can always credibly communicate to buyers information about the relative strengths of the product. Since the seller must be indifferent between the equilibrium messages, the price the winner pays is unaffected by which attribute is highlighted, but the price is different from that when the seller is silent.

Communication increases the chance that the buyer who values the product the most bids the most for it, but the seller need not benefit from this gain in allocational efficiency if the information also softens competition by increasing the spread between buyer valuations.<sup>18</sup> Following the logic of the previous example, the effect on the seller's payoff is positive (negative) if the seller's payoff function is quasi-convex (quasi-concave). At one extreme, if there are at least two buyers with the same weights then  $2^{nd} \max_j \{v_j\} = \max_j \{v_j\}$ , a quasi-convex

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<sup>18</sup>The effect here is therefore distinct from the linkage principle (Milgrom and Weber, 1982) which shows that (committing to) a truthful disclosure policy intensifies competition and thereby increases seller revenues. Chakraborty, Gupta and Harbaugh (2006) apply the linkage principle in their analysis of credible disclosure policies in a common value environment with multiple goods. Here we are considering a private value auction of a single good with multiple attributes.

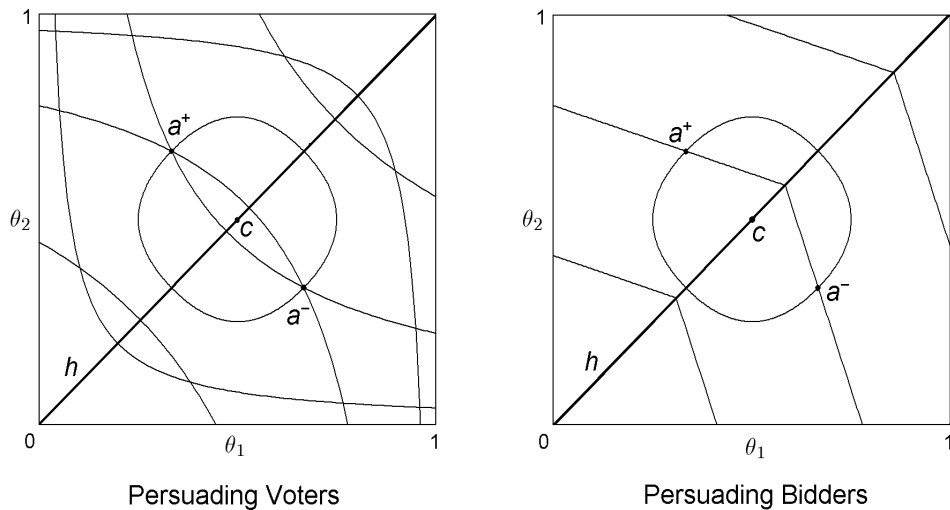


Figure 2: Gains from communication.

function, while at the other extreme if there are only two buyers and they have different weights then  $2^{nd} \max_j \{v_j\} = \min_j \{v_j\}$ , a quasi-concave function. The right panel of Figure 2 shows an intermediate case where there are four buyers with weights  $\lambda_1 = (0, 1)$ ,  $\lambda_2 = (\frac{1}{4}, \frac{3}{4})$ ,  $\lambda_3 = (\frac{3}{4}, \frac{1}{4})$ , and  $\lambda_4 = (1, 0)$  and the distribution of  $\theta$  is symmetric i.i.d. uniform. The seller can credibly disclose whether or not  $\theta_1 \geq \theta_2$ , which in either case implies the second highest bid is  $\frac{1}{4} \frac{1}{3} + \frac{3}{4} \frac{2}{3} = \frac{7}{12}$ . If the seller remains silent each bidder has an expected value of only  $\frac{1}{2}$  so, as seen from the quasi-convexity of seller preferences, communication benefits the seller.  $\square$

The sufficient condition  $T < N$  for the existence of influential equilibria in Theorem 1 is also necessary if one restricts attention to equilibria where the sender discloses the same partition of  $\Theta$  regardless of her motives  $t$ . For instance, if  $T = 2 = N$ , and the indifference curves for the two types satisfy a single-crossing property, it is impossible to find two distinct action profiles that make both types of the sender indifferent. However, the condition  $T < N$  is not necessary for the existence of other kinds of influential cheap talk equilibria, as we illustrate now. The next example provides a robustness check of our first result, since even when the decision maker is nearly certain of the expert's motives, some residual uncertainty may be likely in some cases.

### Example 5 *Hidden Bias*

Consider again the Media Bias example of Section 2 and assume  $N = T = 2$  where the

network might be an impartial type,  $\lambda_1 = \lambda_2$ , or a biased type,  $\lambda_1 = 4$  and  $\lambda_2 = 1$ , with probabilities  $p$  and  $1 - p$  respectively.<sup>19</sup> Assume further, for simplicity, that  $t$  is independent of  $\theta$ , which is, as before, uniform i.i.d. on  $[0, 1]^2$ . Figure 3 (left panel) shows the superimposed indifference curves for each type and the announcement line with slope one intercepting  $c = (\frac{1}{2}, \frac{1}{2})$ . Suppose message  $m^+$  is interpreted as meaning the network is impartial and  $\theta \in R^+(h)$ , while message  $m^-$  is interpreted as meaning either the network is impartial and  $\theta \in R^-(h)$ , or the network is biased and there is no information about  $\theta$ . If  $h$  is the diagonal as pictured then  $a^+ = (\frac{1}{3}, \frac{2}{3})$  and  $a^- = (p(\frac{2}{3}) + (1 - p)(\frac{1}{2}), p(\frac{1}{3}) + (1 - p)(\frac{1}{2}))$ .

