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OPTIMAL RELEVANCE IN IMPERFECT INFORMATION GAMES

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Optimal Relevance in Imperfect Information Games

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June 2017

I analyze how natural language transmits information about intended actions. This work on imperfect information games complements work on incomplete information games where natural language transmits information about a sender's type. Unlike solution concepts based on Nash equilibria, the solution concept first takes into account that a message's literal meaning conveys common understandings, incorporating the semantic feature that only a shared natural language is comprehensible. Second, the equilibrium meaning, which has to do with the actual use of language in a specific game, depends on the strategic context. This setup can be interpreted as a formal pragmatics where the credibility of the message depends on the sender's incentives to be truthful. Words are not proof of what they state, so mistrust equilibria are always possible. In trust equilibria, the sender aims at optimal relevance.

JEL classification codes: D83, C72

Key words: asymmetric information, unilateral communication, conventional signs, semantics, pragmatics

I. Introduction

I propose to analyze unilateral communication in imperfect information games with a framework where one player (the sender) may announce its intentions to another (the receiver) using messages from a shared natural language with a literal meaning that both players can understand. These messages can be seen as either promises or threats.

This framework is most closely related to the analysis of imperfect information games in Roger Myerson (1989), where natural language is the medium of communication, which restricts the interpretation of messages in equilibrium. An important consequence is that the literal and effective meanings coincide for the case of credible messages. However, his setup and equilibrium concepts are quite different: the communication process is a

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negotiation where there is a mediator between both parties, and the mediator uses a correlating device to implement optimal strategies as in the correlated equilibria in Robert Aumann (1974).

The meaning correspondence in Stefano Demichelis and Jörgen Weibull (2008) — the relation between the announced message and the intended action — is close to the emphasis here on literal meaning. However, whereas their focus is on the issue of evolutionary stability, here I am instead concerned about the conditions under which a pre-existing natural language shared by the players allows the sender to successfully communicate to the receiver its intended moves. Another relevant difference is that their analysis is a variant of costly talk games, where they introduce lexicographic preferences of the sender for honesty. As Navin Kartik (2009) explains in the context of incomplete information games, with costly talk a message has a literal or exogenous meaning for the sender and there is a psychological cost of distorting the truth (either because lying is shameful or because misrepresentations have to be fabricated). However, costly talk overlooks the role of the receiver in a verbal communication process, not taking into account that the sender cannot verbally communicate meaning, either true or false, without a shared language because otherwise there is no way for the receiver to understand the messages.

This setup strives to capture the feature that verbal communication allows uttering messages that point to moves by drawing on earlier work in incomplete information games in which language allows pointing to types. This literature was initiated by Vincent Crawford and Joel Sobel (1982) with their analysis of unilateral communication in cheap-talk games where messages are payoff-irrelevant. Joseph Farrell (1993: 515) points out that meaning cannot be learned from introspection in cheap-talk models: if there is an informative equilibrium, there are infinitely many because any permutation of messages across meanings gives another equilibrium. In other words, the interpretation of messages by the receiver is solely given by their assignment to sender types in each (perfect Bayesian) Nash equilibrium, as in a standard signaling game. Building on the strategic framework in Crawford and Sobel (1982), and inspired by Farrell's (1993: 515) deep insight that, credible or not, natural language has a comprehensible meaning, Jorge Streb and Gustavo Torrens (2015) develop an alternative solution concept for sender-receiver games that requires trusted messages to be true in equilibrium. This drastically restricts the set of informative equilibria to those where the literal meaning, or the common understandings it conveys, is the equilibrium meaning. I now extend this idea to imperfect information games where a shared natural language is used as the medium of communication.

Since in unilateral communication games with imperfect information the sender has to pick both a message and a move, this does not allow isolating information transmission. In this sense, these games are more complicated than the sender-receiver games where there is unilateral communication under incomplete information. However, in another sense the analysis is much simpler: there is only one type of sender, so its preferences over outcomes are well defined, unlike incomplete information games where different sender types may wish to achieve different outcomes. Once the sender has the possibility of announcing what it plans to do, it has an incentive to point to its preferred outcome. This is the issue of optimal relevance.

The paper is structured as follows. Section II extends the Streb and Torrens (2015) solution concept of meaningful-talk equilibria from incomplete information games to imperfect information games. Instead of continuation games, there are now subgames, so the sender has an incentive to select its (weakly) preferred outcome. This provides a partial formalization of the suggestion in Thomas Schelling (1960: 59) on how explicit communication can be an alternative to implicit communication through focal points as a way to select among Nash equilibria. Section III illustrates the impact of verbal communication in several classic games. This approach can be linked to the notion of maximal information transmission in Crawford and Sobel (1982), and to the idea of optimal relevance in Dan Sperber and Deirdre Wilson (1995). Section IV shows that this game-theoretic framework can be interpreted as a formal pragmatics, i.e., a study of utterance comprehension within an idealized strategic context. This allows capturing an essential feature of natural language as a conventional sign that can point to moves, as well as to types. Section V contains the closing remarks.

II. Imperfect Information Language Games

While the classic paper by Spence (1974) concentrates on signals about the sender's type, here I look at signals about intended moves. The verbal messages that a sender can utter are a special class of signal that a sender can voluntarily pick to indicate something to the receiver. This parallels the literature on incomplete information games using verbal messages kicked off by Crawford and Sobel (1982), in particular the work by Streb and Torrens (2015). More generally, this provides a framework to analyze language games, i.e., asymmetric information games where verbal messages are used to convey information about moves or types from the sender to the receiver.

A. Message, Meaning, and Referent

Here messages are sentences that can express propositions, where reference assignment in a concrete context is needed to yield a full proposition which is either true or false. Symbolic information is considered as the sole vehicle for information transmission, abstracting from body language like tone of voice which can convey additional information.

In contrast to natural signs like smoke, language is composed of symbols or conventional signs that depend on each specific community: while the phrase "Fire!" is used in English, "¡Fuego!" is used in Spanish (Ricardo Crespo 2012). Signs as such do not provide evidence of anything, they simply point to types or actions. Linguistic symbols are the most important subset of conventional signs. They have three elements (Daniel Chandler 1994): (i) the *signifier* "m", what in economics is typically called the *message*, e.g., "Meet me at noon at the information booth in Grand Central Station."; (ii) the *signified* $\widehat{m}$, what we think of when we read or hear the message — a distinction is drawn below between the *literal* and the *equilibrium meanings*; and (iii) the *referent* m, where both the *object* to which the proposition allegedly applies, e.g., the intended action of the sender, and the *truth-value* of the proposition are considered.

B. Preliminary Concepts and Timing

First consider a simultaneous game without communication where player S has to pick an action $a^S \in \mathrm{A}^\mathrm{S}$ and player R has to pick an action $a^R \in \mathrm{A}^\mathrm{R}$. If there is a unique Nash equilibrium, like in the prisoner's dilemma, then the expected outcome is easy to foresee. In that context, verbal communication by itself does not do anything.

