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Coordination with indirect messages in the stag-hunt game[1]

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Abstract

We theoretically investigate the effect of allowing one-sided communication with costless indirect messages on stag-hunt game outcomes. Since Heinemann et al. (2009) show that players who avoid risk also avoid strategic uncertainty, we chose a sender's level of risk aversion as the indirect message. We show that if both sender and receiver interpret the message content similarly, it is possible that they end up either on the risk-dominant or on the payoff-dominant equilibrium. We also show that players in the extreme risk groups are willing to declare risk attitudes truthfully to increase the probability of coordination. On the other hand, players in the medium risk-averse group are willing to mimic the risk-loving group to achieve efficient coordination.

Key words: Stag-hunt game, coordination, risk information, costless communication.

JEL classification codes: C72, D82, D84.

1. Introduction

In a stag-hunt game, players choose between strategically safe and risky actions (respectively, “A” and “B” in Table 1). Since there is a strategic interaction between two players, they may end up in the payoff-dominant equilibrium ((B, B)) indicating socially desirable efficient coordination, in the risk-dominant equilibrium ((A, A)), or out of equilibrium ((A, B), (B, A)). Due to potential

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coordination problem in this game, some experimental results show that there is a significant Pareto improvement through direct communication i.e., by sending intended action message (Cooper et al., 1992).[2]

In this paper, different than communicating intended-action message, we theoretically analyze the role of using indirect messages on subjects' coordination rates in the stag-hunt game. The allowed message content in the direct communication environment is a sender's potential action choice in the game. On the other hand, the allowed message content in our indirect communication environment is a sender's risk attitude.[3] Such a message is relevant because there are examples in the real world in which people can coordinate by following signals about their co-players. For instance, in a chicken game which is played in the traffic, a sports car can tell something about its user to other drivers, or an old car can give the impression "I do not lose as much as you do if we hit each other" to other drivers. Hence, these can affect other drivers' behavior towards them and help them coordinate in the traffic.

Table 1

2x2 Stag-Hunt Game with Monetary Payoffs

	A	B
A	570, 570	570,70
B	70, 570	770, 770

In this paper, we analyze the outcome of a stag-hunt game with pre-play one-way costless communication.[4] One of the players, sender, is given the chance to signal her risk attitude to the other player, receiver, before playing the game. Such a signal is important for the game when the payoffs from the game are monetary and strategic risk exists in the game.

An indirect signal about a player's risk attitude may affect a player's action (hence the game outcome) for the following reasons: First, there is a relationship between risk and strategic uncertainty. According to Knight (1921) there are two kinds of uncertainty: exogenous uncertainty or risk with given a priori probabilities for all possible states of the World (i.e., lotteries), and endogenous uncertainty given by the lack of such probabilities. Heinemann et al. (2009) found that players who avoid risk also avoid strategic uncertainty.[5] Since there is a strategic risk in the game

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2 Theoretically, Aumann (1990) and Farrell (1988) argue that communication via cheap talk is ineffective in coordination games.

3 Some experiments (Heinemann et al., 2009; Büyükboyacı, 2014) showed the relationship between strategic risk and risk itself.

4 We chose one-way communication for the sake of simplicity. It is possible to extend our model to other communication protocols.

5 Strategic uncertainty is defined by Heinemann et al. (2009) as uncertainty concerning purposeful behavior of players in an interactive decision situation. See also Bohnet and Zeckhauser (2004),

shown in Table 1, giving a player a chance to send a message about her risk attitude may be beneficial for achieving efficient coordination.

Second, agents' utility representations differ according to their risk aversion. In the game, risk-averse, risk-neutral, and risk-loving agents expect different payoffs from playing “A” (or “B”) for the same belief about the other person's action choice. Hence, their optimal action choices may change as a response to their beliefs: It may be optimal for a risk-averse agent to play “A” even when she thinks that her opponent plays “A” with low probability. On the other hand, it may be optimal for a risk-loving agent to play “A” only when she thinks that her opponent plays “A” with high probability. This difference stems from the concave (convex) utility function of a risk-averse (risk-loving) agent. Similarly, when a player gets a signal about how risk averse the other person is, she may form her beliefs accordingly. She may expect a risk-averse (risk-loving) opponent to play “A” with a higher (lower) probability and best respond to her belief by playing “A” (“B”).