As seen in the figure which shows the case of  $p = \frac{1}{2}$ , the actions  $a^+$  and  $a^-$  no longer reverse themselves as the announcement line is spun around, so there is no longer a continuous odd mapping that can be used to apply the Borsuk-Ulam theorem. However, for  $p$  close to one (or zero), the gap between actions disappears, so it is unlikely that any discontinuity will affect the existence of an equilibrium. More formally, arguments based on the implicit function theorem can be used to show that for  $p$  close to 1 an equilibrium exists which is close to that of  $p = 1$ . In such an equilibrium the audience anticipates that an impartial network ranks the scandals truthfully while a biased network always plays up the first scandal. The biased network benefits from the lack of transparency because it would receive a payoff of  $4(\frac{1}{2}) + (\frac{1}{2}) = \frac{5}{2}$  if its bias were known, while here it receives payoff of  $4(p(\frac{2}{3}) + (1 - p)(\frac{1}{2})) + p(\frac{1}{3}) + (1 - p)(\frac{1}{2})$  by always playing up the first scandal.<sup>20</sup>

If preferences are monotone and  $f$  displays affiliation, it is straightforward to show that an equilibrium exists for any  $p$ .<sup>21</sup> These conditions are satisfied by the example, so as seen in the figure, cheap talk is an equilibrium for the pictured case of  $p = \frac{1}{2}$ . Since one type of network always sends the same message, this non-partitional equilibrium is less informative than the corresponding two-message equilibrium that exists if the network is known to be either biased or unbiased.  $\square$

More generally, influential cheap talk equilibria may exist in special environments even

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<sup>19</sup>In contrast with related models of biased and unbiased types in one dimension (Sobel, 1985; Benabou and Laroque, 1992; Morris, 2001; Morgan and Stocken, 2003), our “unbiased” type is unbiased across dimensions but still biased toward a higher action in each dimension.

<sup>20</sup>This gain is increasing in  $p$ , so a biased network gains the most when its bias is unexpected. This result provides a multidimensional perspective on the finding by DellaVigna and Kaplan (2006) that, in an environment where few viewers expected a news network to have a conservative bias, Fox News had a large influence on voting behavior by viewers.

<sup>21</sup>Note also that in special cases there may exist equilibria where the sender (partially) reveals his motives  $t$  together with a possibly informative partition of the state  $\theta$ .

when  $T$  is large, e.g., when  $\mathbf{T} = \Theta$ . For instance, Chakraborty and Harbaugh (2007) show that sufficient symmetry (or independence) in the environment ensures existence for supermodular additively separable preferences. Furthermore, they show that with  $N = 2$  and special preferences (e.g., of the form  $U = \theta \cdot a$ ) that make  $\mathbf{T}$  isomorphic to  $[0, 1]$ , one can essentially import the conditions for influential cheap talk in one dimension of Crawford and Sobel (1982) to obtain existence in the multidimensional case. On the other hand, Levy and Razin (2007) demonstrate the limits to pure cheap talk in multidimensional environments when, for instance, sender preferences are Euclidean, as we discuss in more detail in Section 5.

## 4 Very Informative Cheap Talk

To see how sufficient transparency allows the sender to reveal more information than in the 2-message equilibrium of Theorem 1, we first consider the case of linear preferences.<sup>22</sup> As suggested by the motivating examples, often the sender has a strong incentive for a higher (or lower) action in each dimension, and the main uncertainty is over how much the sender cares about each dimension. A simple way to capture this is the linear specification,

$$U(a; t) = \lambda_1(t)a_1 + \dots + \lambda_N(t)a_N \quad (1)$$

where the  $\lambda_i(t)$  are real numbers that measure the relative importance of the action on dimension  $i$  for type  $t$  of the sender, so that  $\lambda(t) = (\lambda_1(t), \dots, \lambda_N(t))$  summarizes the sender's possibly uncertain weights on each dimension, i.e., the sender's bias across dimensions.

As suggested in Example 2, consider if after stating message  $m^+$  the sender is given an opportunity to again make a two-message comparative statement for the region  $R^+$  (a convex set) corresponding to the area above the announcement line. From Theorem 1, we know that an equilibrium exists for this subgame, but it might seem that anticipation of the subgame will distort the sender's incentives in the first stage. If we set  $c = E[\theta]$  then by the law of iterated expectations  $c$  is a convex combination of  $a^+ = E[\theta|m^+]$  and  $a^- = E[\theta|m^-]$  so all three points must lie on the same linear indifference curve. Similarly, if in the second stage we set  $c = a^+ = E[\theta|m^+]$  then this point of region  $R^+$  is a convex combination of the expectations for the two new subregions, and again all three points are on the same linear indifference

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<sup>22</sup>Linear preferences are standard in the signaling and disclosure/persuasion game literatures, but are not generally used in the cheap talk literature since monotonic preferences preclude credible cheap talk in the one-dimensional case.

curve. Consequently, the sender is indifferent between all three messages and therefore has no incentive to lie at either stage.

Clearly this same logic applies to any number of stages – the sender can keep making additional comparative statements that subdivide the space further, and the potential for further stages does not affect incentives at earlier stages. The logic also applies to simultaneous statements so the sender need not make continually finer statements, but can simply reveal the exact element of the equilibrium partition at the first stage. The first part of the following proposition formalizes these ideas.