In many games there are instead multiple Nash equilibria, like in the battle of the sexes. In that context, I will assume that in the game without communication one of those equilibria holds and treat the beliefs in that equilibrium as the priors. The priors will typically be given by a mixed-strategy equilibrium, but they could potentially be given by a pure-strategy equilibrium. There may now be incentives for verbal communication if player S (for "sender") has the possibility of sending a verbal message to player R (for "receiver") that can affect the equilibrium outcome in the game with unilateral communication. This is the question I tackle.

A bit of terminology, which draws on Streb and Torrens (2015), is presented. A natural language shared by both players is denoted by $"\mathbb{M}"$. This allows talking about different partitions of the world at large $\mathbb{W}$, with statements $"\mathrm{Q}"$ that point to a subset $\mathrm{Q} \subset \mathbb{W}$. Quotes differentiate the plane of language from that of reality. In asymmetric information games, the referent Q is unobservable from the receiver's vantage point (in this case, the action that will be taken by the sender), so the receiver uses the literal meaning or, more generally, the common understandings conveyed by the message $"\mathrm{Q}"$ to ascertain the intended action.

As mentioned in the introduction, the receiver can understand the literal meaning of a message uttered by the sender if and only if it belongs to a shared natural language. This is a basic idea in linguistics. Roman Jakobson and Morris Halle (1956: 72), for instance, state that "the efficiency of a speech event demands the use of a common code by its participants." Sperber and Wilson (1995: 43) state that communication is an asymmetric process where "it is left to the communicator to make correct assumptions about the codes and contextual information that the audience will have accessible and be likely to use in the comprehension process." (Here contextual information has to do with the issue of reference assignment to statements like "The door is open." This will be considered to be an unproblematic issue.) As long as the sender sticks to the conventions in a common language, messages $"m" \in "\mathbb{M}"$ will be *comprehensible*; this includes fiction, lies, and economic models.[1] *Incomprehensible* messages are messages $"m" \notin "\mathbb{M}"$.

[1] As Ludwig Wittgenstein (1953: 19) puts it, "Excalibur has a sharp blade" makes perfect sense, whether or not King Arthur's sword exists. De Saussure's also makes the point that the meaning of messages is crucial in communication.

Here I am interested in the subset of moves $\mathrm{W} = \mathrm{A}^{\mathrm{S}} \subset \mathbb{W}$ that sender S has available, as well as the corresponding subset of messages $"\mathrm{M}" \subset "\mathbb{M}"$, where $"\mathrm{M}"$ is the powerset of $"\mathrm{A}^{\mathrm{S}}"$. This powerset suffices to communicate all the actual moves A^{S} of S in the game, spanning from precise messages that point to any singleton set $\mathrm{Q} = \{\mathrm{a}^{\mathrm{S}}\}$, which refers to a specific move, to imprecise messages that refer to the whole set $\mathrm{Q} = \mathrm{A}^{\mathrm{S}}$. *Relevant* messages refer to a set Q such that $\mathrm{Q} \cap \mathrm{W} \neq \emptyset$ and $\mathrm{Q} \cap \mathrm{W} \subset \mathrm{W}$. Only relevant messages add information to the priors.[2] If, instead, the sender says “I am in New York” in Schelling’s game of *rendez-vous* below, this is the same as no news: though the message $"Q"="\mathrm{A}^{\mathrm{S}}"$ is true, it is irrelevant. Other messages that refer to moves that are not in A^{S} can be treated as equivalent to the message $"\mathrm{A}^{\mathrm{S}}"$, i.e., as *irrelevant* messages that do not add information to the priors.[3]

The sequence is as follows. First, the priors $p(a_i^S) \in \mathrm{P}^S$ about the moves $a_i^S \in \mathrm{A}^{\mathrm{S}}$, for $i = 1, \dots, I$, and $p(a_j^R) \in \mathrm{P}^R$ about the moves $a_j^R \in \mathrm{A}^{\mathrm{R}}$, for $j = 1, \dots, J$, are given by an equilibrium of the game without communication, which in most examples below is the most diffuse mixed-strategy Nash equilibrium. Second, the sender S sends a message $"m_k" \in "\mathrm{M}"$, for $k = 1, \dots, K$, about some intended $a_i^S \in \mathrm{A}^{\mathrm{S}}$. Third, the sender S decides whether to be truthful (veracious) or not, i.e., $V = 1$ or $V = 0$, when picking $a_i^S \in \mathrm{A}^{\mathrm{S}}$, and the receiver R decides whether to be trusting or not, i.e., $T = 1$ or $T = 0$, when picking $a_j^R \in \mathrm{A}^{\mathrm{R}}$. Finally, $v^i\colon \mathrm{A}^{\mathrm{S}}\mathrm{x}\mathrm{A}^{\mathrm{R}} \to \mathcal{R}$ is the utility function of player $i = S, R$. Since A^{S} is a finite set, a finite set of messages "M" suffices to communicate intended actions.

Strategies, beliefs, truth- and trust-functions are given by $(\omega^S, \sigma^S("m"), \sigma^R("m"), \mu("m"), V^S("m", m), T^R("m"))$ where:

- A strategy for the sender is composed of (i) $\omega^S = (\omega^S("m_1"), \dots, \omega^S("m_K"))$, a K-tuple of mixed strategies $\omega^S("m_k") \in [0,1]$, where $k = 1, \dots, K$ and $\sum_{"m_k"} \omega^S("m_k") = 1$, which specifies which messages $"m_k"$ are actually announced, and (ii) $\sigma^S("m") = (\sigma^S("\mathrm{m}_1"), \dots, \sigma^S("\mathrm{m}_K"))$, a K-tuple of probability distributions $\sigma^S("\mathrm{m}_k") = (\sigma^S("\mathrm{m}_k")(a_1^S), \dots, \sigma^S("\mathrm{m}_k")(a_I^S))$, for each $k = 1, \dots, K$,

[2] Sperber and Wilson (1995) define an input as relevant when, together with available contextual assumptions, it yields positive cognitive effects.

[3] Keynes (1921: 59) defines irrelevance in terms of new evidence that does not lead to changing a conclusion.

where $\sigma^S(\text{"m}_\text{k}\text{"})(a_i^S) \in [0,1]$ for $i = 1, \dots, I$, specifying which actions are taken by the sender after each announcement, and $\sum_{a_i^S} \sigma^S(\text{"m}_\text{k}\text{"})(a_i^S) = 1$.