In this paper, we characterize a perfect Bayesian equilibrium in which agents can use such a communication stage to achieve coordination. In the model, we first assume that players belong to one of three groups according to their risk aversion: Group 1 is the risk-loving group, Group 2 is the medium risk-averse group, and Group 3 is the most risk-averse group. Given a player knows her own group but only the risk aversion distribution of the other player, one of the players, sender, has a chance to send a message to her opponent. This message does not have to be truthful. We define a system of beliefs such that the receiver always believes that the received message is true.[6] Our focus is not on the truthful equilibrium, but the receiver believes that the communication is truthful. Therefore, it is just assumed that the receiver believes the message sent is true even though it may not be true in some cases. After the costless communication stage, agents choose their strategies for the game in Table 1. We show that under these conditions, in a Perfect Bayesian equilibrium, a sender, who is in Group 1 or Group 2, sends a message that says she is Group 1, and plays the risky action, “B”, afterwards. A Group 3 sender sends a message that says she is Group 3 and plays the safe action, “A”, afterwards. A receiver, who receives Group 1 (Group 3) message, plays “B” (“A”). This implies that a sender in extreme risk groups (Group 1 and Group 3) is willing to declare her risk attitude truthfully to increase the probability of coordination. On the other hand, a sender in the medium risk-averse group (Group 2) is willing to mimic the risk-loving group to achieve the efficient coordination.

Schechter (2007) and Lange et al. (2011) for more on the relationship between risk-aversion and uncertainty in strategic games.

6 There can be many outcomes in this game, i.e., players can end up with a coordination failure. By assuming that the receiver believes the message content is truthful, and the sender sends a message strategically to increase their coordination on the risk-dominant (or on the payoff-dominant equilibrium), the coordination problem in an equilibrium can be overcome.

2. Analysis

We now provide a model to show that coordination can be achieved via indirect pre play communication in the stag-hunt game. We assume that there are two players: a sender (S) and a receiver (R). We label the sender as player 1 and the receiver as player 2. Player i has a risk aversion parameter, r_i, belonging to one of 10 different risk categories, where each category consists of continuously divided intervals in $\mathbb{R}$.[7] If r_i is in risk categories 1, 2, 3 or 4, we say that player i is in Group 1. If r_i is in risk categories 5, 6 or 7, we say that player i is in Group 2. Moreover, r_i is in risk categories 8, 9 or 10 implies that player i is in Group 3. That is, player i is in risk category k if $r_i \in [L_k, U_k)$ where $\bigcup_{k=1}^{k=10}[L_k, U_k) = \mathbb{R}$. For each risk category, we define a representative risk aversion parameter, which is equal to the average of the upper and lower bound for that category.[8] Each player only knows her own risk aversion parameter and the probability distribution of the other player's risk aversion. Due to observed data in risk elicitation experiments using the Holt and Laury method[9], we assume that all individual risk aversion parameters are normally distributed with a mean of 0.28 and a standard deviation of 0.25.

The sender has an option to send a message m from the set of feasible messages M. Let $\mathrm{M} = \{\mathrm{Group\ 1}, \mathrm{Group\ 2}, \mathrm{Group\ 3}\}$ be the set of feasible messages and $\mathbb{M} = \mathrm{M} \cup \emptyset$. An empty message, $\emptyset$, represents the no message option for the sender. The receiver observes the message coming from the sender. Our focus is not on the truthful equilibrium, but the receiver believes that the communication is truthful. Therefore, it is just assumed that the receiver believes the message sent is true even though it may not be true in some cases. With this knowledge, each agent simultaneously chooses the safe or the risky action for the game in which monetary payoffs in Table 1 are converted into CRRA utilities where the utility of a player i is $u_i(x) = \frac{x^{1-r_i}}{1-r_i}$ if $r_i \neq 1$ and $u_i(x) = \ln x$ if $r_i = 1$, in which x is a monetary payment and r_i is the risk aversion coefficient.