**Theorem 2** *Suppose  $T < N$ . A  $k$ -message cheap talk equilibrium exists for all linear  $U$ , all  $F$ , and all  $k$ . As  $k$  becomes large, the sender can reveal almost all information in  $N - T$  dimensions.*

Regarding the second part of the proposition, as  $k$  becomes large each element of the equilibrium partition becomes “thin” in the sense that any  $B \subset \Theta$ , open in  $\mathbb{R}^N$ , will eventually be divided among at least two elements of the equilibrium partition. This follows from the centerpoint theorem by observing that each element has probability mass at most  $\left(1 - \frac{1}{N+1}\right)^k$  in a  $2^k$ -message equilibrium where, as in the above construction, each subdividing announcement hyperplane goes through the mean of the region it divides. Therefore any ball with positive mass will eventually be split. For instance, when  $N - T = 1$ , all actions must lie on a one-dimensional equilibrium indifference line given by the intersections of the  $T$  equilibrium hyperplanes corresponding to each sender’s type. Therefore, since any ball of any radius on this line will eventually be split, it follows that there must lie an action within any  $\varepsilon > 0$  of any point on the equilibrium indifference line for  $k$  large enough. In this sense, the sender reveals almost all information in one of the  $N$  dimensions as  $k$  becomes large. This result for  $N = 2$  and  $T = 1$  can be seen from the increasingly thin slices in the right panel of Figure 1.

To see how Theorem 2 extends this result to revealing almost all information in  $N - T$  dimensions, consider the case of  $N = 3$  and  $T = 1$  where Theorem 2 asserts that all actions must in the limit fill up a two-dimensional surface corresponding to the equilibrium hyperplane of the sender. We first “slice”  $\Theta$  by constructing a  $k$ -message equilibrium where the equilibrium actions lie on a line in the indifference plane through  $E[\theta]$ . We can choose this line freely because of the extra degree of freedom given by  $N - T = 2$ . We then “dice” each slice with a  $k$ -message equilibrium for the subregion where the equilibrium actions lie on lines that are, again using the extra degree of freedom, chosen to be orthogonal to the original line. Since all these  $k^2$  actions lie on the true sender type’s indifference plane through  $E[\theta]$ ,

they constitute a  $k^2$ -message equilibrium. For large  $k$  the action lines form an arbitrarily fine grid of the sender's equilibrium indifference hyperplane, allowing us to conclude by the centerpoint theorem arguments above that the equilibrium hyperplane is asymptotically dense in the equilibrium actions as  $k$  increases.

Theorem 2 returns to an idea due to Battaglini (2002) that in two dimensions it can be possible to reveal full information in a one-dimensional subspace on which there is no conflict of interest. As Battaglini noted, for state-dependent preferences such revelation can only occur in special cases with special distributions.<sup>23</sup> We find that such revelation is possible generally for linear preferences that are transparent. Transparency ensures that the expert's preferences do not depend on the expert's private information, so the decision maker can fully adjust for any biases. Linearity ensures that the conditional expectations for each subregion can be kept on the same indifference curve.

Do  $k$ -message equilibria exist for nonlinear preferences? A difficulty arises because the need to keep the actions on the same nonlinear indifference curve conflicts with the requirement from the law of iterated expectations that the conditional expected values for each subregion be on the same straight line as the unconditional expected value for the whole region. Nevertheless, the next example demonstrates that the possibility of mixed messages allows one to construct similar equilibria when preferences are strictly quasi-convex or quasi-concave.

**Example 6** *Mixed Messages*

Consider again the voter persuasion model from Example 3 for the quasi-convex case where support from one of two blocs is needed,  $U = p(a) = a_1 + a_2 - a_1a_2$ . We ask if the expert can make a long informative speech involving possibly mixed messages. The right panel of Figure 3 shows a four-message equilibrium for this case generated by the following algorithm.

The algorithm starts by constructing the 2-message equilibrium of Theorem 1 through the ex-ante expected value  $c = E[\theta]$ , with an equilibrium announcement line  $h$  and resulting actions  $a^+$  and  $a^-$  where  $U(a^+) = U(a^-)$ . Next, as done in Example 2, we draw an equilibrium announcement line  $h^+$  treating  $R^+$  as the entire space, giving actions  $a_+^+$  and  $a_-^+$  where  $U(a_+^+) = U(a_-^+)$ . Similarly, we draw an equilibrium announcement line  $h^-$  for the lower region  $R^-$ , giving actions  $a_+^-$  and  $a_-^-$  where  $U(a_+^-) = U(a_-^-)$ . If the payoffs for each subregion region all equal each other,  $U(a_+^+) = U(a_-^+) = U(a_+^-) = U(a_-^-)$ , we have a four-message equilibrium. If

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<sup>23</sup>Battaglini discusses the difficulty of obtaining full revelation by one sender in one dimension as a step toward understanding why multiple senders are needed to obtain full revelation in all dimensions.