- A strategy for the receiver is $\sigma^R(\text{"}m\text{"}) = (\sigma^R(\text{"m}_1\text{"}), \dots, \sigma^R(\text{"m}_\text{K}\text{"}))$, a K-tuple of probability distributions $\sigma^R(\text{"}m_k\text{"}) = (\sigma^R(\text{"}m_k\text{"})(a_1^R), \dots, \sigma^R(\text{"}m_K\text{"})(a_J^R))$, for $k = 1, \dots, K$, where $\sigma^R(\text{"}m_k\text{"})(a_j^R) \in [0,1]$ for $j = 1, \dots, J$, specifying which actions are taken by the receiver after each announcement, and $\sum_{a_j^R} \sigma^R(\text{"}m_k\text{"})(a_j^R) = 1$.
- A belief for the receiver is $\mu = (\mu(\text{"m}_1\text{"}), \dots, \mu(\text{"m}_\text{K}\text{"}))$, a K-tuple of probability distributions $\mu(\text{"m}_\text{k}\text{"}) = \left(\mu(\text{"m}_\text{k}\text{"})(a_1^S), \dots, \mu(\text{"m}_\text{k}\text{"})(a_I^S)\right)$ for $k = 1, \dots, K$, where $\mu(\text{"m}_\text{k}\text{"})(a_i^S) \in [0,1]$ and $\sum_{a_i^S} \mu(\text{"m}_\text{k}\text{"})(a_i^S) = 1$.
- A sender's *truth function* (or, equivalently, *veracity function*) $V^S: \text{"M"} \text{x} \text{A}^\text{S} \rightarrow \{0,1\}$ specifies whether a message is truthful (veracious), where $V^S(\text{"}m\text{"}, a_i^S) = 1$ if and only if $a_i^S \in \text{Q}$ when $\text{"}m\text{"} = \text{"Q"}$, otherwise $V^S(\text{"}m\text{"}, a_i^S) = 0$.
- A receiver's *trust function* $T^R: \text{"M"} \rightarrow \{0,1\}$, where $T^R(\text{"}m\text{"}) = 1$ if message "m" is trusted, i.e., interpreted according to its literal meaning, and $T^R(\text{"}m\text{"}) = 0$ if not.

C. Equilibrium

As mentioned before, we single out a Nash equilibrium of the game without communication to characterize the priors, in analogy to the idea of common priors in incomplete information games. There is no point in talking if the default equilibrium is Pareto optimal for the sender. In the examples, we generally take the common priors to correspond to the strategy p^S of the sender in the least informative mixed-strategy Nash equilibria of the game, and the corresponding strategy p^R of the receiver in that equilibrium. If there are more specific priors or ad-hoc information shared by all players, such as Schelling's (1960) focal points, the default equilibrium without communication would instead be something more informative.

The sets A^S and A^R are finite. Though the set of messages "M" need not be finite, we assume $\text{"M"} = \text{"P(A}^\text{S}\text{)"}$ because the powerset of messages that refer to A^S is sufficiently rich to convey all the relevant messages that are possible in the game. It includes the true but irrelevant message "I won't tell what I plan to do" which points to the whole set A^S.

Incomprehensible messages "Q"$\notin$"$\mathbb{M}$" and irrelevant messages "Q"$\in$"$\mathbb{M}$" such that $\mathrm{Q} \cap \mathrm{A}^{\mathrm{S}} = \emptyset$ are informationally equivalent to "Q"="A^{S}" so they can be ignored without loss of generality.

DEFINITION 1: *Meaningful-talk equilibrium* (MTE). In an imperfect information game where the sender can first communicate a verbal message unilaterally to the receiver, a MTE is given by strategies, beliefs, truth- and trust-functions

$(\tilde{\omega}^S, \tilde{\sigma}^S(\text{"}m\text{"}), \tilde{\sigma}^R(\text{"}m\text{"}), \tilde{\mu}(\text{"}m\text{"}), \tilde{V}^S(\text{"}m\text{"}, w), \tilde{T}^R(\text{"}m\text{"}))$ that satisfy conditions (1) through (4):

(1) For each "m_k" $\in$ "M",

$$\tilde{\sigma}^S(\text{"}m_k\text{"}) = \arg\max_{\sigma^S(\text{"}m_k\text{"})} \sum_{a_i^S} \sigma^S(\text{"m}_\text{k}\text{"})\left(a_i^S\right) \sum_{a_j^R} \tilde{\sigma}^R(\text{"}m_k\text{"})(a_j^R)\, v^S(a_i^S, a_j^R).$$

and

$$\tilde{\omega}^S = \arg\max_{\omega^S} \sum_{\text{"}m_k\text{"}} \omega^S(\text{"}m_k\text{"}) \sum_{a_i^S} \tilde{\sigma}^S(\text{"m}_\text{k}\text{"})\left(a_i^S\right) \sum_{a_j^R} \tilde{\sigma}^R(\text{"}m_k\text{"})(a_j^R) v^S(a_i^S, a_j^R).$$

(2) For each "m_k" $\in$ "M",

$$\tilde{\sigma}^R\left(\text{"}m_j\text{"}\right) = \arg\max_{\sigma^R(\text{"}m_k\text{"})} \sum_{a_j^R} \sigma^R(\text{"}m_k\text{"})(a_j^R) \sum_{a_i^S} \tilde{\mu}(\text{"}m_k\text{"})\left(a_i^S\right) v^R(a_i^S, a_j^R).$$

(3) If for message "m_k"="Q"$\in$"M", $\tilde{\omega}^S(\text{"}Q\text{"}) > 0$:

- (i) $\tilde{\mu}(\text{"}Q\text{"})\left(a_i^S\right) = \tilde{\sigma}^S(\text{"}Q\text{"})\left(a_i^S\right)$ if "Q"$\neq$"A^{S}", $T^R(\text{"}Q\text{"}) = 1$, and $V^S\left(\text{"}Q\text{"}, a_i^S\right) = 1$ (i.e., $\tilde{\sigma}^S(\text{"}Q\text{"})\left(a_i^S\right) > 0$ for $a_i^S \in \mathrm{Q}$, $\tilde{\sigma}^S(\text{"}Q\text{"})\left(a_i^S\right) = 0$ for $a_i^S \notin \mathrm{Q}$).
- (ii) Otherwise $\tilde{\mu}(\text{"}m_k\text{"})\left(a_i^S\right) = p(a_i^S)$, so beliefs are given by priors, and a switch from $T^R(\text{"Q"}) = 0$ to $T^R(\text{"Q"}) = 1$ cannot improve the receiver's payoffs.

(4) If for a message "m_k" ="Q"$\in$"M", $\tilde{\omega}^S(\text{"}m_k\text{"}) = 0$,

- (i) $\tilde{\mu}(\text{"Q"})\left(a_i^S\right) > 0$ for $a_i^S \in \mathrm{Q}$, $\tilde{\mu}(\text{"}Q\text{"})\left(a_i^S\right) = 0$ for $a_i^S \notin \mathrm{Q}$, and $\sum_{a_i^S \in \mathrm{Q}} \tilde{\mu}(\text{"}m_k\text{"})\left(a_i^S\right) = 1$ if "Q"$\neq$"A^{S}" and $T^R(\text{"Q"}) = 1$.
- (ii) Otherwise, $\tilde{\mu}(\text{"}m_k\text{"})\left(a_i^S\right) \in [0,1]$ and $\sum_{a_i^S} \tilde{\mu}(\text{"}m_k\text{"})\left(a_i^S\right) = 1$.

Conditions (1) and (2) are the same as in a perfect Bayesian equilibrium (PBE): that strategies be optimal given beliefs. The novelty has to do with how beliefs are formed on and off the equilibrium path. Conditions (3) and (4) of a MTE differ from a PBE, where the following conditions hold instead:

(3') If for a message "m_k"="Q", $\tilde{\omega}^S(\text{"}m_k\text{"}) > 0$, then $\tilde{\mu}(\text{"}m\text{"})\left(a_i^S\right) = \tilde{\sigma}^S(\text{"}m_k\text{"})\left(a_i^S\right)$.

