ECONOMICS BULLETIN

Price competition, level-k theory and communication

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Abstract

This paper analyzes communication in a price competition game using the level-k theory of bounded rationality. The level-k analysis predicts prices to be higher with communication than without. Our experimental evidence lends support to the view that communication affects subjects in a way that is compatible with the level-k model, indicating that people lie in order to fool other players that they believe do less thinking. Moreover, the results indicate that the predictive power of the level-k model does crucially depend on the possibility for high level players to form homogenous beliefs about the behavior of the level-0 players.

This paper was partly written while I visited the Department of Economics at University College London, whose hospitality I thankfully acknowledge. Special thanks to Ola Andersson, Kerstin Enflo, Hans Carlsson, Vince Crawford, Hakan J. Holm, Steffen Huck, Randolph Sloof for comments and suggestions. I am also thankful for helpful comments made by participants at the ESA European Meeting in Alessandria and seminar audiences in Lund and Tilburg. Financial support from the Wallander-Hedelius Foundation and the Lars Hierta Memorial Foundation is gratefully acknowledged.

Citation: Wengström, Erik, (2008) "Price competition, level-k theory and communication." *Economics Bulletin,* Vol. 3, No. 66 pp. 1-15

Submitted: September 19, 2007. **Accepted:** October 17, 2008.

URL: http://economicsbulletin.vanderbilt.edu/2008/volume3/EB-07C70032A.pdf

1 Introduction

In most strategic situations, agents have possibilities to communicate. Standard game theory gives us despite this fact, often poor predictions about how communication affects outcomes. Yet, a large body of experimental evidence suggests communication to have an impact on outcomes that standard game theory cannot fully explain. The effects are often ascribed to increased opportunities of coordination or cooperation (cf. Charness and Dufwenberg (2006) and Ellingsen and Johannesson (2004)). In contrast, this paper examines if communication may be viewed as a mechanism for players to deceive opponents that they believe do less thinking. More specifically, we examine if the *level-k theory* of bounded rationality can enhance our understanding of the effects of communication.[1] This idea seems appealing since this model has proved successful in explaining strategic behavior in various games, most notably in guessing games (cf. Nagel (1995).

In contrast to standard game theory this approach does not assume common knowledge of rationality. The basic idea is instead that the majority of players maximize profits given their beliefs but since they expect their opponents to be boundedly rational, their beliefs do not correspond to equilibrium beliefs. Based on the empirical observation that players differ in their lengths of reasoning, a hierarchy of different types of players is assumed to exist. In its simplest form, the least sophisticated players, the level-0 players, do not assume anything about their opponents and choose their actions randomly. The next level of players, level-1, believe their opponents to be level-0 players and best respond to the strategy of the level-0 player. More generally, a level-k player believes the other players to be of level-(k-1) and hence choose the best action, given the strategies of the level-(k-1) players. Since players' beliefs of others are mistaken, a Nash equilibrium of the game need not be reached.

Inspired by the theoretical work by Crawford (2003) who used the level-k model to analyze cheap-talk in two-person zero-sum communication games, we evaluate if pay-off irrelevant communication affects outcomes through the creation of a sort of "pseudo" focal point that anchors the behavior of the level-0 players; or at least the higher level players' beliefs about the level-0 players. See also the related applications by Ellingsen and Östling (2006) and Crawford (2007) to the stag hunt and battle of the sexes games; and the application to information transmission games by Cai and Wang (2006). In summary, these level-k approaches assume that communication shifts the actions of the level-0 players, which then carries over to the beliefs and actions of the higher level players.[2]

Here, the level-k model is applied to a slightly perturbed price competition game. Applying the level-k model to price competition does not only put this reasoning in an economically important setting, but also allows for a direct experimental evaluation. The

[1] The level-k, or level-n, model was first introduced in Stahl (1993). See also Stahl (1993), Stahl and Wilson (1994), Nagel (1995), Stahl and Wilson (1995), Haruvy, Stahl, and Wilson (2001), Bosch-Domenech, Montalvo, Nagel, and Satorra (2002) and Camerer, Ho, and Chong (2004).