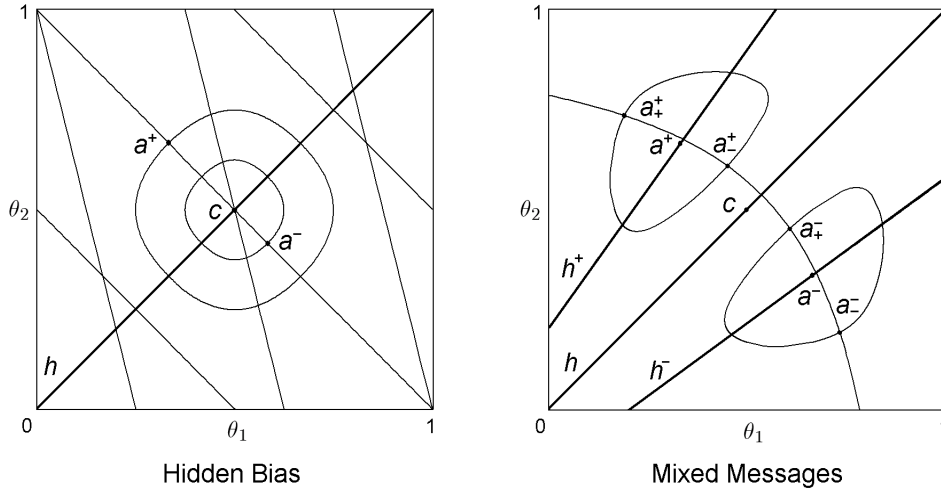


Figure 3: Non-partitional equilibria.

not, assume without loss of generality that the top pair offers a higher payoff. By the strict quasi-convexity of  $U$ ,  $U(a_+^+) = U(a_-^+) > U(a^+) = U(a^-)$ , so that by continuity there exist  $\alpha, \beta \in (0, 1)$ ,  $\alpha > \beta$ , such that  $a' = \alpha a_+^+ + (1 - \alpha)a_-^+$  and  $a'' = \beta a_+^+ + (1 - \beta)a_-^+$  satisfy  $U(a') = U(a'') = U(a_+^-) = U(a_-^-)$ . Indeed notice that  $\alpha > \pi > \beta$  where  $a^+ = \pi a_+^+ + (1 - \pi)a_-^+$ . It follows that  $(a', a'', a_+^-, a_-^-)$  are the equilibrium actions corresponding to a four-message equilibrium where a sender in  $R_+^+$  sends the first message with probability  $\alpha$  and the second message with probability  $1 - \alpha$ , a sender in  $R_-^+$  sends the first message with probability  $\beta$  and the second message with probability  $1 - \beta$ , and senders in  $R_+^-$  and  $R_-^-$  send the third and fourth messages respectively. Iterative application of the algorithm can be used to generate equilibria with  $2^k$  messages for any  $k > 2$ .<sup>24</sup> Looking at Figure 3, the symmetry of the problem ensures that  $U(a_+^+) = U(a_-^+) = U(a_+^-) = U(a_-^-)$ , so no mixing is required for the four-message equilibrium. But the four subregions in Figure 3 are not symmetric, so any additional messages using this algorithm will require mixing.

By strict quasi-convexity, the expected sender payoffs in these equilibria are strictly increasing in  $k$ . As with the fully partitional equilibria of Theorem 2, each such equilibrium has associated with it a convex partition of  $\Theta$  with arbitrarily thin elements when  $k$  is large. Furthermore, since all of the actions lie on the same indifference curve, this mixed message equilibrium is also a sequential cheap talk equilibrium.<sup>25</sup> Finally, the algorithm above gener-

<sup>24</sup>A related algorithm can be used to generate equilibria with an odd number of messages.

<sup>25</sup>Krishna and Morgan (2006) consider mixed strategies in a multi-stage one-dimensional cheap talk game.

alizes to the case  $N > 2$  and depends only on the strict quasi-convexity (or quasi-concavity) of preferences, with less mixing required as preferences become more linear.<sup>26</sup>  $\square$

## 5 Epsilon Cheap Talk

Following Crawford and Sobel (1982), sender preferences based on the distance between the sender’s ideal action and the receiver’s ideal action (the sender’s “bias”) are widely used in the literature. In the one-dimensional case, the sender faces a tradeoff between actions that are too small and actions that are too large, so informative communication is only possible if the sender’s bias toward a higher action is limited. In the multidimensional case, the tradeoff can be across rather than within dimensions, so it is useful to analyze situations where the sender’s bias toward a higher (or lower) action on each dimension is arbitrarily strong.

To see how linear preferences are a simple way to represent large biases within and across dimensions, consider the following standard specification of Euclidean preferences:

$$U(a; t) = -d(a, \tau(\theta)) = - \left( \sum_{i=1}^N (a_i - (\theta_i + b_i))^2 \right)^{1/2} \quad (2)$$

where  $d(\cdot, \cdot)$  is the Euclidean distance function and  $b = (b_1, \dots, b_N) \in \mathbb{R}^N$  is the vector of known biases representing the distance between the receiver’s ideal action  $\theta$ , and the sender’s ideal action  $\tau(\theta) = \theta + b$ . Since  $\theta$  is the sender’s private information, the sender’s type is  $t = \tau(\theta)$ .<sup>27</sup>

In this section we show that as the sender’s bias in each dimension increases, Euclidean preferences converge uniformly to linear preferences with known biases across dimensions equal to the ratios of these biases within dimensions. As a result, pure cheap talk is an equilibrium at the limit of infinite biases even for arbitrary asymmetries. We then use this result to show that the set of approximate or “ $\varepsilon$ -cheap talk” equilibria for Euclidean preferences converges to

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They describe how the uncertainty of mixed strategies and multiple stages of communication can capture some of the “art of conversation.”

<sup>26</sup>The example considers the case of perfect transparency,  $T = 1$ . The existence of  $k$ -message equilibria,  $k > 2$ , for general non-linear preferences and distributions and  $T > 1$ , is an open question at this time. In particular, analogous to Crawford-Sobel (1982), to show the existence of many message *partitioned* equilibria for non-linear preferences one needs, in general, an iterative argument in which the orientation of the hyperplane used in the second stage depends continuously on the orientation of that used in the first. We have been unable to ascertain general conditions under which such a continuous selection exists.