(4') If for a message $"m_k"="\text{Q}"$, $\widetilde{\omega}^S(w)("m") = 0$ for all $w \in \text{W}$, then $\tilde{\mu}("m")(w) \in [0,1]$ and $\sum_w \tilde{\mu}("m")(w) = 1$.

By condition (4)(ii) of MTE, out-of-equilibrium beliefs are not restricted, just as in condition (4') in a PBE, unless (4)(i) out-of-equilibrium messages are relevant and trusted. This feature (4)(i) implies that the sender is deterred from sending some messages precisely when they are trusted.

What is key is condition (3) of a MTE, in order to capture the specificity of symbolic signals. While the assignment of actions to messages does not depend on the content of the messages themselves in condition (3') of a PBE, in a MTE the assignment in (3) depends on the literal meaning of the message and whether the receiver trusts the message or not. Condition (3) requires that (i) beliefs on the equilibrium path be determined by Bayes rule if messages are relevant and trusted (in equilibrium, they must of course also be true), otherwise (ii) the receiver falls back on the priors of the game without communication, and payoffs cannot increase if the receiver switches from not trusting the equilibrium messages to trusting them. This implies that on the equilibrium path the receiver either trusts a message's literal meaning and uses it to update the priors, or disregards it and the interpretation of the message is context-dependent, hinging on the priors of the game. This isolates the literal meaning (or, more generally, the common understandings it conveys) as the vehicle for information transmission.

D. Informative Equilibria and Trust Equilibria

Imprecise messages are less informative than precise messages, but they can be true and informative. The equilibria themselves can be either *informative*, if the receiver changes beliefs after some message on the equilibrium path, or *uninformative*, if not (Sobel 2011: 5).

In an informative equilibrium, conformity between what the receiver literally trusts and the underlying equilibrium strategies of the game is required. It is "as if" the required equilibrium constellation is sparked off by verbal communication. A pedestrian way to achieve this, without requiring any imagination on the part of the receiver, would be for the sender to add a reminder about the intended equilibrium strategies. This resembles the discussion in Myerson (1989), where the sender may promise to do something or suggest that the receiver do something.

While a given game may have no informative equilibria, it is trivial to establish that uninformative equilibria always exist. This leads to the following remark.

REMARK 1 (Existence): *In all imperfect information games, MTE exist.*

PROOF: *It is trivial to establish that MTE exist because uninformative MTE always exist: if the receiver disregards all messages, the sender has no incentive to choose a message that is conditional on its move; vice-versa, if the sender chooses a message that is not conditional on its move, the receiver has an incentive to disregard all messages. Under these conditions priors are not updated after communication, so the equilibrium is uninformative.*

Equilibria can alternatively be classified as either trust or mistrust equilibria (Streb and Torrens 2015). A *trust* equilibrium is a MTE where $T^R("m") = 1$ for some message $"m" \in "M"$ such that $"m" \neq "A^S"$, i.e., such that the message is relevant. A *mistrust* equilibrium is a MTE where $T^R("m") = 0$ for all messages $"m" \in "M"$.

For a trust equilibrium to exist, there must either be some relevant message on the equilibrium path that allows the receiver to update priors, or some relevant message off the equilibrium path that the receiver is willing to trust. The following remark relates trust and informative equilibria.

REMARK 2 (Informative equilibria): *In imperfect information games, an informative equilibrium is a trust equilibrium.*

PROOF: *In informative equilibria, the receiver changes beliefs after some message on the equilibrium path. For that to happen, the receiver must trust some message that differs from the common priors. Hence, that message provides information that is either more precise than the common priors (if the priors point to a mixed-strategy Nash equilibrium), or that differs from the common priors (if the priors point to a pure-strategy Nash equilibrium). Thus, that message is relevant since it refers to a strict subset to the available moves. Since the receiver trusts a relevant message on the equilibrium path, it is a trust equilibrium.*

Informative equilibria are thus a subset of trust equilibria, and in some games this inclusion is strict because there may be a trust equilibrium that is not informative.

Conversely, mistrust equilibria are a subset of uninformative equilibria, and this inclusion may be strict because there may be uninformative equilibria that are trust equilibria, i.e., equilibria where either the relevant messages on the equilibrium path that are trusted add no information to the common priors, or the relevant messages that are trusted are off the equilibrium path.

E. Credibility

Finally, credible (or trustworthy) messages are defined.

DEFINITION 2: A message is *credible* if a trust equilibrium exists where the message is either both true and trusted, on the equilibrium path, or else trusted, off the equilibrium path.

Under this definition, credibility is a characteristic of certain strategies in a game: if trust equilibria exist, these strategies are trusted by the receiver in some equilibrium. But since mistrust equilibria are always possible, credible messages need not be trusted in all equilibria. Hence, there is no necessary relation between credibility and trust, unlike other characterizations of credibility where credible messages are always trusted such as Farrell (1993) or Myerson (1989).

Note that credible messages on the equilibrium path are messages that the sender is willing to utter truthfully, choosing that actual move when these messages are trusted by the receiver. Demichelis and Weibull (2008: 1304) call these credible messages in imperfect information games *self-committing*, because the sender has an incentive to carry out the strategy when the receiver trusts the corresponding message.

III. Examples

Some classic examples of imperfect information games with unilateral communication are used to illustrate how MTE works through natural language. The general conclusion is that what one cannot expect maximal relevance, as in Paul Grice (1975), but rather optimal relevance, as in Sperber and Wilson (1995). This reflects the insight of Crawford and Sobel (1982) that sometimes informative communication is only possible if imprecise statements are available.

A. Rendez-Vous

In Schelling's (1960: 55-56) famous example of tacit coordination that involves two people who have to meet in an unspecified spot of New York, at an unspecified hour, the number of meeting times and places is unbounded. Instead of tacit coordination, consider what happens if it is possible to briefly talk beforehand over the phone. This example can represent decentralized markets like the market for lemons where seller and buyer have to coordinate a meeting time and place.

Start first with the version of *rendez-vous* with only two potential moves: left (l) and right (r). Let the meeting time be at twelve noon. In the game without communication in Table 1, there are two pure strategy Nash equilibria, (l, l) and (r, r), as well as a mixed strategy Nash equilibrium where l is played with probability $p(l) = 1/2$ and r with probability $p(r) = 1/2$. If any of the pure strategy equilibria were expected by both players, there would be no point in engaging in explicit communication, so we take the mixed strategy equilibrium to define the priors.

[Insert Table 1 Here]

In the game with communication in Figure 1, the sender (say, row) can send a message. There are two actions and, hence, only two relevant messages: one where the sender says "l" ("move left"), another where it says "r" ("move right"). In the subgame to the left, the sender is either truthful, so it indeed picks l, or misleading, and instead picks r. As to the receiver, if it trusts the message, then it will be willing to play l, else it will disregard the message and revert to the priors that either move is equally likely. A similar story applies to the subgame to the right.

