# Complexity versus Conflict in Communication

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*Abstract*—**Equilibrium models of costless strategic communication provide four insights, which can be summarized informally by: failure to communicate is always possible; perfect communication is not possible when conflict of interest exists between the informed Sender and the uninformed Receiver; whenever non-trivial communication is possible, there are multiple equilibrium outcomes; the quality of information communicated in equilibrium and the potential benefits of communication increase when the conflict between the Sender and Receiver decreases. I will review these insights and point out that parallel properties emerge in a new model of strategic communication when the Sender and Receiver must make costly investments that determine their abilities to encode and decode (respectively) messages. That is, there is a parallel foundation to the economic theory of strategic communication in which the reason for limited communication is complexity rather than conflicting interests.**

## I. Introduction

Conflict of interest is a fundamental factor in economic activity. If Bob values Alice's car more than Alice does, then there is a trading possibility. Differences of opinion about the value of the car make a mutually beneficial transaction possible. A worker wants a high salary; her boss wants to keep salary low. The conflict could lead to a strike. It is essential to study the implications of conflicts to understand bargaining and exchange. Coordination is an important goal too. Alice and Bob cannot benefit from their desire to trade if they cannot find each other. The firm and worker may both benefit from avoiding a strike even though they disagree about wages.

Communication is a way to solve coordination problems. A canonical model of communication studies a two-player situation in which an informed Sender sends a message to an uninformed Receiver who then makes a decision relevant to both players. In this paper I concentrate on the case where the cost of communication does not depend on the Sender's information (so-called "cheap-talk" models).[1]

Section II reviews the conflict-of-interest model, a simple model of communication in which the key assumption is that the Sender and Receiver have different preferences over actions. Section III proposes an alternative model, the complexity model, in which players have common interests, but both players must pay to increase the precise of information transmitted. I argue that these models, which highlight quite different barriers to communication, lead to similar qualitative predictions. The analysis suggests that it might be useful to develop broader models of coordination based on complexity rather than (or in addition to) conflict of interest.

While the two models reach similar conclusions, the conclusions follow from different assumptions. Different models will be appropriate for different situations. My failure to teach a student a basic concept could be because my explanation is careless or because the student did not pay attention, rather than the student's concern that I would provide misleading information. These explanations are consistent with the complexity model. My failure to learn the accident history of a used car probably is because it is not in the interests of the car dealer to reveal information that would lower my willingness to pay. This phenomenon is more in keeping with the conflict-of-interest model. These are fundamentally different situations and they suggest different remedies to those interested in improving communication outcomes. This paper provides a rudimentary framework for the study of complexity issues in economics.

This is far from the first paper to add complexity to economic models of communication. Hertel and Smith [12] and Jäger, Koch-Metzger, and Riedel [13] analyze broadly related models in which the message space is finite and communication is costly for the Sender. The underlying communication game in these papers is similar to basic Sender-Receiver game in this paper.[2] By assuming only one player bears the cost of communication, these papers avoid the possibility of coordination failure and hence the multiplicity problem identified here. Dewatripont and Tirole [8] study a specific model in which there are complementarities in the communication process that lead to multiple equilibria. Finally, there is a substantial theoretical literature on communication in organizations that focuses on complexity as the barrier to efficient information exchange. Arrow [1] provides a conceptual framework for this line of research. Cremer, Garicano, and Prat [6] is a more recent contribution.

Information theory is not concerned with conflict of interest but, to my knowledge, does not pay attention to the implications of an environment in which parties non-cooperatively

[1] This restriction rules out standard signaling models (pioneered by Spence [17]). In Spence's model, which has broad applications, a Sender with more favorable information has a lower marginal cost of signaling. For example, the ability to communicate innate skill by doing well on a test or acquiring more education may be increasing in skill level. The restriction also rules out disclosure games (Grossman [10] and Milgrom and Roberts [16]) in which the Sender can hide information by making an imprecise statement but cannot lie.

[2] Models that incorporate costly lying, for example Kartik [14], have fundamentally different motivations and conclusions than the complexity models.

make decisions that determine their ability to communicate. This paper contains a simple formulation of complexity. I ignore natural and important questions motivated by computational or algorithmic complexity. Specifically, I do not study whether it is difficult to compute a best response or an efficient coding of messages. I also ignore problems that arise because the communication channel is noisy so that the Sender does not perfectly control what the Receiver hears.[3]

The next two sections present the conflict-of-interest and the complexity models and highlights their common features. Section IV points out that the two models do not make identical predictions. There are ways to analyze the influence of conflict and complexity on communication. Section V is a conclusion.