[2] See Crawford and Iriberri (2007) and Stahl and Haruvy (2008) for two examples from other contexts where tilts in the distribution of level-0 choices and level-1 beliefs improves the fit of the level-n model considerably.

choice of price competition is further motivated by earlier experimental and empirical studies reporting that communication plays a role that standard theory fails to explain. Holt and Davis (1990), Brown-Kruse, Cronshaw, and Schenk (1993) and Cason (1995) find non-binding pre-play communication to raise prices in experimental markets.

Our level-k analysis of the price competition game with communication suggests that communication leads to higher prices, a result that is confirmed by our experimental evidence. Moreover, the quantitative and qualitative data indicate that the effects of communication can be modelled by the impact it has on subjects' beliefs about boundedly rational opponents.

2 Theoretical Framework

Consider a one-shot game with two players each choosing a price, p from the discrete range of prices, $\{1, \ldots, 14\}$. The player with the lowest price gets the whole market and earns a payoff equal to the chosen price, whereas the other player gets a payoff of zero. In case of a tie, players split the market equally between them and consequently get a payoff of $\frac{p}{2}$. In addition to these standard rules, the player with the winning price receives an additional payoff of two currency units, if her price is exactly two numbers lower than the other player's price. The bonus is included in order to facilitate the analysis of the experimental data by making it able to distinguish between data generated by the level-k model and other processes. The Nash prediction of both treatments is the familiar Bertrand equilibrium, in which both players choose either 1 or both players choose 2.[3] We now proceed by analyzing this game using a simple version of the level-k model.

2.1 No Communication

Following the literature we start by assuming level-0 players to act randomly. In this setting, the natural assumption is that they assign equal probability to all prices, i.e. the level-0 players assign probability $\frac{1}{14}$ to prices, $p \in \{1, \ldots, 14\}$. The players of the next level—the level-1 players—maximize profits believing the others to be of level-0. Straightforward calculations yield that the solution to this problem is choosing 7. Consequently, level-2 players will best respond to the strategy of the level-1 types by choosing $p = 7 - 2 = 5$ and level-3 players will best respond to the level-2 players by setting $p = 3$. Players of level-$k \geq 4$ will hence set price equal to 1. We let α_k, $k = 0, 1, 2\ldots$ denote the fractions of level-k players. With these assumptions, the scheme of boundedly rational players leads up to the following claim.[4,5]

Claim 1 *If* $\sum_{k=0}^{2} \alpha_k > 0$ *the average price without communication is above 1.*

[3] Note that both players choosing 2 is an equilibrium, since demand is constant. The equilibrium in which both players choose 1 is however preferred by various refinement concepts. For example, it is the only strict equilibrium and 1 is the only evolutionarily stable strategy.

[4] Throughout the paper prices refer to the submitted prices of all players and not the winning price in each pair.

[5] With slightly stricter requirements on the fractions of high level players, e.g. $\sum_{k\geq 4} \alpha_k < 0.5$, prices will also be above the high Nash equilibrium of 2.

2.2 Communication

Introducing one-way communication – giving one of the players the possibility to announce a price suggestion to the other player, does not alter the Nash prediction. In the level-k model, on the other hand, the predicted outcome changes dramatically if the actions of the level-0 types are assumed to be affected by the messages.

Assume the strategy of a level-0 sender to consist of sending a random message and choosing a price truthfully according to the sent message. Similarly, assume that the strategy of a level-0 receiver is to truthfully choose the number suggested in the message. The optimal action of a level-1 sender is then to send the highest possible message of 14, and undercut the message by 2. To spell out the complete strategy, assume that a level-1 sender will undercut the sent message by 2 numbers irrespective of which message is being sent. Analogously receivers of level-1 will undercut the received message by 2. A level-2 sender will send a message of 14 and undercut the sent message with 4, believing that the opponent is of level 1. A level-2 receiver best responds to the strategy of the level-1 sender by setting a price 4 numbers lower than the received message. Assume further that higher level players follow a similar path. We can then state the following claim concerning the submitted prices of the players.