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7 These 10 intervals are similar to the intervals in Holt and Laury (2002). We used Holt-Laury grouping in this paper, because there are many experimental papers that elicit risk aversion through the Holt-Laury method. This paper tries to answer whether or not indirect communication with risk attitude messages can increase the level of coordination in either equilibria as much as the direct communication with intended-action messages.

8 These representative risk aversion parameters are presented in Table 2. For the first and last risk categories, we take 1 below the upper bound and 1 above the lower bound respectively.

9 We determine the distribution according to the observed proportions in low-real treatment of Holt and Laury (2002).

Table 2
Risk Categories and Representative Risk Aversion Parameter

Risk Category k	Group	$[L_k, U_k)$	Representative Risk Aversion Parameter
1	1	$[-\infty, -0.95)$	-2
2	1	$[-0.95, -0.49)$	-0.72
3	1	$[-0.49, -0.15)$	-0.32
4	1	$[-0.15, 0.15)$	0
5	2	$[0.15, 0.41)$	0.28
6	2	$[0.41, 0.68)$	0.55
7	2	$[0.68, 0.97)$	0.83
8	3	$[0.97, 1.37)$	1.17
9	3	$[1.37, 1.53)$	1.45
10	3	$[1.53, \infty)$	2.5

3. The main result

In this section, we provide the following main result of our paper, and also provide a proof of the result. The result states that pre-play communication about risk attitudes can be used as a coordination device on both risk-dominant and payoff-dominant equilibria. Moreover, there is a perfect Bayesian equilibrium in which Group 1 and Group 2 senders pool by sending a message that say they are in Group 1 and playing the risky action "B" after the communication stage. In the equilibrium, Group 3 senders separate by sending a truthful message that say they are in Group 3, and playing the safe action "A" afterwards. This result is also stated as a part of hypothesis 3 without a proof, and experimentally tested in Büyükboyacı and Küçükşenel (2017). The intuition behind this result is that Group 3 senders, the most risk averse group members, would not be much tempted to send Group 1 message and play the risky action given baseline expectations about the receiver. Note that Group 3 senders can send Group 1 message and mimic other senders. However, this deviation does not guarantee that the receiver would play the risky action for sure. There is still a chance that the receiver can be a high risk category Group 3 agent (e.g. risk category 10) and play the risky action only if the sender is a low risk category Group 1 agent (e.g. risk category 1). Therefore, agents who are very risk averse (Group 3 members) would have to reveal it, and this would lead two players to play the risk-dominant equilibrium. Note that, our focus is not on the truthful equilibrium, but the receiver believes that the communication is truthful. Therefore, it is just assumed that the receiver believes the message sent is true even though it may not be true in some cases.

Proposition 1: There exists a perfect Bayesian equilibrium in which a sender, who is in Group 1 or Group 2, sends a message that says that she is Group 1 and plays the risky action, “B”, afterwards. A Group 3 sender sends a message that says that she is Group 3 and plays the safe action, “A”, afterwards. A receiver, who receives Group 1 (Group 3) message, plays “B” (“A”).