<sup>27</sup>The set of such types is not finite so existence results from Theorem 1 do not apply. These preferences satisfy the conditions for influential cheap talk in multiple dimensions for the (near) symmetric case (Chakraborty and Harbaugh, 2007), but here we are interested in arbitrary asymmetries.

the set of equilibria for linear preferences, implying that many environments where the sender is very biased can be modeled using simple linear preferences.

More formally, let  $b = (\rho_1 B, \dots, \rho_N B)$  for  $B \geq 0$  and  $\rho = (\rho_1, \dots, \rho_N) \neq 0$ . For any  $\theta$ , as  $B$  increases without bound the sender's ideal point  $\tau(\theta)$  becomes more and more distant from  $\theta$ , so the circular indifference curves for Euclidean preferences become straighter, and in particular they converge to those of known linear preferences of the form in (1) with weights  $\rho_i$  instead of  $\lambda_i$ .<sup>28</sup> To see this, consider two equilibrium actions  $a^+$  and  $a^-$  for a 2-message equilibrium for the corresponding linear preferences. By Theorem 1 we know it is always possible to find such actions. By Pythagoras' Theorem, for any  $\theta$  the difference  $d(a^-, \tau(\theta)) - d(a^+, \tau(\theta))$  decreases monotonically to 0 in the limit as  $B$  increases and  $\tau(\theta)$  moves out perpendicular to the line through  $a^+$  and  $a^-$ . Therefore, since these actions are on the same linear indifference curve, the sender is indifferent in the limit between them, implying that the linear preferences equilibria identified in Theorem 2 obtain for Euclidean preferences at the limit as the biases go to infinity.

To show that this limiting result extends to large but finite biases if there is any cost to lying, we modify the game so that the sender's payoff from any action  $a$  and message  $m$  given  $\theta$  is  $U(a, m; \theta) = -d(a, \tau(\theta))$  less an arbitrarily small cost  $\varepsilon > 0$  of lying if the message  $m$  is not consistent with  $\theta$ .<sup>29</sup> We study if influential equilibria exist in such a game for large  $B$ . In particular, extending the idea of an  $\varepsilon$ -equilibrium to cheap talk games, we say that a convex partitional announcement strategy is an  $\varepsilon$ -cheap talk equilibrium for large biases of the game with distance preferences (2) if and only if for each  $\varepsilon > 0$  there exists  $\bar{B}$  such that for all  $B > \bar{B}$  and any  $\theta$ , the incentive to lie for a sender is at most  $\varepsilon$ . Our next result shows an equivalence between such equilibria and the cheap talk equilibria for linear preferences characterized by Theorem 2.

**Theorem 3** *For all  $F$  and all  $k$ , an announcement strategy is a  $k$ -message  $\varepsilon$ -cheap talk equilibrium for Euclidean  $U$  with large  $B$  if and only if it is a cheap talk equilibrium for the limiting linear  $U$  with  $\rho = \lambda$ .*

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<sup>28</sup>If in (2) there are different weights on the dimensions then the indifference curves are elliptical, in which case the asymptotic preference weights are products of the weights and biases with Euclidean preferences, leaving the analysis qualitatively unchanged. The analysis also covers the case where some but not all  $b_i$  are bounded.

<sup>29</sup>Since the meaning of a message is derived from a (candidate) equilibrium announcement strategy, the notion of what constitutes a "lie" is endogenous here. Therefore this equilibrium notion is distinct from that of an "almost cheap talk" equilibrium (Kartik, 2005) or a "costly talk" equilibrium (Kartik, Ottaviani, and Squintanni, 2007) in which the sender's reports have an exogenous meaning corresponding to the true value of the state and any deviation from this true value is costly.

This existence result is worth comparing in detail with the non-existence result of Levy and Razin (2007). They show that even slight asymmetries in distributions can preclude informative cheap talk when preferences are lexicographic, and then show that Euclidean (and related) preferences have the same properties for sufficiently large but finite  $B$ . We show that informative cheap talk equilibria always exist for transparent continuous preferences, and then show that Euclidean preferences converge uniformly to transparent linear preferences as  $B$  becomes large. Therefore cheap talk is an equilibrium at the limit of infinite  $B$ , while  $\varepsilon$ -cheap talk is an equilibrium for sufficiently large  $B$ .

More precisely, for finite  $B$ , a two-message cheap talk equilibrium with Euclidean preferences requires that the line of ideal points  $\tau(\theta)$  of types on the announcement line bisect the line joining the two actions and also be perpendicular to it. This assures that types along the announcement line are indifferent and that, due to the supermodularity of Euclidean preferences, types on either side prefer the appropriate action. Levy and Razin show that as  $B$  becomes large the actions are increasingly bound to be on the same linear indifference curve through the expected value of  $\theta$  so it is increasingly difficult to adjust the announcement line to account for any asymmetries. As a result, cheap talk becomes impossible in asymmetric environments for sufficiently large  $B$ . However, even if large  $B$  makes it more difficult to keep types along the announcement line exactly indifferent, we find that the incentive for any type to deceive the receiver is decreasing toward 0 as  $B$  increases. Therefore, as  $B$  becomes sufficiently large, communication becomes easier rather than harder to sustain if one introduces an arbitrarily small cost of lying.<sup>30</sup>

In a one-dimensional model the primary issue is whether the sender's bias is too large to permit communication. Theorem 3 shows that in a multidimensional environment extremely biased senders have transparent motives when the ratio of biases is known, so that large biases are not in themselves a fundamental barrier to communication. In particular, the result implies that a simple linear specification can be used to capture many situations where the sender is known to be extremely biased. This approach allows attention to be focused on what this paper argues is often the central issue of whether or not the receiver knows the sender's bias across dimensions.