## II. Conflict of Interest

There are two agents, an informed Sender ($S$) and an uninformed Receiver ($R$). These agents have preferences that depend on an action $a \in A$ and a state of the world $\theta \in \Theta$. I refer to $\theta$ as the type of the Sender. Denote these preferences by $U^i(\cdot)$ for $i = R, S$. There is an abstract set of messages $M$. Nature selects $\theta$ according to a common-knowledge distribution, $p(\cdot)$. $S$ learns $\theta$, selects a message $m \in M$, and $R$ selects an action $a \in A$. Formally, a (mixed) strategy for the Receiver is denoted by $\alpha$, where $\alpha(a \mid m)$ is the probability that the Receiver takes action $a \in A$ given message $m \in M$. A (mixed) strategy for the Sender is denoted by $\sigma$, where $\sigma(m \mid \theta)$ is the probability that the Sender sends message $m$ when her type is $\theta \in \Theta$. An equilibrium consists of a strategy profile $(\alpha^*, \sigma^*)$ and a belief function $\mu^*$, where $\mu^*(\theta \mid m)$ is the probability that the Receiver believes that the Sender's type is $\theta$ given message $m$, such that:

$$\alpha^*(a \mid m) > 0 \text{ implies } a \text{ solves } \max_{a' \in A} \int U^R(a', \theta) d\mu(\theta \mid m), \tag{1}$$

$$\sigma^*(m \mid \theta) > 0 \text{ implies}$$

$$m \text{ solves } \max_{m' \in M} \int U^S(a, \theta)\alpha^*(a \mid m')dm', \tag{2}$$

and

$$\mu(\theta \mid m) = \frac{p(\theta)\sigma^*(m \mid \theta)}{\int p(\omega)\sigma^*(m \mid \omega)d\omega} \tag{3}$$

whenever $\int p(\omega)\sigma^*(m \mid \omega)d\omega > 0$. Condition (1) states that $\alpha^*$ is a best response to $\mu^*$. Condition (2) states that $\sigma^*$ is a best response to $\alpha^*$. Condition (3) states that $\mu^*$ is consistent with the prior and $\sigma^*$ (Bayes's Rule determines $\mu^*(\cdot \mid m)$ for all $m$ whenever possible). An equilibrium $(\alpha^*, \sigma^*; \mu^*)$ induces a distribution over $(\theta, a)$ ($\int_m \alpha^*(a \mid m)\sigma^*(m \mid \theta)dm$) that I call the **equilibrium outcome**.

I study a special case of this model in which $A = \Theta = [0, 1]$, $U^i$ are smooth functions, strictly concave in action and with strictly positive mixed partial derivative. The structure of $M$ is not important provided that its cardinality is sufficiently large. For concreteness, take $M = [0, 1]$. Under these assumptions, there is a unique solution to $\max_{a \in [0,1]} U^i(a, \theta)$, which I denote $a_i^*(\theta)$. The assumption that the mixed partial derivative is positive implies that $a_i^*$ is strictly increasing. Assume further that the Sender's preferences include a parameter $b$ such that $U^S(a, \theta; b) = U^R(a, \theta)$ when $b = 0$ and that

$$\frac{\partial^2 U^S(a, \theta; b)}{\partial\theta\partial b} > 0.$$

When $b = 0$, $S$ and $R$ have identical preferences. When $b > 0$, $a_S^*(\theta) > a_R^*(\theta)$ and the difference between $a_S^*$ and $a_R^*$ is increasing in $b$. These properties make $b$ a sensible measure of the degree of conflict of interest between $S$ and $R$. A tractable special case of this model, which I will subsequently call "the uniform-quadratic example," arises when $U^S(a, \theta; b) = -(a - \theta - b)^2$, $U^R(a, \theta) = -(a - \theta)^2$, and $p(\theta) = \theta$ on $[0, 1]$. Assume $b > 0$.

Crawford and Sobel [5] provide a characterization of equilibria for this model. Before stating the result, I make a definition and introduce more notation.