Proof: The game is symmetric for the representative agents who belong to the same risk category but there is an asymmetry in utilities if the representative agents do not belong to the same risk category. A pure strategy perfect Bayesian equilibrium is a system of beliefs[10] and profile of strategies (m^*, s_1^*, s_2^*) which are best responses to each other while maximizing the following conditional expected payoff for each player's each possible risk aversion coefficient after the communication stage:

$$s_i \in argmax_{\{A,B\}} \mathbb{E}_{r_{-i}} U_i(s_i, s_{-i}^*(r_{-i}), r_i | m^* \in \mathbb{M}). \quad (1)$$

Let p_2 denote the equilibrium probability that player 2 plays “A” after a message $m \in \mathbb{M}$ given player 2’s type is r_2. Given this belief, the expected utility of playing “A” for player 1 with risk aversion parameter r_1 given that she has played m^* in the communication stage and believes that player 2 with risk aversion parameter r_2 plays “A” with probability p_2 after receiving message m^* is

$$\mathbb{E}_{r_2} U_1(s_1 = A, s_2^*(r_2), r_1 | m^* \in \mathbb{M}) = \begin{cases} \frac{570^{1-r_1}}{1-r_1}, & \text{if } r_1 \neq 1 \\ \ln 570, & \text{if } r_1 = 1 \end{cases} \quad (2)$$

and similarly the expected utility of playing “B” for player 1 with risk aversion parameter r_1 given that she has played m^* in the communication stage and believes that player 2 with risk aversion parameter r_2 plays “B” with probability p_2 after receiving message m^* is

$$\mathbb{E}_{r_2} U_1(s_1 = B, s_2^*(r_2), r_1 | m^* \in \mathbb{M}) = \begin{cases} p_2 \frac{70^{1-r_1}}{1-r_1} + (1-p_2) \frac{770^{1-r_1}}{1-r_1}, & \text{if } r_1 \neq 1 \\ p_2 \ln 70 + (1-p_2) \ln 770, & \text{if } r_1 = 1 \end{cases}. \quad (3)$$

Therefore, playing “A” is optimal for player 1 with $r_1 \neq 1$ if:

$$570^{1-r_1} > p_2 70^{1-r_1} + (1-p_2) 770^{1-r_1}. \quad (4)$$

[10] See Mas-Colell et al. (1995) for a formal definition of belief systems in sequential games.

In other words, playing "A" is optimal for player 1 with $r_1 \neq 1$ if $p_2 > \frac{770^{1-r_1}-570^{1-r_1}}{770^{1-r_1}-70^{1-r_1}} := F(r_1)$ or taking the inverse of the function F if $r_1 > F^{-1}(p_2)$. By symmetry of monetary payoffs player 2 with $r_2 \neq 1$ will have a similar equilibrium strategy, i.e., "A" is optimal for player 2 with $r_2 \neq 1$ if $p_1 > \frac{770^{1-r_2}-570^{1-r_2}}{770^{1-r_2}-70^{1-r_2}} := F(r_2)$ or $r_2 > F^{-1}(p_1)$. Note that $F(r) = \frac{770^{1-r}-570^{1-r}}{770^{1-r}-70^{1-r}}$ is decreasing in r.

The above arguments imply that the symmetric equilibrium strategies follow a certain pattern: Player i from risk category k plays "B" if $r_i \in (-\infty, r_k^*)$ and plays "A" if $r_i \in [r_k^*,\infty)$ where $r_k^* = F^{-1}(p_{-i})$.[11] Given the equilibrium strategy, the probability that the other player, player $-i$, plays "A" is $p_{-i} = Prob(r_{-i} > r_k^*)$. For a category representative risk parameter, one can find bounds for p_{-i}. Since it is assumed that the distribution of risk parameters is $N(0.28,0.25)$, we can also find the cut off values, r_k^*, for each risk category k. If player i belongs to the first risk category, it is optimal for her to play "A" if her belief about her opponent's safe action choice is higher than $0.59 = F(-2)$.[12] This implies that player i in the first risk category believes that her opponent chooses "A" if $r_{-i} > r_1^*$, chooses "B" if $r_{-i} < r_1^*$. The highest belief that leads a player in the first category to choose "B" is 0.58, i.e., $Prob(r_{-i} < r_1^* | r_i = -2) = 0.58$. Given that risk aversion distribution is $N(0.28,0.25)$, r_1^* can be found as 0.33. Given the equilibrium beliefs in each risk category, the cut off risk aversion parameters $r_2^*, r_3^*, r_4^*, r_5^*, r_6^*, r_7^*, r_8^*, r_9^*$ and r_{10}^* are 0.22, 0.18, 0.14, 0.1, 0.06, 0.02, -0.04, -0.09, and -0.23 respectively.[13]