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<sup>30</sup>The literature often uses a simpler quadratic variant of the Euclidean specification which drops the square root term in (2). Such preferences are also equivalent to linear preferences *at* the limit of infinite biases, but the difference in the sender's utilities from actions  $a$  and  $a'$  is unbounded in  $B$ , implying Theorem 3 obtains only if the cost of lying also increases in the unit of payoffs  $B$ , e.g., if it is equal to  $\varepsilon B$  for any  $\varepsilon > 0$ .

## 6 Conclusion

We show that sufficient transparency over the expert's motives ensures the existence of influential cheap talk equilibria in multidimensional environments. When the expert's motives are known, our results provide an intuitive solution where the decision maker treats comparative statements with enough skepticism for communication to be credible. When the expert's motives are not known but the uncertainty is limited, our results indicate when communication is still possible. These results cover a large class of important economic environments, including the limiting case of standard Euclidean preferences.

These results provide a stronger foundation for regulations and social conventions that promote increased transparency. Nevertheless, there is still room for stronger regulations that directly affect expert incentives. In particular, regulations might be able to reduce biases within dimensions as well, so that non-comparative statements are more credible. For instance, a completely unbiased stock analyst would be able to reveal credible information about the exact prospects of individual stocks, not just about their relative prospects. However, a key issue facing any formal or informal regulation of expert advice is whether it creates additional ambiguity due to enforcement uncertainties. In particular, if rules or norms requiring disclosure of or reduction of biases are only partially enforced, decision makers might face increased uncertainty over whether to adjust for biases or not.

## 7 Appendix

**Proof of Theorem 1:** We look for an influential cheap talk equilibrium involving a single hyperplane  $h$  of orientation  $s \in \mathbb{S}^{N-1}$  passing through  $c \in \text{int}(\Theta)$  that partitions  $\Theta$  into two non-empty sets  $\mathbf{R}^+(s; c)$  and its complement  $\mathbf{R}^-(s; c)$ , with corresponding receiver actions  $a^+(s; c)$  and  $a^-(s; c)$ . Let  $\mathbf{R}^+(s; c)$  be the region that contains the point  $s + c$ . Notice first that under the assumed conditions on  $f$ ,  $a^+(s; c) \in \text{int}(\mathbf{R}^+(s; c))$  and  $a^-(s; c) \in \text{int}(\mathbf{R}^-(s; c))$ , implying in particular that  $a^+(s; c) \neq a^-(s; c)$  so that any such equilibrium, if it exists, is influential. Furthermore,  $a^+(s; c)$  and  $a^-(s; c)$  are continuous functions of  $s$  (with the subspace topology for  $\mathbb{S}^{N-1}$  relative to the usual one on  $\mathbb{R}^N$ ), for any fixed  $c \in \text{int}(\Theta)$ . Notice next that for any two antipodal orientations  $-s, s \in \mathbb{S}^{N-1}$ , we must have  $\mathbf{R}^+(s; c) = \mathbf{R}^-(-s; c)$  and so  $\mathbf{R}^-(s; c) = \mathbf{R}^+(-s; c)$ . It follows that  $a^+(s; c) = a^-(-s; c)$  implying in particular that the map  $G^t(\cdot; c) : \mathbb{S}^{N-1} \rightarrow \mathbb{R}$  defined by

$$G^t(s, c) = U(a^-(s; c); t) - U(a^+(s; c); t) \tag{3}$$

is a continuous odd function of  $s$ , for any arbitrary  $c \in \text{int}(\Theta)$  and each  $t \in \mathbf{T}$ . By the Borsuk-Ulam theorem, when  $N - 1 \geq T$ , there exists  $s^* \in \mathbb{S}^{N-1}$ , such that  $G^t(s^*, c) = 0$  for all  $t \in \mathbf{T}$ . The hyperplane through  $c$  with orientation  $s^*$  therefore constitutes the announcement hyperplane of an influential equilibrium. ■

**Proof of Theorem 2.** Let  $h(s; c)$  denote a hyperplane of orientation  $s \in \mathbb{S}^{N-1}$  passing through  $c \in \text{int}(\Theta)$ . Formalizing the discussion in the text, note that for the first hyperplane  $h = h(s, c)$  obtained via Theorem 1 the region  $\mathbf{R}^+(h)$  is a convex set since it is the intersection of a convex set  $\Theta$  and one of the half-spaces associated with  $h$ . Further, it has a non-empty interior since  $a^+(h) \in \text{int}(\mathbf{R}^+(h))$ . Picking  $c = a^+(h)$  and applying Theorem 1 again, we are guaranteed the existence of a second hyperplane  $h^+ = h(s^+, a^+)$  and associated convex regions  $\mathbf{R}_+^+(h^+)$  and  $\mathbf{R}_-^+(h^+) = \mathbf{R}^+(h) \setminus \mathbf{R}_+^+(h^+)$ , and corresponding actions  $a_+^+(h^+) \in \text{int}(\mathbf{R}_+^+(h^+))$ ,  $a_-^+(h^+) \in \text{int}(\mathbf{R}_-^+(h^+))$ , such that  $U(a_+^+(h^+); t) = U(a_-^+(h^+); t)$  for all  $t \in \mathbf{T}$ . Since the actions are all conditional expectations, by the law of iterated expectations, there must exist  $q \in (0, 1)$ ,  $q = \Pr[\theta \in \mathbf{R}_+^+(h^+) | \theta \in \mathbf{R}^+(h)]$ , such that