Given an equilibrium $(\alpha^*, \sigma^*; \mu^*)$, the set of actions induced by the equilibrium is

$$\{a : \int \int \alpha^*(a \mid m)\sigma^*(m \mid \theta)p(\theta)d\theta dm > 0\}.$$

For a Borel measurable $P \subset [0, 1]$, let

$$\bar{a}(P) = \arg\max_a \int_P U^R(a, \theta)p(\theta)d\theta.$$

For $\theta' > \theta$ and $P$ equal to the interval $(\theta, \theta')$, overuse notation slightly and let $\bar{a}(\theta, \theta') \equiv \bar{a}(P)$.

*Proposition 1:* There exists $N^*$ such that for every $N$ with $1 \le N \le N^*$, there exists an equilibrium in which the set of induced actions has cardinality $N$ and there is no equilibrium that induces more than $N^*$ actions. Equilibria are described by a partition $\theta(N) = (\theta_0(N), \ldots, \theta_N(N))$ with $0 = \theta_0(N) < \theta_1(N) < \cdots < \theta_N(N) = 1$, and distinct messages $m_i$, $i = 1, \ldots, N$, such that for all $i = 1, \ldots, N - 1$,

$$U^S(\bar{a}(\theta_i(N), \theta_{i+1}(N)), \theta_i(N)) - U^S(\bar{a}(\theta_{i-1}(N), \theta_i(N)), \theta_i(N)) = 0, \tag{4}$$

$$\mu(m \mid \theta) = \begin{cases} 1 & \text{if } \theta \in (\theta_{i-1}(N), \theta_i(N)] \text{ and } m = m_i \\ 0 & \text{otherwise,} \end{cases} \tag{5}$$

and

$$\alpha(a \mid m_i) = \begin{cases} 1 & \text{if } a = \bar{a}(\theta_{i-1}(N), \theta_i(N)) \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

The proposition characterizes the relationship between types and actions in equilibrium. In equilibrium the Sender partitions $\Theta$ into a finite set of intervals. Equilibrium messages identify which interval contains the Sender's type. The Receiver's action responds optimally to this information. Condition (4) guarantees that the Sender accurately identifies the partition element that contains her type. The proposition implies that

[3] Hernández and Bernhard von Stengel [11] is a recent example.

there is always an equilibrium in which no information is transmitted ($N = 1$) and there is never an equilibrium with full communication (because $N^*$ is finite). It suggests that there are multiple equilibria. Indeed, when $b$ is sufficiently small $N^* > 1$, Crawford and Sobel show that if a regularity condition (satisfied in the uniform-quadratic example) holds, then these is essentially one equilibrium outcome for each $N$ with $1 \leq N \leq N^*$; $N^*$ decreases with $b$;[4] and if $U_i^*(N)$ denotes Player $i$'s expected utility in the equilibrium with $N$ induced actions, then $U_i^*$ is increasing in $N$ and, for fixed $b$, $U_i^*(N)$ is decreasing in $b$.

The standard cheap-talk game therefore provides four qualitative insights, summarized informally are:

1) Failure to Communicate is always possible.
2) Perfect Communication is not possible in equilibrium when conflict of interest exists.
3) Whenever non-trivial communication is possible in equilibrium, there are multiple equilibrium outcomes.
4) When $b$ decreases, the quality of information communicated in equilibrium and the potential benefits of communication increase.

The conclusion that non-trivial communication is possible ($N^* > 1$) in interesting situations was perhaps the most surprising conclusion. In a wide range of natural economic examples, the conflict of interest between Sender and Receiver is so strong that $N^* = 1$. For example, imagine a labor-market setting in which $\theta$ represents the true productivity of a worker (Sender) and $a$ is her wage. Competitive forces may force wages to be equated to expected productivity. If so, it is sensible to assume that $U^R(a, \theta) = -(a - \theta)^2$. On the other hand, one would expect the worker's utility to be strictly increasing in $a$. In this setting, the worker will make whatever message leads to the highest wage independent of her type. If all types send the same message, the message will convey no information. Non-trivial communication is possible in the model because $S$ and $R$ have some reasons to coordinate.

## III. Complexity

The main insights from the model in Section II follow from the assumption that the Sender and Receiver have different interests. Full communication is an equilibrium (and arguably the most plausible prediction) when the Sender and Receiver have identical preferences. Nonetheless, it is absurd to attribute all failures to communicate to conflicts of interest. This section introduces a simple model of communication with no conflict of interest over actions that shares all of the conclusions highlighted from conflict-of-interest model.