Claim 2 *If* $\sum_{k=1}^{6} \alpha_k > 0$*, the average price is higher with communication than without communication.*

Note that we have assumed that a level-k receiver best responds to the strategy of a level-(k-1) sender, which irrespective of the message m entails choosing $\max\{1, m\text{-}2(k\text{-}1)\}$. That is, a level-$k$ receiver assigns probability one to the other player being of level-(k-1), irrespective of the message being received. If this was not the case, a high level player ($k \geq 3$) might want to send a low message pretending to be of level 0. A simple belief updating procedure could for example be to assume that the receiver believes the opponent to be of level 0 upon receiving a non-14 message. This would imply that level 3 and level 4 senders would send a message of 13 instead. And even higher level players would set 12 and so on. Yet, Claim 2 would hold also under such assumptions.

3 Experimental Design

In the experiment subjects first had to complete a small problem set, constructed to ensure full understanding of the rules. Thereafter each subject participated in one of the following treatments of the price competition game discussed in section 2.[6]

No Communication Subjects had no possiblity to communicate before they made their price choices.

Communication One of the subjects in each pair was randomly designated to be the sender. He/she sent a message to the other subject indicating what number she

[6] See appendix C for the instructions of the experiment.

thought was appropriate. The other participant (the receiver) was informed about the sender's message but could not reply.

After the participants made their price choices, but before they received any feedback, subjects were asked to state their distribution of beliefs. To make this procedure incentive compatible, two participants in each session were selected and paid according to a quadratic scoring rule. After the belief elicitation part, subjects filled in a questionnaire containing various open questions about their reasoning and strategy choices.

In order to induce a truly reliable one-shot environment, the game was only played once. This design also left the subjects with a fair amount of time to think the game through and answer the questionnaire carefully. The experiment was conducted at University College London. 18 subjects participated in each of the treatments. The range of prices were given in pounds sterling and subjects nominal earnings in the experiment therefore directly corresponded to their final earnings. The average earnings were £9 and each treatment took approximately 50 minutes to conduct.

4 Results

4.1 Prices and Beliefs

Table 1 summarizes the experimental results. It is evident that communication affects prices and beliefs. The level of prices and beliefs follow the pattern suggested by the level-k model. As predicted by Claim 1 prices is above the Nash equilibrium prices. Moreover, in line with Claim 2, prices and individual mean beliefs in the communication treatment are higher than in the no communication treatment (Mann-Whitney U-tests: Prices one-sided p-value: 0.052; Mean beliefs one-sided p-value: 0.024).

Figures 1 and 2 display the distribution of prices and average beliefs in the two treatments.[7] For the no communication treatment in Figure 1 the level-k model predicts modes in the histogram at 7 (level-1), 5 (level-2) and potentially even at 3 (level-3). Looking at the actual data this is only partly the case. There is a mode at 5, but no evidence of modes at 3 and 7. The average beliefs give however some more support for the level-k theory with tractable modes at 5 and 7. The overall impression from both the price data and the average beliefs is however that there is a substantial number of players with Nash beliefs. To statistically test the predictions of the level-k model we used the one-sided binomial test to test if there are significantly more level-1 to level-3 observations than would be the case if prices were randomly distributed between 1 and 14. That is, we checked if the fraction of prices at the predicted 7, 5 and 3 were statically higher than 3/14, the fraction predicted by a uniform distribution. We can reject the null hypothesis at the 10-percent level giving some weak support for the predictions of the level-k model (p-value; one-sided: 0.071).