[Insert Figure 1 Here]

If the receiver disregards all messages, and the sender babbles (e.g., by picking the message "l", but then moving with equal probability either l, so $T = 1$, or r, so $T = 0$), the equilibrium is uninformative; the outcome corresponds to the mixed strategy Nash equilibrium. Thus, despite the common interests, MTE, just like PBE, does not allow ruling out uninformative equilibria. There are also two informative pure-strategy equilibria: one where the sender says "l", another where it says "r", and the receiver trusts these messages (to complete the description, the beliefs in response to irrelevant out-of-equilibrium messages, which are not depicted, are that any move is equally likely). There is also an informative equilibrium with no parallel in the game without communication, in which the sender mixes between announcing "l" and playing l with probability $p(l)$, and announcing "r" and playing r with probability $p(r)$; the payoffs correspond to a correlated equilibrium (Aumann 1974).

Unlike PBE, an informative equilibrium is not possible if messages are not used in their ordinary sense. In Figure 1, if the sender plays l when it announces "r", or plays r when it announces "l", the outcome will be either a payoff of 0 for both players, if the receiver trusts the message (T=1), or a payoff of $1/2$, if the receiver disregards the message and sticks to the priors (T=0). MTE thus imposes a strong restriction on how beliefs may be updated on the equilibrium path (as in Streb and Torrens 2015): it is not possible for the receiver to reinterpret the message as meaning something else than the priors when it is not trusted. The general problem with misrepresentations in *rendez-vous* is, of course, that there is no way for the receiver to interpret the possible direction of the bias. Why use language in a non-ordinary way if you don't want to stand someone up? Imagine you invite a colleague for lunch on Tuesday when you intend to go to campus on Thursday.

Moreover, though there is an obvious alternative interpretation when there are only two options, this is not so in the original coordination problem proposed by Schelling (1960) where two people have to meet somewhere in New York at an unspecified hour. What happens if the message "Meet me at noon at the information booth in Grand Central Station" is not trusted? Instead of second-guessing whether this message might instead mean something else like "Meet me at 9 a.m. in the lobby of the Chrysler Building", with meaningful talk the receiver returns to its diffuse priors that any place and time is equally likely. The representation can be stripped down to its bare essentials by ignoring the specific messages, because the players are indifferent in regard to any of the meeting places and times, and the payoffs if they do not meet are always the same. Figure 2 graphically represents any of the subgames after a message indicating one of meeting places (say, any street corner in New York) and times (say, any hour between 10 a.m. and 6 p.m.). In the subgame, the sender may be truthful by sticking to what it announced, or pick instead any of the remaining $N-1$ strategies (which, for simplicity, are collapsed into a single alternative mixed strategy where each component gets equal weight), while the receiver may literally trust the sender's message or disregard it.[4]

[Insert Figure 2 Here]

The trust equilibria are informative: the sender reveals its true intentions, and the receiver trusts the message. The mistrust equilibria are uninformative: messages are not conditional on move, or they are outright misleading, and receivers disregard them.[5]

B. Battle of the Sexes

The battle of the sexes has two pure strategy Nash equilibria, and a mixed strategy equilibrium where each player picks its preferred strategy 2/3 of the time, for row going to a shopping mall, for column a football match.

[Insert Table 2 Here]

The mixed-strategy Nash equilibrium is the fall-back position in mistrust equilibria where priors are not updated through communication. The two pure-strategy Nash equilibria in the battle of the sexes are the outcome of two different trust equilibria: *shopping* is the outcome if only the corresponding message is expected, and trusted, by the receiver, and the response to any out-of-equilibrium message is to disregard it and return to the priors; similarly for *football*. However, if both messages are trusted, this introduces an element of

[4] The sender has an incentive not only to be truthful, but also to be precise as possible. Later on we discuss the issue of imprecise messages. The sender, using mixed strategies, can achieve intermediate degrees of truthfulness which range from stating the plain truth to being deceitful; the dividing line between helpful and misleading messages is when the seller says the truth $1/N$th of the time, which implies that messages are uninformative. The receiver, using mixed strategies, can achieve intermediate degrees of trust, which range from taking the sender's message at face value to ignoring it and sticking to the priors; priors are updated whenever the receiver plays strictly mixed strategies.

[5] In regard to misleading messages, see discussion on uninformative equilibrium in Figure 1 when messages are not used in their ordinary sense. More generally, there are uninformative equilibria where the seller says the truth less than $1/N$ of the time, because the buyer cannot reinterpret the messages beyond what is implied by the priors. There is an equilibrium in mixed strategies where the seller says the truth with probability 1/N, while the buyer disregards the message; it is not an equilibrium for the receiver to trust the message, because then the sender will always want to say the truth.

selection, where *shopping* is the outcome if row is the sender and *football* is the outcome if column is the sender. This issue is revisited below when talking of optimal relevance.

C. Zero-sum Games

In *rendez-vous* and battle of the sexes there is no incentive whatsoever to misrepresent intentions: the sender is better off by being as clear as possible. More generally, in games of coordination the premium is on revelation because, as Schelling (1960: 83) puts it, there is an "essential need for the signaling of intentions and the meeting of minds." This is just the opposite of games of pure conflict where the premium is instead on secrecy. Take matching pennies: if both players call "heads" or "tails" at the same time, row wins, else column wins. The unique Nash equilibrium is in mixed strategies, where the players mix equally between both strategies.

[Insert Table 3 Here]

No informative communication is possible because row has a clear incentive to deceive column: if row thinks that column will trust the message, it will want to say the opposite of what it actually plans to do; given that, column might not trust this message, interpreting that row will do just the opposite; if row anticipates that, it will then have an incentive to state the truth. This can go on and on. Though there is a clear incentive to misrepresent the true intentions, it is not at all clear whether the sender will finally state what it plans to do, just the opposite, or mix between both. Given that, our formulation of the trust function where the receiver can either trust the message literally, or else revert to the priors if it does not trust the message, captures the only equilibrium with communication: a mistrust equilibrium that is uninformative.

Next consider a penalty kick in soccer. The kick is converted to goal unless the goalkeeper correctly guesses where the ball will go. The unique Nash equilibrium is for the kicker to pick each strategy with probability 1/3 and for the goalkeeper to do the same.

[Insert Table 4 Here]

Since there are three options, the goalkeeper has two ways of being untruthful if it were to announce its intentions. This again leads to a chain of reasoning where both players can try to outguess each other. Only a mistrust equilibrium is possible where the players use their Nash strategies and messages are not informative.[6]

D. Prudent Alice

In the imperfect information game devised by Aumann (1990), prudent Alice prefers to play safe and choose d even if she and Bob verbally agreed to play c. She gains from falsely promising to agree since, if Bob trusts her, she gets a payoff of 8 instead of 7.

[Insert Table 5 Here]

To capture some of the flavor of Aumann's story in the current framework with unilateral communication, let the priors be given by (d, d).[7] There is a mistrust equilibrium where Prudent Alice announces "c" but both players pick d, which resembles the Aumann outcome. But there is also a trust equilibrium where Prudent Alice announces "c" and both players pick c. There is no way within this framework to solve the multiplicity of equilibria.