$$a^+(h) = qa_+^+(h^+) + (1 - q)a_-^+(h^+). \quad (4)$$

Since  $U$  is linear, we conclude that

$$U(a_+^+(h^+); t) = U(a_-^+(h^+); t) = U(a^+(h); t) = U(a^-(h); t) \text{ for all } t \in \mathbf{T} \quad (5)$$

so that a three-message influential equilibrium exists with induced actions  $a_+^+(h^+)$ ,  $a_-^+(h^+)$  and  $a^-(h)$ . The  $k$ -message case uses the argument above as an inductive step. This demonstrates the first part of the statement.

For the second part, note that for any  $k$ -message equilibrium, all induced actions lie on the  $N - T$  dimensional compact set  $\mathbf{A}^* = \{a | U(a; t) = U(E[\theta]; t), t \in \mathbf{T}\}$ . We wish to demonstrate that for every  $\varepsilon > 0$ , there exists a  $k$ -message equilibrium with  $k$  large enough, with an induced action  $a^* \in \mathbf{A}^*$  that is within  $\varepsilon$  distance of  $a$ , for all  $a \in \mathbf{A}^*$ . In this sense, the set  $\mathbf{A}^*$  is asymptotically (in  $k$ ) dense in the induced actions and we say that the sender reveals all information in the  $N - T$  dimensions corresponding to  $\mathbf{A}^*$ .

First consider the case where  $T = N - 1$  and fix  $\varepsilon > 0$ . Notice that  $\mathbf{A}^*$  is a line uniquely pinned down by the preferences of the  $T$  sender types. Consider the ball  $B_\varepsilon(a)$ , open in  $\mathbb{R}^N$ , of radius  $\varepsilon$  and centered around  $a$ . Notice that for  $k$  large enough, there exists an element  $\mathbf{P}$  of the equilibrium partition such that  $\mathbf{P} \cap \mathbf{A}^* \subset B_\varepsilon(a)$ . This follows from the centerpoint theorem (see, e.g., Grunbaum, 1960) that each element has probability mass at

most  $(1 - 1/(N + 1))^{\log_2 k} < \min_{a \in \mathbf{A}^*} \Pr\{\theta \in B_\varepsilon(a)\}$ , for  $k$  large enough. But then the equilibrium action  $a^* \in \mathbf{P} \cap \mathbf{A}^*$ , corresponding to the element  $\mathbf{P}$ , must lie within  $\varepsilon$  of  $a$ .

Next consider the case where  $T < N - 1$ , and construct a  $k$ -message equilibrium with the desired property as follows. Introduce  $N - T - 1$  fictitious types  $\mathbf{T}^1 = \{t_1^1, \dots, t_{N-T-1}^1\}$  with linear preferences  $U = \lambda(t_j^1) \cdot a$  where  $\lambda(t_j^1) \neq \lambda(t)$  for all  $t \in \mathbf{T}$ ,  $j = 1, \dots, N - T - 1$ . Construct a  $k$ -message equilibrium for the types  $t \in \mathbf{T} \cup \mathbf{T}^1$ , following the procedure of the first part of the proof above. The resulting  $k$  action profiles lie on a unique line  $\mathbf{A}_1^* = \{a | U(a; t) = U(E[\theta]; t), t \in \mathbf{T} \cup \mathbf{T}^1\} \subset \mathbf{A}$ . Next, choose a second distinct set of  $N - T - 1$  fictitious types  $\mathbf{T}^2$  and construct a  $k$ -message equilibrium for the types  $t \in \mathbf{T} \cup \mathbf{T}^2$ , for each element  $i = 1, \dots, k$  of the  $k$  element partition obtained in the previous step, treating that element as the entire state-space, following once again the procedure of the first part of the proof above. Observe that this can be done in a manner such that the resulting  $k$  action profiles lie on a unique line  $\mathbf{A}_{2,i}^* = \{a | U(a; t) = U(E[\theta]; t), t \in \mathbf{T} \cup \mathbf{T}^2\} \subset \mathbf{A}$  that is orthogonal to  $\mathbf{A}_1^*$  for each  $i = 1, \dots, k$ , for a total of  $k^2$  actions. Repeat this procedure  $N - T$  times, at each step using a new set of  $N - T - 1$  distinct fictitious types to obtain the lines  $\mathbf{A}_1^*, \{\mathbf{A}_{2,i}^*\}_{i=1}^k, \dots, \{\mathbf{A}_{N-T,i}^*\}_{i=1}^{k^{N-T-1}}$  such that the lines obtained in any step are orthogonal to all lines obtained in previous steps. Notice that the resultant actions and associated partition of  $\Theta$  is a  $k^{N-T}$ -message equilibrium for the true types  $t \in \mathbf{T}$ , with each induced action on some line  $\mathbf{A}_{N-T,i}^*$ ,  $i = 1, \dots, k^{N-T-1}$ . By the centerpoint theorem it follows that for any  $\varepsilon > 0$  and  $k$  large enough, the element  $\mathbf{P}$  of the partition with  $a \in \mathbf{P}$ , any  $a \in \mathbf{A}^*$ , must satisfy  $\mathbf{P} \cap \mathbf{A}^* \subset B_\varepsilon(a)$ , implying the existence of an equilibrium action  $a^* \in \mathbf{P} \cap \mathbf{A}^*$  within  $\varepsilon$  of the given point  $a$ . ■