Assume that the state space $\Theta$, the action space $A$, the prior $p(\cdot)$, and the players $S$ and $R$ are as before. Assume that Sender and Receiver have common preferences $U(\cdot) = U^R(\cdot) = U^S(\cdot)$ ($U^S(\cdot)$ no longer depends on $b$) defined over state and action. To incorporate complexity into the model, prior to sending a message, the Sender and Receiver simultaneously and independently select positive integers, $c_i$, called capacities, for $i = R, S$. I assume that capacity $c_i$ costs $C_i(c_i)$, where $C_i(\cdot)$ is strictly increasing and $\lim_{c_i \to \infty} C_i(c_i) = \infty$.

The players learn the capacity choice of their opponent and then play a communication game. The communication game operates like the game in Section II. The values $c_R$ and $c_S$ determine the message space and how the Receiver perceives the messages. Specifically, $M = \{1, \ldots, c_S\}$. $c_R$ determines the number of messages that the Receiver can distinguish. Concretely, assume that if $S$ sends $m$, then if $c_R \geq c_S$ or $m \leq c_R$, $R$ receives $m$; if $m > c_R$, then if $S$ sends $m$, the message that $R$ receives is 1.[5]

$c_i$ is Player $i$'s investment in communication skills. For example, $S$ may need to pay a cost to describe each successive digit of $\theta$ and $R$ may need to pay to be able to understand each digit sent by $S$. Notice that the minimum of $c_R$ and $c_S$ determines the maximum amount that can be communicated.

Given the choices of $c_S$ and $c_R$, the communication game typically has multiple equilibria. For example, the Sender can "force" the Receiver to invest in extra communication capacity. Suppose that $S$ picks $c_S = 2$, and sends $m = 1$ for all $\theta$ if $c_R = 2$ and $m = 1$ if $\theta < .5$ and $m = 2$ if $\theta \geq .5$ if $c_R > 2$. Provided that the cost of capacity is sufficiently small, a best response for $R$ would be to set $c_R = 3$ and to respond optimally to the information in $S$'s message. (To support this kind of outcome, $R$'s action conditional on $c_i = 2$ for $i = R, S$ would be to play $\bar{a}([0, 1])$ independent of $S$'s message.) As in the conflict-of-interest model, multiple equilibria arise because there are different ways in which the players can coordinate on language. The potential problem is heightened for the model of this section because, as the example illustrates, players can use the choices of capacity to coordinate on play in the communication stage. I will rule out indeterminacy in the communication stage by restricting attention to **maximal** equilibria. In a maximal equilibrium, given $c_S$ and $c_R$, players coordinate on the (unique) efficient outcome of the communication game. That is, loosely, players communicate as much as possible given capacity constraints. Formally, let $c^* = \min\{c_S, c_R\}$. Let $\mathbb{P}$ be the set of partitions of $\Theta$ with cardinality at most $c^*$. A generic element of $\mathbb{P}$ is $P = (P_1, \ldots, P_{c^*})$, where $P_i$ are disjoint (possibly empty) subsets of $\Theta$ with $\cup_{i=1}^{c^*} P_i = \Theta$. I assume that the continuation equilibrium induces a partition $P^*$ that solves:

$$\max_{P \in \mathbb{P}} \sum_{i=1}^{c^*} \int_{P_i} U^S(\bar{a}(P_i), \theta) p(\theta) d\theta. \tag{7}$$

If $P^*$ solves (7), then an associated equilibrium of the communication game involves $S$ sending message $m$ if and only if $m \in P_m^*$ ($m = 1, \ldots, c^*$) and $R$ responding to message $m$ with the action $\bar{a}(P_m^*)$.

Under the maintained assumptions on preferences, the solution to (7) is an interval partition with no empty segments.

[4] $N^*$ depends on $b$. I suppressed this dependence in the notation.

[5] More generally, let $\gamma : M \to \Delta(\{1, \ldots, c_R\})$, where $\Delta(X)$ is the set of probability distributions on $X$ and $x \in X$ is identified with the distribution in $\Delta(X)$ that places probability 1 on $x$. Assume that $\gamma(m) = m$ for $m \leq c_S$ and arbitrary otherwise. When $S$ sends $m$, $R$ receives the distribution $\gamma(m)$.