The aggregate results of the communication treatment, shown in Figure 2, is not too informative since different players sent and received different messages. Still, it is worth

[7]Average beliefs are obtained by aggregating the given beliefs for each price, thereafter dividing by the number of observations.

noting the modes at 10 and 5. Moreover, the belief histogram shows modes at 14, 12 and 10 as predicted by the theoretical analysis. In order to more accurately describe how the messages affected actions and beliefs, Figure 3 contains the distribution of prices and beliefs relative to the messages sent and received. It is visually clear from the data that sending and receiving a message affect actions and beliefs quite substantially. The most common price was four numbers lower than the sent or received message. Notably, a few players post a price equal to the suggestion trying to cooperate. Messages do hence have a clear impact on the actions of subjects. Moreover, the modes at 0 and -2 in the belief data point in the direction that the belief formation follows a step pattern. We once again tested if the step pattern is significant by using the binomial test. We reject the null hypothesis that the fraction of prices at 0, -2 and -4 is no higher than 3/14 (p-value; one-sided: 0.007).

4.2 Level-k Theory? Some Insights from the Questionnaire

The above analysis suggests that the data fits reasonably well with the predictions of the level-k model. To gain additional insights about to the thought processes behind subjects' behaviour we study the answers to the open question about the subjects' price choices from the post-experimental questionnaire. After an exploratory overview of the answers, five general categories seemed broadly capable of capturing the described thought processes. First, there are Nash players trying to secure a profit by choosing 1 or 2. Second, some players describe their strategy as picking a number somewhat randomly. A third category of subjects explicitly tries to guess what the opponent might choose and consequently takes the best action given these beliefs. We denote this group as maximizers or level-($k \geq 1$) players, since these players are maximizing payoffs given their beliefs. Still, we can only deduce that they think at least one step since in some cases their beliefs might stem from longer (implicit) processes of reasoning. In contrast, the fourth group, the level-($k \geq 2$) players explicitly give an account of thought processes of at least two steps.[8] Finally, the fifth group consists of players choosing the number that they think the opponent will play in order to cooperate. In Table 2, the frequencies of the different types are presented, by treatment. Moreover, Tables 3 – 4 in appendix B contains examples of answers leading up to the different classifications. The numbers of Nash players and cooperative players are generally low. Most subjects seem to form some sort of baseline beliefs and thereafter reason 1–4 steps. High level players are more common in the communication treatment. Communication seems to make it more natural, or easier, for subjects to form clear beliefs about the opponents' actions, which is of importance for the ease and meaningfulness of the iterating process.

Looking at the distribution of sent messages in Table 1 we observe that the modal message in all sessions is 14, but the number of non-14 messages seems quite high. The question why subjects sent messages such as 10, 7 and 6, therefore arises. Does this suggest that the level-k model is unable to fully describe the pattern of communication? To address this concern and explore the intentions behind the subjects' messages we systematically analyzed the answers to the following question in the questionnaire: "What

[8]The longest described process corresponded to a level-4 type.

number did you send in your message? And Why?". The reasons behind the non-14 choices can broadly be divided into two categories with equal numbers of observations. One group consists of randomizing players that may be interpreted as level-0 types. A second group consists of players that post prices like 13 and 10 in order to raise prices but for some reason refrain from choosing 14.

Clearly, subjects did not completely follow the clean structure outlined before when it came to choosing messages. On the other hand, if we scrutinize the intentions behind these choices, the picture that emerges is not too far away from the level-k predictions. The players sending non-14 messages either tried to increase prices by sending high messages or sent messages randomly without any clear intentions. One reason for the non-14 messages may be signalling motives, as discussed briefly in section 2. If a simple belief updating procedure is assumed, senders of level-($k \geq 3$) may believe that they can fool the receiver that they are of lower level by sending a non-14 message. However, at least with the simplest updating procedure mentioned in 2, this would predict messages of 13 and 12 rather than the more frequently observed 10 and 8.

Another important issue related to the messages, is the motives of the players sending 14 as their message. In contrast to many other studies of communication, the model presented in the previous section assumes that messages are sent in order to fool other players and not in order to encourage cooperation. The data gives support for this assumption. None of the subjects that send a message of 14 actually picked 14 in the subsequent game indicating that they were not primarily interested in coordinating on the Pareto optimal outcome.