Demichelis and Weibull (2008: 1298) show in an evolutionary setup that, in a communication game where the two players make their announcements simultaneously, there is an equilibrium where both players announce "d" and play c when the other player announces "d". Unlike evolutionary games, this convention cannot be established in one-shot games. The problem here is quite different: the literal meaning is exogenously given and what is at stake is whether to trust the message or not.

E. Imprecise messages

Rendez-vous is the best-case scenario for successful communication because the sender wants to be as precise as possible. In other strategic situations, imprecise messages may

[6] In actual soccer games, the goalkeeper sometimes signals its intentions, e.g., pointing to one of the sides, but that goes beyond the purely symbolic level explored here because it implies the use of signals to unnerve the kicker.

[7] If the priors of the game without communication where given by the diffuse mixed-strategy Nash equilibrium where c is played with probability 7/8 and d with probability 1/8, there would also be a point in talking. If the priors of the game were instead given by the pure strategy Nash equilibrium (c,c), there would be no point in talking.

help information transmission take place. Consider the game below where there is a pure-strategy Nash equilibrium, (l, l), and two mixed-strategy Nash equilibria where both players pick either mixed strategies (0, 1/2, 1/2) or (9/11, 1/11, 1/11).

[Insert Table 6 Here]

Let the equilibrium without communication be given by the Nash equilibrium with the most diffuse priors, where the beliefs are that the three strategies are played with probabilities (9/11, 1/11, 1/11). The set of precise messages { "l" }, {"m" }, {"r" } only allows to reach the pure strategy equilibrium where l is played. If the partition { "l" }, { "m" or "r"} is considered instead, it is possible to reach the Pareto-superior mixed strategy equilibrium where m or r are played with probability 1/2. This, of course, follows the thrust of Crawford and Sobel's (1982) pioneering contribution on the most informative partition achievable for different degrees of bias of the sender.

F. Optimal relevance

Crawford and Sobel's (1982) idea of strategic information transmission contrasts with Grice's (1975) Cooperative Principle. Grice's (1975: 45–47) four maxims on the Cooperative Principle are well known (Ariel Rubinstein 2000 discusses them in chapter 3). The maxims are: informativeness, truthfulness, relevance, and perspicuity. These maxims hold in the most informative trust equilibrium of pure coordination games such as *rendez-vous*, where the sender prefers to reveal everything, but they do not hold in all games. Grice (1975: 45) is aware of this because he explicitly considers talk exchanges in which there is a common purpose, or at least a mutually accepted direction.

As to these maxims, perspicuity is not a limiting factor as long as the sender can name any action it wants to. The sender can also truthfully state "I won't tell what I plan to do". Hence, in the present context informativeness basically hinges on relevance. In this regard, Sperber and Wilson (1995: 268) characterize Grice's Cooperative Principle as a principle of maximal relevance that will not be satisfied in many situations because the interests of the sender will limit the amount of information it will be willing to reveal. Though they do not carry out an explicit strategic analysis, Sperber and Wilson (1995: 270) propose a principle of optimal relevance instead.

Demichelis and Weibull (2008:1303-4), in a setup with costly talk, remark that unilateral communication in imperfect information games tends to lead play toward the Nash equilibrium preferred by the sender, a nice insight that is not pursued further. The same happens here. This can be characterized, using Sperber and Wilson's term, by the principle that the sender aims at optimal relevance:

REMARK 3 (Optimal relevance): *In imperfect information games, the sender selects the message that leads to the highest payoffs.*

PROOF: *Sequential games are solved by backwards induction. In the first stage, the sender will select the message that leads in the second stage to the subgame with the highest payoffs.*

In the battle of the sexes, when both the message "Let's meet in the shopping mall" and "Let's meet at the football match" are trusted, the sender will pick the message that it prefers. On the other hand, in matching pennies verbally communicating intentions beforehand is useless, so the optimal strategy is being irrelevant. In some games, another way of putting this is that the sender will select the optimal degree of precision (Sobel 2011), for example in the game of Table 6 the sender will select the optimal degree of precision if all credible messages are trusted.

Introducing unilateral communication in imperfect information games leads to a strategic setup somewhat similar to the agenda-setter model of Thomas Romer and Howard Rosenthal (1978), where the agenda setter can propose its most preferred alternative, subject to the restriction that the proposal must not be worse than the status-quo for the veto player. The proposals there, however, are legally binding, so they are not mere words but rather speech acts. Hence, mistrust equilibria do not arise.

The result on optimal relevance does not mean that the sender is capable of reaching the Nash equilibrium where it gets the highest payoffs, because this depends on what messages are trusted in each subgame; rather, within the messages that are trusted by the receiver, the sender picks the best one. A more general view of optimal relevance requires exploring an equilibrium refinement in the spirit of an early example in Schelling (1960: 59): one player announces his position and states that his transmitter, but not his receiver, works, adding that he will wait where he is until the other arrives. In the present framework, the Schelling example implies that the lazy parachutist is selecting, among the myriad of possible actions, the one that implies walking less, staying put.

IV. Natural Language as a Source of Information

Meaningful talk integrates what Barton Lipman (2000) calls the *logical approach*, based on the meaning of a sentence in isolation, and the *equilibrium approach*, which takes into account the context and other extra-logical factors as modeled in game theory. More generally, this game-theoretic framework of natural language as a vehicle to talk about types or moves draws on the approaches in linguistics, semiotics, philosophy of language, psychology, and anthropology. Some links are discussed here.

A. Lewis on Convention

Meaningful talk distinguishes between linguistic conventions per se (i.e., the literal meaning) and their actual use (i.e., the equilibrium meaning). David Lewis (1969) touches both issues in the specific context of coordination games with incomplete information, where he introduces a signal from a sender to a receiver about the state of the world, which is followed by an action taken by the receiver. His signals are, in our context, specifically verbal messages.

Lewis (1969) finds both informative equilibria, which he calls “signaling system equilibria,” and non-informative equilibria. In Lewis the interpretation of the messages depends on the specific equilibrium. This indetermination can explain conventions as something that is arbitrary. Lewis (1969) then moves on to say that everyone has an individual incentive to follow a convention once it is the Nash equilibrium.

More explicitly, Michael Rescorla (2015, Section 7) discusses how in Lewis (1975) the expectation of conformity to a linguistic convention, which gives everyone a good reason to conform, is based on epistemic reasons (beliefs of others). Lewis (1975) says that a language is used by a population if and only if senders are truthful and receivers are trusting most of the time (if not all the time). The requirement in Lewis (1975) seems unduly stringent. The illustrations in the previous section show that depends instead on each specific game.

It may clarify matters to distinguish (i) understanding a message, which depends on the linguistic conventions shared by the speakers, and (ii) being truthful and trusting a message, which depends on the specific equilibrium of each game. While the literal meaning of a word depends on the linguistic conventions, and these also apply in equilibrium when there are no incentives for misrepresentation, these conventions are still present in the background even when that is not the case. The distinction between linguistic conventions and their use helps to understand why conventions are in some instances more honored in the breach than in the observance (Rescorla 2015). For instance, the fact that in the market for lemons sellers may refrain from saying "This car is a lemon", lest their words be taken at face value, attests to the underlying linguistic conventions in society (Streb and Torrens 2015: 25).