That is, $P^* = (P_1^*, \ldots, P_{c^*}^*)$ can be represented by cutoffs $t_0, \ldots, t_{c^*}$, where $0 = t_0 < t_1 < \cdots < t_{c^*} = 1$ and $P_i^* = (t_{i-1}, t_i)$ for $1 < i \le c^*$ and $P_1^* = [0, t_1]$. Furthermore, $U^S(\bar{a}(P_i^*), t_i) = U^S(\bar{a}(P_{i+1}^*), t_i)$ for $t_i = 1, \ldots, c^* - 1$. Crawford and Sobel's [5] arguments guarantee that such a partition exists for all $c^*$ when $U^S(\cdot) = U^R(\cdot)$.

Since $S$ and $R$ have identical preferences in the communication phase, the equilibrium outcome that I select conditional on the choice of $c_S$ and $c_R$ is (uniquely) efficient in the set of equilibria. A variety of equilibrium-refinement arguments (for example, Chen, Kartik, and Sobel [4] and Kartik and Sobel [15]) make the selection.

Let $V^*(c^*)$ be the value of problem (7). $V^*(\cdot)$ is strictly increasing and bounded above (by $\int U^R(a^R(\theta), \theta) d\theta$). Characterizing the equilibria of the full game is now simple. For $i \neq j$, Player $i$ chooses $c_i$ to maximize $V^*(\min\{c_R, c_S\}) - C_i(c_i)$ (taking $c_j$ as given). Since capacity is costly, $c_i \le c_j$ in equilibrium for all $i$ and so players choose equal capacities.

Let $n_i^*$ solve $\max_{c_i} V^*(c_i) - C_i(c_i)$. Since $\lim_{c \to \infty} C_i(c) = \infty$ and $V^*(\cdot)$ is bounded, $n_i^*$ exists. Let $n^* = \min\{n_S^*, n_R^*\}$. I say that the positive integer $n$ is **attainable** if $n \le n^*$ and $\max_{1 \le c \le n} V^*(c) - C_i(c) = V^*(n) - C_i(n)$. Clearly $n = 1$ and $n = n^*$ are attainable. All $n \in \{1, \ldots, n^*\}$ are attainable if $V(c) - C_i(c)$ is increasing in $c$ for $c \in \{1, \ldots, n^*\}$.

*Proposition 2:* For every attainable $n$, there exists a maximal equilibrium in which $c_S = c_R = n$ and in every maximal equilibrium $c_S = c_R = n$ for some attainable $n$. The signaling component of equilibrium strategies is described by a partition $t(n) = (t_0(n), \ldots, t_n(n))$ with $0 = t_0(n) < \cdots < t_n(n) = 1$, and distinct messages $m_i$, $i = 1, \ldots, n$, such that for all $i = 1, \ldots, n-1$,

$$U^S(\bar{a}(t_i(n), t_{i+1}(n)), t_i(n)) - U^S(\bar{a}(t_{i-1}(n), t_i(n)), t_i(n)) = 0, \tag{8}$$

$$\mu(m \mid t) = \begin{cases} 1 & \text{if } t \in (t_{i-1}(n), t_i(n)] \text{ and } m = m_i \\ 0 & \text{otherwise,} \end{cases} \tag{9}$$

and

$$\alpha(a \mid m_i) = \begin{cases} 1 & \text{if } a = \bar{a}(t_{i-1}(n), t_i(n)) \\ 0 & \text{otherwise.} \end{cases} \tag{10}$$

The Receiver will never receive a message $m > c_S$, since capacity is costly, he would not pick $c_R > c_S$ in equilibrium. Similarly, if $c_S > c_R$, the Sender would not gain from sending $m > c_R$ because she would do at least as well with one of the first strategies. If $c_S = c_R = n$ and $n$ is not attainable, then one player has a profitable deviation.