In conclusion, the ways in which the players approach the game can be captured by a few broad categories. Moreover, the vast majority of subjects fall in one of the categories directly connected with the level-k model. Hence, there is nothing in this qualitative analysis to suggest that the level-k model is unable to explain the effects of communication in the data. Quite contrary, most subjects seem to reason in a way that that is compatible with the scheme of boundedly rational players laid out in Section 2.

5 Concluding Discussion

Summarizing the experimental findings we have confirmed that non-binding communication raises prices in experimental price competition games. The majority of subjects did not assume their opponents to be fully rational or at least did not assume their opponents to believe other players to be fully rational, which opened a possibility for communication to have an impact on the level of prices.

The evidence indicates that the level-k model appears to be compatible with the effects of communication displayed in the experimental data and the motivations expressed in the post-experiment questionnaire. However, the predictions seem more accurate with communication than without. In absence of communication, beliefs tend to be fairly heterogeneous rendering a distribution failing to fully match the predicted pattern. Our result without communication thereby seems to confirm the findings from first price auctions by Gneezy (2005). Although he observes a distribution of bids that resembles the predicted pattern of the level-k model he questions that the model provides the right explanation. This first look at the data from our extended setup with belief elicitation and the 2£ bonus corroborates his conclusion. However, when introducing communication the players get a means to anchor their beliefs about the level-0 players more firmly, which seems to enhance the accuracy of the level-k model considerably.

To understand why and how communication affects outcomes in strategic situations is of great importance for our ability to analyze a wide variety of economic phenomena. The findings of this study indicate that a level-k model of strategic lying is indeed useful to consider for future research of these issues. More specifically, it would be interesting to validate the findings of this paper studying a wider set of games in a design allowing for a more structured data analysis.

A Tables and Figures

Table 1: Descriptive Statistics

Treatment	Average price	Average Beliefs	Messages sent
No communication	5.17	5.87	
Communication	6.94	8.33	{14, 14, 14, 13, 10, 10, 8, 7, 6}

Note: Average beliefs are the average expected means of opponent.