**Proof of Theorem 3:** Pick an arbitrary announcement line  $h$  of orientation  $s \in \mathbb{S}^{N-1}$  passing through  $c \in \text{int}(\Theta)$  and let  $L$  be the line joining the corresponding actions  $a^+ = a^+(s, c)$  and  $a^- = a^-(s, c)$ . Pick any  $\theta \in \Theta$  and let  $p(\theta)$  be the point where the perpendicular from  $\tau(\theta) = \theta + B\rho$  on to  $L$  meets  $L$ . Then

$$p(\theta) = q(\theta)a^+ + (1 - q(\theta))a^- \quad (6)$$

where  $q(\theta) \in \mathbb{R}$  is given by

$$q(\theta) = \frac{(\theta - a^-) \cdot (a^+ - a^-) + B\rho \cdot (a^+ - a^-)}{(a^+ - a^-) \cdot (a^+ - a^-)}. \quad (7)$$

Notice that this is well-defined since  $a^+ \neq a^-$ . Notice next that

$$\begin{aligned} d(a^+, \tau(\theta)) - d(a^-, \tau(\theta)) &= \frac{d^2(a^+, \tau(\theta)) - d^2(a^-, \tau(\theta))}{d(a^+, \tau(\theta)) + d(a^-, \tau(\theta))} \\ &= \frac{d^2(a^+, p(\theta)) - d^2(a^-, p(\theta))}{d(a^+, \tau(\theta)) + d(a^-, \tau(\theta))} \end{aligned} \quad (8)$$

where in the second line we have used Pythagoras' theorem.

For the if part consider first a two message cheap talk equilibrium with induced actions  $a^+$  and  $a^-$  when  $U$  is given by (1), so that  $\rho \cdot (a^+ - a^-) = 0$ . Then  $q(\theta)$  and so  $p(\theta)$  do not depend on  $B$ . Furthermore, using (8) ,

$$\begin{aligned} |U(a^+; \tau(\theta)) - U(a^-; \tau(\theta))| &= |d(a^+, \tau(\theta)) - d(a^-, \tau(\theta))| \\ &= \left| \frac{d^2(a^+, p(\theta)) - d^2(a^-, p(\theta))}{d(a^+, \tau(\theta)) + d(a^-, \tau(\theta))} \right| \\ &\leq \max_{\theta \in \Theta} \left| \frac{d^2(a^+, p(\theta)) - d^2(a^-, p(\theta))}{d(a^+, \theta + B\rho) + d(a^-, \theta + B\rho)} \right|. \end{aligned} \quad (9)$$

Let  $\theta_B$  be the solution to the last maximization problem. As  $B$  rises,  $\theta_B$  stays bounded in the compact set  $\Theta$ , so that  $p(\theta_B)$  stays bounded as well, implying that the numerator stays bounded. However the denominator becomes arbitrarily large. It follows that for any  $\varepsilon > 0$ , for  $B$  large enough,  $|U(a^+, \theta) - U(a^-, \theta)| < \varepsilon$  for all  $\theta$ . An analogous argument obtains for the  $k$ -message equilibria of Theorem 2,  $k \geq 2$  and finite, if we consider pairs of equilibrium actions that must all lie on the same line  $L$  and run the logic above.

For the only if part, suppose that two actions  $a^+$  and  $a^-$  do not constitute a 2-message cheap talk equilibrium when  $U$  is given by (1). W.l.o.g., suppose that  $\rho \cdot a^+ < \rho \cdot a^-$ . Consider type  $\theta = a^+$  and observe via (8) that

$$\begin{aligned} \lim_{B \rightarrow \infty} [U(a^+; \tau(a^+)) - U(a^-; \tau(a^+))] &= \lim_{B \rightarrow \infty} [d(a^+, \tau(a^+)) - d(a^-, \tau(a^+))] \\ &= \lim_{B \rightarrow \infty} \left[ \frac{d^2(a^+, p(a^+)) - d^2(a^-, p(a^+))}{d(a^+, a^+ + B\rho) + d(a^-, a^+ + B\rho)} \right] \\ &= \lim_{B \rightarrow \infty} \frac{(1 - 2q(a^+)) [(a^+ - a^-) \cdot (a^+ - a^-)]}{B\sqrt{\rho \cdot \rho} + \sqrt{(a^- - a^+ - B\rho) \cdot (a^- - a^+ - B\rho)}} \\ &= \frac{\rho \cdot (a^- - a^+)}{\sqrt{\rho \cdot \rho}} \end{aligned} \quad (10)$$

where we have used (6) and (7) in the last two lines. It follows that when  $\varepsilon < \rho \cdot (a^- - a^+) / \sqrt{\rho \cdot \rho}$ , and  $B$  is large enough, type  $\theta = a^+$  would gain by more than  $\varepsilon$  from lying (i.e., by inducing the receiver to choose the action  $a^-$  instead of  $a^+$ ), implying in turn that  $h$  is not an  $\varepsilon$ -cheap talk equilibrium for large  $B$  when  $U$  is given by (2). An identical argument obtains for the  $k$ -message equilibria of Theorem 2,  $k \geq 2$  and finite, if we consider some pair of actions for which  $\rho \cdot a^+ \neq \rho \cdot a^-$ . ■

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