Playing "A" is optimal for player i with $r_i = 1$ if:

$$\ln 570 > p_{-i} \ln 70 + (1 - p_{-i}) \ln 770. \tag{5}$$

In other words, playing "A" is optimal for player i with $r_i = 1$ if $p_{-i} > \frac{\ln 770 - \ln 570}{\ln 770 - \ln 70} := F(1)$. Note that $F(1) \cong F(1.17)$, and hence the cutoff risk aversion for the player i with $r_i = 1$ is r_8^* since the player is also in the risk category 8.

By using Table 2 and these cut off parameters, player i from risk category 1 ($r_1^* = 0.33$)

plays "B" if $r_{-i} \in (-\infty, L_6)$ and plays "A" if $r_{-i} \in [L_6,\infty)$. That is, player i plays the risky action if she thinks that the other player belongs to the first five risk categories, and plays the safe action if she thinks that the other player belongs to

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11 We assume that without loss of generality player i plays "A" whenever she is indifferent.

12 The critical value is found using the representative risk aversion parameter for the 1^{st} risk category in Table 2. The critical beliefs for the $2^{nd}, 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th}, 8^{th}, 9^{th}$ and 10^{th} risk categories are 0.41, 0.34, 0.29, 0.24, 0.19, 0.15, 0.1, 0.07, and 0.02 respectively.

13 If the cut off we found for the risk category is above (below) the representative risk aversion parameter for that category, we assume the agent plays "B" ("A") for that category.

the last five risk categories. Therefore, the critical level of opponent's risk category to switch from playing the risky action to playing the safe action is risk category 6 for the player. Similarly, the critical level of opponent's risk category is 5 for a player belonging to risk categories $2 \leq k \leq 7$, and it is risk category 4 for a player belonging to risk categories $8 \leq k \leq 10$.

Given these optimal strategies for the last stage of the game, we can find the optimal messages for the communication stage. Suppose that Group 1 message is received and the receiver believes that this message is truthful. That is, the sender's risk category is either 1, 2, 3, or 4. Then, it is optimal for a receiver belonging to risk categories $1 \leq k \leq 7$ to play "B" by the definition of the equilibrium strategy. Note that the critical level of sender's risk category 4 for a receiver belonging to risk categories $8 \leq k \leq 10$. The expected utility of playing "A" for player 2 (receiver) in risk category 8 is $\mathbb{E}U_2(s_1^*(r_1), s_2 = A, r_2 | m = \text{Group 1}) = \frac{570^{1-r_2}}{1-r_2} < \ln 570 = \mathbb{E}U_2(s_1^*(r_1), s_2 = A, r_2 = 1 | m = \text{Group 1})$ and the expected utility of playing "B" is $\mathbb{E}U_2(s_1^*(r_1), s_2 = B, r_2 | m = \text{Group 1}) = prob(r_1 \leq -0.32 | m = \text{Group 1}) \frac{770^{1-r_2}}{1-r_2} + prob(r_1 \in (-0.32, 0) | m = \text{Group 1}) \frac{70^{1-r_2}}{1-r_2} < \mathbb{E}U_2(s_1^*(r_1), s_2 = B, r_2 = 1 | m = \text{Group 1})$. Therefore, choosing "A" is optimal for player 2 in risk categories 8, 9, and 10 since $\mathbb{E}U_2(s_1^*(r_1), s_2 = A, r_2 | m = \text{Group 1}) \geq \mathbb{E}U_2(s_1^*(r_1), s_2 = B, r_2 | m = \text{Group 1})$. Thus, expected utility of player 1 (sender) by sending Group 1 message is $\mathbb{E}U_1(s_1 = B, s_2^*(r_2), r_1 | m = \text{Group 1}) = prob(r_2 \leq 0.83) \frac{770^{1-r_1}}{1-r_1} + prob(r_2 \geq 0.83) \frac{70^{1-r_1}}{1-r_1}$. Note that $\mathbb{E}U_1(s_1 = B, s_2^*(r_2), r_1 | m = \text{Group 1}) > \frac{570^{1-r_1}}{1-r_1}$ for a sender in Group 1 and Group 2 in which $r_1 \neq 1$. This implies that it is optimal for Group 1 and Group 2 senders to send Group 1 message and thus convey their intentions to play "B" (the risky action) rather than sending another message $m' \in \mathbb{M} \backslash \{\text{Group 1}\}$ and playing the safe action. However, Group 3 sender will not mimic other groups since $\mathbb{E}U_1(s_1 = B, s_2^*(r_2), r_1 | m = \text{Group 1}) < \frac{570^{1-r_1}}{1-r_1} < \ln 570$ for all risk categories such that $k \geq 8$.[14] This implies that Group 3 sender sends a message that says she is in Group 3 to convey her intention to play "A", the safe action.[15] Therefore, pre-