B. Gertz on Culture

Linguistic signs are a source of information that has not been duly recognized in economics. While words, sentences, and language as a whole, are in a sense an arbitrary set of conventions to communicate meaning, in another they are not: we are born into them. Michael Rescorla (2015) points out that for Hume social conventions arise without need for either an explicit covenant (as in Hobbes) or a tacit agreement (as in Locke). Hume's approach is described by Friedrich Hayek (1963) as an evolutionary view according to which institutions evolve spontaneously as the result of human actions, not of human design.[8] Languages thus have two faces: linguistic symbols are arbitrary (or artificial) because something can be given different names in different languages, and ordinary (or natural) because speakers of a given society share those names (Rescorla 2015).[9]

Another way of putting that language is a social convention is to say that language is an element of *culture*: for Clifford Geertz (1966: 3), this "denotes an historically transmitted pattern of meanings embodied in symbols, a system of inherited conceptions expressed in symbolic forms by means of which men communicate, perpetuate, and develop their

[8] Brian Skyrms (1996) formally shows how one of the multiple informative equilibria in the coordination games studied by Lewis (1969) can be selected in a dynamic setup through evolutionary stable strategies. This approach offers an interesting formalization of the evolutionary ideas on language as a convention established by chance, without any explicit agreement among the players.

[9] Rescorla (2015) trace the idea of natural language as a social convention, i.e., as something both natural and artificial, back to Plato, Aristotle, and Hume, and gives Lewis (1975) as the standard modern reference.

knowledge about and attitudes toward life."[10] In the channel we explore, culture affects payoffs indirectly through its role in information transmission and equilibrium selection. Geertz (1966: 5-6) adds that:

> So far as culture patterns, that is, systems of complexes of symbols, are concerned, the generic trait which is of the first importance for us here is that they are extrinsic sources of information. By 'extrinsic,' I mean only that — unlike genes, for example — they lie outside the boundaries of the individual organism as such in that intersubjective world of common understandings into which all human individuals are born, in which they pursue their separate careers, and which they leave persisting behind them after they die. By 'sources of information,' I mean only that — like genes — they provide a blueprint or template in terms of which processes external to themselves can be given a definite form.

While Ken Binmore (1994: 3) acknowledges the importance of common understandings, pointing out that common knowledge of this historical data helps to predict the equilibrium on which members of a society will coordinate in a specific game, he does not explore further the role of sharing a common language in sustaining an equilibrium (Binmore 1994: 140–143).

C. Semantics and Pragmatics

The focus in this paper is not on language as a social convention, but rather on how language is employed as a means of communication. Another way of putting this is to distinguish between the semantic and pragmatic planes.

From the semantic point of view, sentences have a literal meaning. From the pragmatic point of view, the actual interpretation of linguistic signs depends on each concrete situation. This relates to the distinction Wittgenstein (1953) draws between a grammar, i.e., norms for meaningful language, and language games, i.e., activities where language is used (Anat Biletzki and Anat Matar 2009). In giving the actual meaning of a word, Wittgenstein (1953: 21) states: "The meaning of a word is its use in the language." Wittgenstein (1953:

[10] Culture is a central concept in anthropology. George Akerlof (1989: 2) quotes precisely this passage to define culture. Gary Becker (1996: 16) uses a slightly different definition, also from Geertz.

31) considers that any explanatory generalization should be replaced by a description of its use: “don’t think, but look!” (see Anat Biletzki and Anat Matar 2009). Hence, Wittgenstein (1953) proposes to study language games in all its details.

Wilson and Sperber (2012: 1-10) contrast the ordinary language philosophy in the tradition of the later Wittgenstein, Austin, and Strawson, which analyzes actual language use in all of its complexity, to ideal language philosophy in the tradition of Frege, Russell, Carnap, and Tarski, which treats sentences as encoding something close to full propositions. They also identify an intermediate position, that of Grice, Lewis, and Searle, which distinguishes between sentence meaning and speaker meaning. Sentence meaning, or literal meaning, is still considered to encode something close to a full proposition, with reference assignment being needed to yield a full proposition. The present approach fits within this intermediate position.

Meaningful talk is inspired by the distinction in Farrell (1993) between the comprehensibility and the credibility of a message, but the end result relates to Sperber and Wilson (1995:2), who oppose the traditional code model (or semiotic model) of communication to the inferential model of Paul Grice and David Lewis, where the hearer must infer the speaker’s intention from the verbal information that is uttered. This is achieved treating the traditional code model as a two-sided process: while the encoding-decoding process (or semiotic process) itself corresponds to the code model of communication, the flip side is an inferential process which introduces strategic considerations that determine whether the message is considered true, and thus trusted, by the receiver.

Though Sperber and Wilson (1995) do not use a formal game-theoretic framework, their focus is at times very close to the approach presented here.[11] In studying language games, this paper leaves aside pragmatic issues like irony and metaphorical uses of speech, and the vagueness, incompleteness and ambiguity of actual speech (Wilson and Sperber 2012). The point it tries to make is different: even if the sender has messages to encode all the relevant

[11] Sperber and Wilson (1995:175-6) go on to develop an ostensive-inferential model, where the verbal information that the sender manifestly points out by uttering it is used by the receiver to try to infer what the sender means. The ostensive-inferential model exceeds the purely symbolic dimension explored here, since it includes body language, e.g., things like tone of voice to express irony so the exact opposite of what is literally being said reflects the speaker’s intention or “propositional attitude” (Sperber and Wilson 1995: 9−11).

information, the literal meaning still cannot be taken at face value because the senders' incentives to be truthful depend on the strategic context of each specific game. At a highly abstract level, the use of words (i.e., the equilibrium meaning) varies with the strategic incentives in each game: words at times are literally true, at others they must be interpreted in terms of the priors of the game.[12]

Given that utterance comprehension is studied within an idealized strategic context, the present approach is thus a formal pragmatics (Michael Franke 2013 has a discussion of the subfield of game-theoretic pragmatics).

V. Closing Words

There is a widespread use of language to coordinate actions. Language is so ubiquitous that Adam Smith relates markets and exchange to our "faculties of reason and speech" (*Wealth of Nations*, book I, chapter 2). In this line, language is treated here as a symbolic instrument to inform about things.[13]

The formal contribution of this paper is to extend the Streb and Torrens (2015) model of unilateral communication using natural language from incomplete information games to imperfect information games. The specificity of imperfect information games is that messages open the door to different subgames, in contrast to incomplete information games where there are no proper subgames but rather continuation games.

The literal meaning of sentences is taken as something given by pre-existing social conventions in order to study how linguistic symbols can constitute an additional source of information about the sender's intentions. The epistemic feature that verbal messages allow transmitting information is captured through a trust function by which, on the equilibrium path, the receiver may either trust the literal meaning of the message or else interpret it in terms of the common priors. Conceptually, this can be interpreted as a formal pragmatics (Franke 2013): while social conventions determine the semantic content of language, the

[12] Parikh (2010) discusses the equilibrium meaning of language, but his main concern is about the costs for the sender of being more precise, not about credibility. In this regard, the cost-benefit approach in Sobel (2011: 30-33) offers an interesting approach to describe and interpret information.