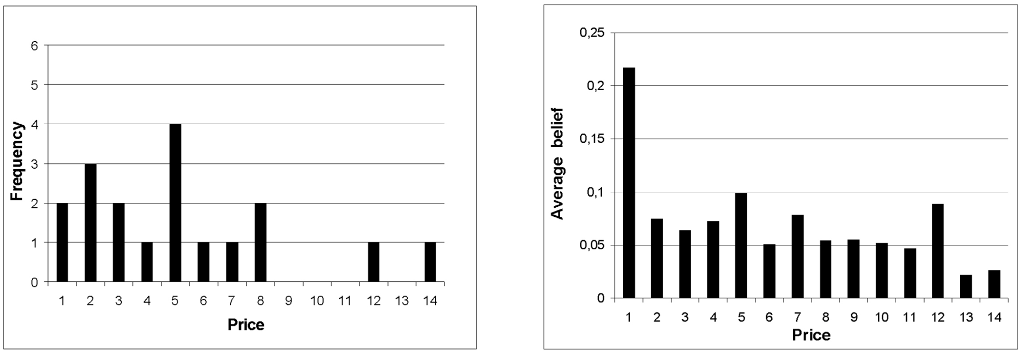

Figure 1: Prices and average beliefs, no communication treatment

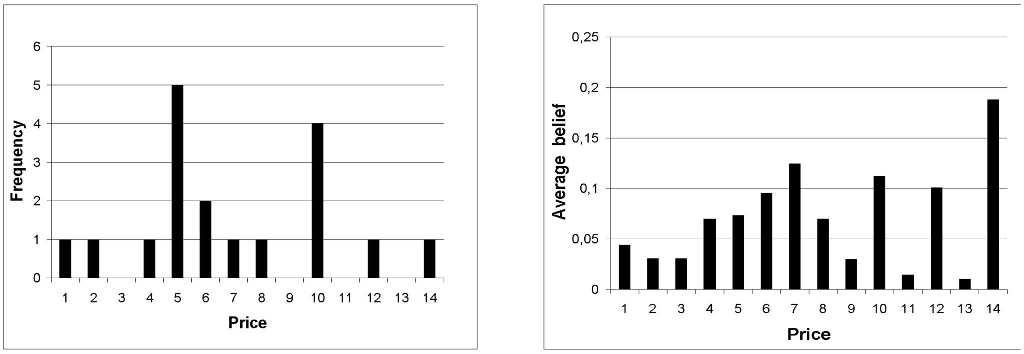

Figure 2: Prices and average beliefs, communication treatment

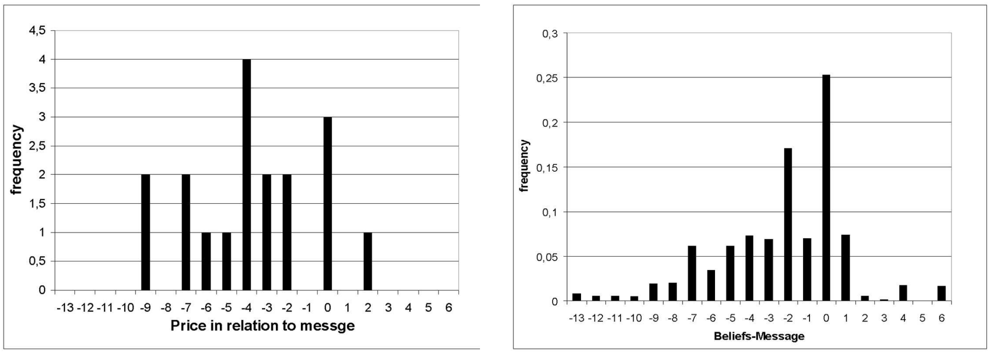

Figure 3: Prices and beliefs given the message sent or received, communication treatment

Table 2: Approaches

Category	All treatments	No Communication	Communication
Nash players	7	4	1
Ranomizers & gamblers	14	3	3
Maximizers (level-($k \geq 1$))	15	7	4
level-($k \geq 2$) thinkers	18	3	7
Cooperative	4	1	3

B Examples of motivations from the open questions

Table 3: Examples of motivations, no communication treatment

Nash players
"If pick number 1 definitely get money, so think other participant would pick number 1. That means I have to pick number 1 or I lose."
"Rather than choosing 1, I chose 2 to increase slightly the amount of profit"
"Similarly the other participant might may have have thought exactly what I've done. So she/he is most likely to choose 1 just in case she/he gets nothing"
Randomizers
"seven is my lucky number"
"[5 will give a] satisfactory payoff of at least 2.5"
Maximizers (step-k ≥ 1)
"I choose 12 because this will result in a greater profit if the other participant really chooses 14."
"just 2 less than 7"
"I reasoned that my partner would choose 5 . . . from this I chose 2 numbers lower . . . "
"I thought most people would choose between the range of 4 and 8 ... most people would choose integer 6, so I tried to gauge an integer slightly lower."
"I thought that it is highly likely that people will choose the no. 7 because this is midway between 1 and 14 . . . I chose the no. 5 to be exactly two places less . . . "
"I think the other participants randomly chosen will end in high probability close from 8–12. So I chose 6 . . . "
Step-k ≥ 2 thinkers
"I chose 8 because i felt it likely someone else would chose 10 in the hope their partner would chose 12 to get the maximum amount"
"I chose 2 banking on the chance that the other person might put 4, as that was quite a low number that he might conceivably put, considering that he's also trying to put a low number to gain the money . . . "
"I did think that they would presume I would prefer more money and so would choose say 9. Thus they would choose 7 in order to obtain the extra £2 . . . Therefore I chose 5 to try to do the same thing."
Cooperative
"I chose 14 . . . by working together you achieve the greater good for the greatest number."