Proposition 2 provides qualitative conclusions that parallel those of Proposition 1. Failure to communicate is always possible because there exists an equilibrium in which neither player invests in capacity. Perfect communication is not possible in equilibrium because capacity is costly. Eventually, the marginal gain from communication does not justify the added cost in capacity necessary to increase the precision of messages. There are multiple equilibria whenever $n^* > 1$. The multiplicity is a consequence of the coordination problem that comes from simultaneous capacity choice. Finally, the equilibrium with capacity $n^*$ is the most preferred equilibrium for both players. This property follows because a player can force an equilibrium with smaller capacity through a unilateral deviation to a smaller capacity. That is, if $n' > n$ and $V^*(n) - C_i(n) > V^*(n') - C_i(n')$ for some $i$, then $n'$ cannot be an equilibrium. Finally, observe that uniform increases in $C_i$ lead to decreases in $n^*$ (in the same way that increases in $b$ led to decreases in $N^*$ in the conflict-of-interest model).

While the propositions deliver similar conclusions, the conclusions follow for different reasons. The existence of informative equilibria is obvious in the complexity model when capacity costs are small: Information is valuable to the Receiver and, by assumption, the players will exploit opportunities to communicate when communication channels exist. If $V(2) - V(1) > C_i(2) - C_i(1)$ for $i = S$ and $R$, then it will be optimal for the one player to invest in communication capacity if the other does. The argument is not so simple in the conflict-of-interest model. When the Sender and Receiver have identical preferences, it is clear that there exists a fully informative equilibrium in which the Sender's message fully reveals the state. Hence it is tempting (and, with appropriate care in formulation, true) to assert that informative equilibria exist when there is a small conflict of interest "by continuity." This argument is subtle because fully revealing equilibria do not exist when the conflict of interest is small.

Multiple equilibrium outcomes arise in the conflict-of-interest game because the association between messages and actions (the meaning of messages) arises endogenously. In both models there is always an equilibrium outcome in which the Receiver takes the same action in all states of the world. In the conflict-of-interest model, one can take $\alpha(\bar{a}([0,1]) \mid m) = 1$ for all $m$, so that the Receiver takes the ex ante optimal action independent on the message; $\sigma(m^* \mid \theta) = 1$ for all $\theta$ and some $m^*$, so that $S$'s message is type independent; and $\mu(\theta \mid m) = p(\theta)$ for all $\theta$, so that $R$'s posterior beliefs are always equal to the prior. In the complexity model, setting $c_R = c_S = 1$ rules out communication in the second stage. The existence of this equilibrium reflects a common feature in the models: One person cannot unilaterally guarantee effective communication, but one person can guarantee a complete breakdown. The way in which one player can shut down communication differs. In the conflict-of-interest model, $R$ learns nothing if $S$'s message does not depend on the state and $S$ cannot influence $R$ if $R$'s action is independent of the message. In the complexity model, one player cannot communicate if the other makes no investment ($c_i = 1$).

Multiple equilibrium outcomes arise in the complexity game because players must coordinate on their choice of capacity.[6]

[6]The assumption that the Sender and Receiver have common preferences over actions is not sufficient to rule out multiplicity due to the endogenous association between messages and actions. I rule out this multiplicity by assumption because when there is no conflict of interest, coordinating on a mutually beneficial association is easy to justify intuitively and possible to justify theoretically.

The coordination problem is a direct consequence of the assumption that players choose capacities simultaneously and that their choices are complementary. If only one player needs to make a complexity choice (for example, if $R$ had an infinite capacity), or if players chose complexity sequentially, then multiplicity would disappear. To confirm the second assertion, assume $V^*(c) - C_i(c)$ is strictly increasing for $c \leq c_i^*$ and first one player selects capacity and then the other does. The only maximal equilibrium outcome involves $c_R = c_S = c^*$. If the first mover sets $c \leq c^*$, then the second mover will match it. Hence the first mover will never choose a capacity less than $c^*$. Whichever player has $c_i^* = c^*$ will play to guarantee that equilibrium capacity never exceeds $c^*$.

The idea that communication requires complementary investments seems relevant in most natural settings, but my formulation neglects the possibility that one player's investment may substitute for another's. It is easy to imagine situations in which the Sender can reduce the Receiver's cost of interpretation by making a more careful argument. Complexity models in which capacity investments are substitutes need not have multiple maximal equilibria. Concretely assume that the sum of capacity choices (rather than the minimum) determines how much information that can be transmitted. In a maximal equilibrium, Player $i$ selects $c_i$ to maximize $V^*(c_1 + c_2) - C_i(c_i)$. This game will have a unique equilibrium under plausible assumptions on the cost functions.