[13] Ángel Alonso-Cortés (2008: 7) distinguishes two views of language in Adam Smith: "persuasive communication" to inform about things and "empathic communication" to make known personal thoughts and feelings. In this sense, meaningful talk looks at persuasive communication, remaining within a purely symbolic plane.

actual use in an idealized strategic context has to do with pragmatic issues. Within the set of credible message that are trusted in a given game, the sender will choose the one with the highest payoffs. For this reason, the equilibrium solution is characterized by optimal relevance. This provides a partial way of formalizing Schelling's illustrations on explicit coordination through verbal communication.

Linguistic symbols do not provide direct evidence of the sender's intentions, they merely point to them, so a leap of faith is involved in verbal communication: trusting what you can't see. Hence, mistrust equilibria are always possible. As a consequence, a multiplicity of equilibria arise whenever trust equilibria exist. This can be carried beyond the consistent beliefs view of Nash equilibrium (Nicola Giocoli 2004: 651–655), exploring equilibrium refinements that restrict beliefs.

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TABLE 1— *RENDEZ-VOUS*

	left (*l*)	*right* (*r*)
left (*l*)	1,1	0,0
right (*r*)	0,0	1,1

TABLE 2— BATTLE OF THE SEXES

	shopping (*s*)	*football* (*f*)
shopping (*s*)	2,1	0,0
football (*f*)	0,0	1,2

TABLE 3— MATCHING PENNIES

	heads (*h*)	*tails* (*t*)
heads (*h*)	1,-1	-1,1
tails (*t*)	-1,1	1,-1

TABLE 4— SOCCER PENALTY KICK

	left	*center*	*right*
left	0,0	1,-1	1,-1
center	1,-1	0,0	1,-1
right	1,-1	1,-1	0,0

TABLE 5— BOB AND PRUDENT ALICE

	c	*d*
c	9,9	0,8
d	8,0	7,7

TABLE 6— GAME WHERE IMPRECISE MESSAGES ARE HELPFUL

	l	*m*	*r*
l	1,1	0,0	0,0
m	0,0	9,0	0,9
r	0,0	0,9	9,0

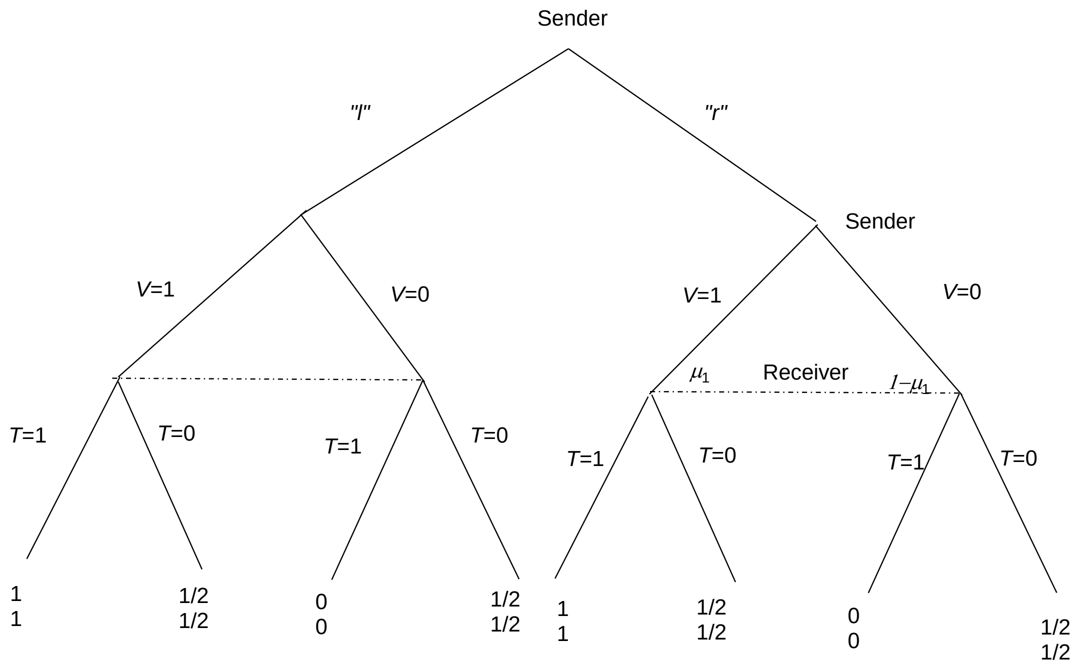

Figure 1. *Rendez-vous*: Announcing Move to Left or Right

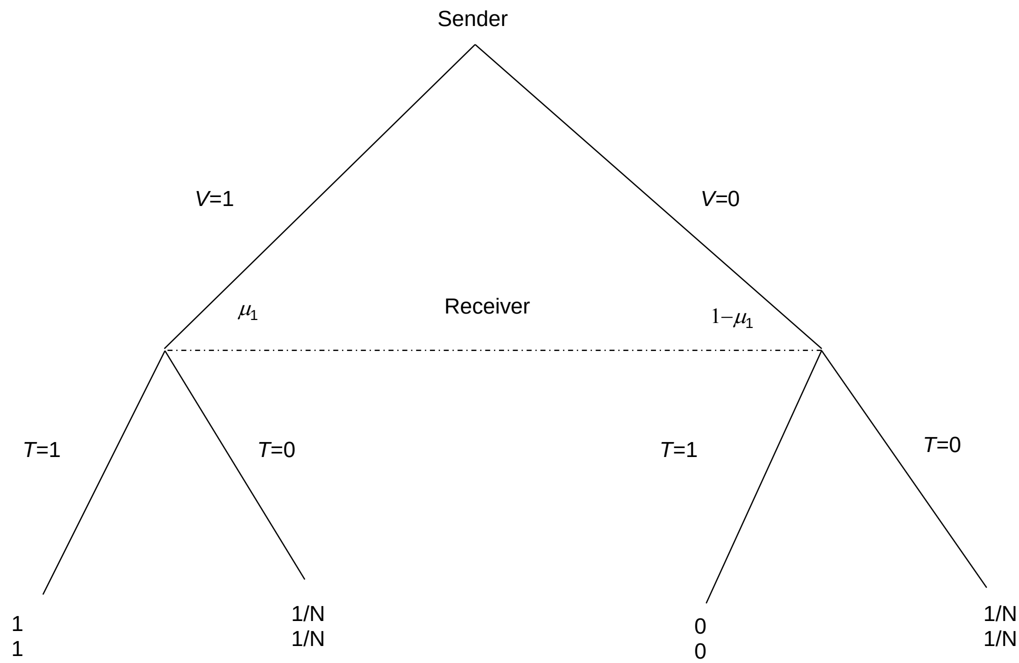

Figure 2. *Rendez-vous* with *N* Options (Different Locations and Meeting Times): Subgame