Note: Answers are based on the the answers to the following questions: Please describe in words how you reasoned before you chose your number. What number did you send in your message? And Why

Table 4: Examples of motivations, communication treatment

NASH PLAYERS
RANDOMIZERS
"...lost my nerve and went for 5 reasoning that this was at least likely to get me some return."
"I thought not to be lower than 5, in case, I win it is not a bad amount ..."
MAXIMIZERS (STEP-K ≥ 1)
"I thought that people will probably choose 6 or 7 so I chose 4 which is with a gap of 2."
"2 less then 8, which I thought to be the number that most likely to be chosen..."
"I thought since the message sent to me 14 as the number they will choose, ..., I decided to maximize profit and choose 12 ..."
STEP-K ≥ 2 THINKERS
"If I choose 14, the other person would do best by choosing 12. So I decided to go a step further and take the risk of choosing 10 (assuming the other person chose 12)."
"I thought they would normally go for the £2 less option so I based my decision there."
"I picked a fairly high number to send as a message to increase the amount I could earn. I think the other participant would have chosen lower than this so they could win more money. So I chose lower than what I thought they would chose, so I could win."
"I saw the signal of 13 so I want to undercut 2 but anticipating that she may anticipate that I would do so. She might want to choose 9 and in turn I will choose 7 ..."
"It is highly likely that most chose 14 giving everyone equal share. Therefore to take advantage of this and the x+2 rule quite a few will have chosen 10 or 12 ...this leaves 8 as the best option ..."
"I think he will think that I picked $x-2$ and he will pick $x-2-2$. To be sure that my number is smaller than this, I picked a number that is $x-2-2-1$."
COOPERATIVE
"I decided to choose 10 as a matter of good will."
"I reasoned that my goal is to match the other player if he/she offered 14. This way we would both get 7 ..."
"Since I am a trusting person and easily suffers from a bad conscious, I chose the 10, trying to cooperate."

Note: Answers are based on the the answers to the following questions: Please describe in words how you reasoned before you chose your number. What number did you send in your message? And Why

C Instructions

Welcome to this experiment! Please, read the instructions thoroughly so that you understand the structure of the experiment. Do not talk to other participants during the experiment. Whenever you have any questions please raise your hand and wait for one of us to come to you.

Whatever happens in the experiment you will receive a £ 5 show-up fee. Your additional reward will depend on your own choice as well as on the choice of one other randomly selected person in this room. Note that you will stay anonymous to the other participants both during and after the experiment.

The choice you have to make is to select an integer number (i.e. no decimals allowed) between 1 and 14 and write down that number and your ID-number on a choice form that we will hand out soon. We will thereafter collect your form and match it with one other randomly selected participant.

- If you choose a number which is higher than the other participant's you will earn 0 pounds.
- If you choose a number which is lower than the other participant's you will earn as many pounds as the number you chose. Moreover, if you choose a number that is exactly 2 numbers lower than the other participant's then you will receive an additional 2 pounds.
- If you and the other participant choose the same number then you will split the value of the number you chose and earn the corresponding amount in pounds.

In a couple of minutes, before we start the actual experiment you will be asked to complete a small problem set. The questions are designed to make sure that everybody understands the rules of the experiment. Before we move on, you will need to answer each question correctly. So please take your time and read the instructions again!

In the communication treatment the following paragraph was included before the last paragraph:

Before you choose your numbers, one participant in each pair gets the possibility to send a message about what number she thinks is appropriate. If the message form that you have in front of you says "Sender" then you get the possibility to the send a message to the other participant. If the message form says "Receiver" then the other participant will send a message to you. Please fill in your ID-number and hand in the form even if you are a receiver. Note that the message is non-binding, i.e. you do not have to choose the number you wrote in the message or the number that the other participant wrote in her message.

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