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[14] We assume that there is a pre-play communication whenever the sender is indifferent.

[15] A belief system is defined using Bayes' rule for the possible risk category nodes at the risk group information set on the equilibrium path. Moreover, off the equilibrium path beliefs are defined such that belief [1] is assigned to the highest risk category node, and belief [0] is assigned to the other nodes at the risk group information set. For example, given that information set Group 1 is on the equilibrium path, positive beliefs are assigned only to risk category nodes 1, 2, 3, and 4 using the prior, and belief [0] is assigned to risk category nodes 5, 6, 7, 8, 9, and 10. At the information set Group 2 (3) off the equilibrium path, belief [1] is assigned to the risk category node 7 (10) and belief [0] is assigned to the risk category nodes 5 and 6 (8 and 9).

play communication about risk attitudes can be used as a coordination device on both types of equilibrium. This completes the proof of our main result. □

4. Conclusion

In this paper, we present a stag hunt game in which agents are allowed to communicate with each other before playing the game through indirect messages. In this set up, we characterize a perfect Bayesian equilibrium in which agents use this type of messages to achieve coordination. We find that allowing players to use such indirect messages can be used as a coordination device on both equilibria. We also show that the extreme risk groups, risk-loving group (Group 1) and the most risk-averse group (Group 3), are willing to declare risk attitudes truthfully to increase the probability of coordination. The medium risk-averse group are willing to mimic the risk-loving group to achieve efficient coordination, and hence maximize the expected return. These results also provide a theoretical background for the experimental test of hypothesis 3 in Büyükboyacı and Küçükşenel (2017).

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Özet

Dolaylı mesajlarla geyik avı oyununda koordinasyon

Bu makalede, tek taraflı ve maliyetsiz iletişime izin verilmesinin geyik avı oyunu sonuçları üzerine etkisi kuramsal olarak incelenmektedir. Heinemann vd. (2009) tarafından belirtildiği üzere riskten kaçınan oyuncular stratejik belirsizlikten de kaçınacağı için dolaylı iletişim içinde gönderebilecek mesaj kümesi olarak göndericinin riskten kaçınma seviyesi seçilmiştir. Eğer gönderici ve alıcı mesaj içeriğini benzer bir şekilde yorumlarsa, oyun sonucu olarak koordinasyonun iki farklı dengede sağlanabileceği gösterilmiştir. Ek olarak, uç risk gruplarında olan oyuncular risk tercihlerini koordinasyon olasılığını artırmak için doğru olarak ileteceklerdir. Ara risk gruplarında olan oyuncular ise risk seven grubu taklit ederek etkin koordinasyon seviyesini artırmaya çalışacaktır.

Anahtar kelimeler: Geyik avı oyunu, koordinasyon, risk bilgisi, maliyetsiz iletişim.

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