The assumption that players learn their opponent's capacity choice is strong. The consequences of relaxing this assumption depend critically on what players do learn and how one models what happens when the Sender uses messages that the Receiver cannot understand. Blume and Board's [2] analysis provides some insight into possible results.

Another important assumption is that $S$ makes her capacity investment prior to learning $\theta$. If the Sender conditions her choice of $c_S$ on the state of the world and the Receiver can observe $c_S$, then the Sender's capacity choice would become an additional signal to $R$. One can imagine situations in which the Receiver learns more about the state of nature from $S$'s choice of language than from her choice of message.

When $U^S = U^R$ conflicts of interest may arise in this model because the players have different costs for adding capacity. Players could easily have different preferences over the choice of complexity. A player with lower capacity costs would prefer a higher choice of $c^*$ than the other player. The analysis demonstrates that the players do not have conflicts over equilibrium capacities because the preferences of the higher-cost agent determine the outcome (because this player can simply refuse to make the higher investment). This observation also has a parallel in model of Section II. It is clear that the players have different preferences over outcomes. It is a conclusion of the analysis that (under regularity conditions) they do not have conflicts over equilibrium outcomes.

## IV. Identification

The main conclusions of the two models are similar, but both models can be useful. This section briefly describes situations that in which complexity and conflict are both likely to influence outcomes and ways in which one might distinguish the predictions of one model from the other.

One could design laboratory experiments that control for differences in preferences and study the extent to which the predictions of the conflict-of-interest model hold. In the lab, one can induce values for $U^S$ and $U^R$ and test predictions of the conflict-of-interest model.[7] It would be straightforward to induce complexity costs as well, although it may be difficult to control for costs that are inherent in an experimental design.

The models made different predictions. Consequently, one might distinguish between them through their predictions. The form of communication in the models differ. For example, in the uniform-quadratic example, the equilibrium partition of states will involve intervals of equal length in the complexity model. In the conflict-of-interest model, the equilibrium partition involves intervals that increase in length as $\theta$ increases. This difference is not an intrinsic difference between the two approaches. Hertel and Smith [12] introduce a model of communication in which messages have differential costs to the Sender (the Receiver processes these messages without cost). In this model, it is in the Sender's interest to use more costly messages less frequently. This effect leads to non-uniform equilibrium partitions even in the uniform-quadratic example with no conflicts of interest.

Although both models typically exhibit multiple equilibria, equilibrium selection arguments may operate differently. Applied work typically selects the "most informative" equilibrium in the conflict-of-interest model.[8] This selection has theoretical support (for example, Chen, Kartik, and Sobel [4], Kartik and Sobel [15], and Gordon [9]). Selecting the equilibrium outcome with capacity $n^*$ in the complexity model would require a different argument. This outcome leads to higher ex ante expected utility than any other equilibrium, but lower capacity choices are likely to lead to lower risk. Indeed, the capacity choice in the complexity model shares characteristics of "minimum games" (see Van Huyck, Battalio, and Beil [18]) in which players rarely reach the efficient equilibrium in practice. This discussion suggests that inefficient equilibria may be more likely to arise in the complexity model than in the conflict model. Whether conflict or complexity leads to more losses relative to the benchmark of perfect communication (rather than the most efficient equilibrium) depends on the parameters (degree of conflict versus cost of capacity).

Agents may respond to different strategic environments differently. In the complexity model, $R$ would be happy to delegate decision making to the Sender. That is, the Receiver would willingly give $S$ the authority to make decisions without communicating to the Receiver. This arrangement would save

[7]In fact, there is a literature on this topic. See, for example, Cai and Wang [3].

[8]The literature focuses on equilibrium outcomes in which $N^*$ actions are induced. Since the equilibrium partition associated with an $N'$-action equilibrium need not be a refinement of the partition for an $N$-action equilibrium for $1 < N < N'$, the equilibrium with $N^*$ actions need not be (uniquely) the most informative. No equilibrium with fewer than $N^*$ actions induced will be more informative than the $N^*$-action equilibrium.

communication costs but would not reduce the quality of the type-action distribution. On the other hand, when conflicts of interest arise, delegating has the benefit of permitting decisions to be made using full information but will lead to decisions that are different from what an informed Receiver would make.[9]

In natural settings, there will often be strong intuition about which model is more appropriate, although sometimes both conflict and complexity might place a first-order role in influencing outcomes. For example, when an informed doctor fails to educate her patient about treatment options, we could attribute the failure to both complexity and conflict of interest. The complexity comes from the fact that the doctor has expert knowledge. It may take time and skill to communicate this knowledge to a patient who must still devote energy to evaluating the technical information. The conflict may arise from the fact that the doctor has different preferences than the patient. Perhaps the doctor likes to perform surgery or has financial incentives to over treat. More innocently, the patient may have different trade offs about the costs and benefits of particular treatments.

## V. Conclusion

Complexity plays a role in communication, but economic models that treat conflict of interest as the driving force in strategic interaction may be paying insufficient attention to complexity. This paper notes that complexity considerations may lead to many of the same qualitative conclusions that follow from the assumption of conflict of interest. The logic behind the results for the complexity model are much simpler and the conclusions are intuitively and formally less surprising than parallel conclusions from the conflict-of-interest model. Specifically, the conclusion that non-trivial communication is possible when there is conflict may be surprising. The conclusion that non-trivial communication is possible when there is no conflict and sufficiently small capacity costs is not. The existence of multiple type-action distributions may be surprising in the conflict-of-interest model. It is not a surprise in the complexity model, but even there it is subtle, since the multiplicity is a consequence of the assumption that there are complementaries in the production and processing of information. The complementarity seems to capture an important feature in natural communication, but it is rarely given prominence in the literature.

Economic models of communication that focus on conflict of interest may distract attention from something obvious. It would be valuable to study the implications of richer models of communication costs on the nature of communication.

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[9] Dessein [7] is a paper that compares cheap talk to delegation when there is conflict of interest.

## References

[1] Kenneth J. Arrow. *The Limits of Organization*. Norton, New York, NY, 1974.

[2] Andreas Blume and Oliver J. Board. Language barriers. Technical report, University of Pittsburgh, November 30 2009.

[3] Hongbin Cai and Joseph Tao-Yi Wang. Overcommunication in strategic information transmission games. *Games and Economic Behavior*, 56(1):7–36, 2006.

[4] Ying Chen, Navin Kartik, and Joel Sobel. On the robustness of informative cheap talk. *Econometrica*, 76(1):117–136, January 2008.

[5] Vincent P. Crawford and Joel Sobel. Strategic information transmission. *Econometrica*, 50(6):1431–1451, November 1982.

[6] Jacques Cremer, Luis Garicano, and Andrea Prat. Language and the theory of the firm. *The Quarterly Journal of Economics*, 122(1):373–407, 2007.

[7] Wouter Dessein. Authority and Communication in Organizations. *Review of Economic Studies*, 69(4):811–838, 2002.

[8] Mathias Dewatripont and Jean Tirole. Modes of Communication. *Journal of Political Economy*, 113(6):1217–1238, 2005.

[9] Sidartha Gordon. Iteratively stable cheap talk equilibrium. Technical report, Université de Montréal, May 2011.

[10] Sanford Grossman. The role of warranties and private disclosure about product quality. *Journal of Law and Economics*, 24:461–483, 1981.

[11] Penélope Hernández and Bernhard von Stengel. Nash codes for noisy channels. Technical report, LSE, February 2012.

[12] Johanna Hertel and John Smith. Not so cheap talk: Costly and discrete communication. Technical report, Rutgers University-Camden, June 2010.

[13] Gerhard Jäger, Lars Koch-Metzger, and Frank Riedel. Voronoi languages: Equilibria in cheap talk games with high-dimensional types and few signals. *Games and Economic Behavior*, 73:517—537, 2011.

[14] Navin Kartik. Strategic communication with lying costs. *Review of Economic Studies*, 76(4):1359–1395, 2009.

[15] Navin Kartik and Joel Sobel. Effective communication in cheap-talk games. Technical report, UCSD, in preparation 2012.

[16] Paul Milgrom and John Roberts. Limit pricing and entry under incomplete information: An equilibrium analysis. *Econometrica*, 50(2):443–459, March 1982.

[17] A. Michael Spence. *Market Signaling*. Harvard University Press., Cambridge, MA., 1974.

[18] John B. Van Huyck, Raymond C. Battalio, and Richard O. Beil. Tacit coordination games, strategic uncertainty, and coordination failure. *The American Economic Review*, 80(1):234–248, 1990.