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## Abstract

Central to all theories of behaviour in games is the idea that players think about what the other players might or might not do. Behaviour then depends on exactly what they think. This paper investigates a presupposition underlying this story – that people actually do think about the others. We present here a very simple test of this presupposition, with no assumptions being made about the preferences of the players (other than that they respect dominance), and with no conflict of interest between the players. We find that the evidence strongly suggests that players do not think about what the others might do. Nor do they seem to learn with experience. These findings have rather alarming implications for much of game theory.



Keywords: game theory, anticipation, planning.

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## 1. **Introduction**

What players in games think about what the other player(s) might do is crucial to the whole of game theory. This presumes that players actually think about what the other player(s) might do. We present here a very simple test of this presumption. Our test is straightforward, and makes no assumptions about the preferences of the players (other than that they respect dominance). Moreover, our test is conducted in a game where there is no conflict of interest between the players. Our results suggest that this presumption has dubious validity. Moreover, experience (by the players) does not seem to improve its validity.

## 2. **The background to the test**

The simplest way to explain the test is through an example. We use a particularly simple sequential game in which there are two players, Player 1 and Player 2, and two decision nodes. Player 1 takes the decision at the first decision node and Player 2 at the second decision node. Interleaved with these decision nodes and the payoff nodes are two chance nodes. At the chance nodes, the move is determined by Nature – who moves randomly in such a way that the two possibilities are equally likely and independent of any past moves by Nature or by the players. An example of the type of game is given in Figure 1, where the game is represented in the form of a tree. In this tree, the green boxes (indicated with a 'D' in Figure 1) are decision nodes and the red boxes (indicated with a 'C' in Figure 1) are chance nodes. Player 1 takes the decision at the first decision node and Player 2 at the second decision node. This is the tree as seen by Player 1. The tree as seen by Player 2 is *exactly the same* except for the form of words in the box at the centre of the screen. One crucial feature of this game is that the payoffs (indicated with a 'P' in Figure 1) are the same for both players.

The other crucial feature of the game is the *structure* of the payoffs – the 16 numbers down the right-hand side of the screen. These determine what the players should do. Consider first Player 2 – who takes the decision at the second decision node. Obviously, his or her decision depends upon which of the four second decision nodes he or she is at when he or she takes the decision. Suppose he or she is at the top node. Then if he or she chooses Up the payoff would be either 13 or 8 (each with equal probability); if Down then the payoff would be either 16 or 8 (again with equal probability). Down is preferable as the payoffs dominate those for Up. Whatever the preferences of the second player (assuming that they satisfy dominance), he or she would choose Down at this decision node. Similarly, and again just assuming that the preferences of the second player satisfy dominance, Up would be chosen at the second of these second decision nodes (getting 20 or 6 instead or 18 or 6), Up at the third (getting 15 or 17 instead of 2 or 4) and Up at the fourth (getting 20 or 8 instead of 8 or 0).

Let us now move back to the first decision node, and to the decision of Player 1. If Player 1 thinks ahead to what Player 2 is going to do, the choice is between getting one of 16, 8, 20 or 6 (all equally likely) by choosing Up and getting one of 15, 17, 20 or 8 (all equally likely) by choosing Down. Clearly the four equally-likely numbers (15, 17, 20, 8) dominate the four equally-likely numbers (16, 8, 20, 6) and so Player 1 should choose Down at the first decision node. So the correct decision for Player 1 – *if he or she thinks ahead to what Player 2 is going to do* – is to play Down. (Of course, this prediction presupposes that the preferences of both players satisfy dominance – but this seems a basic minimal requirement on preferences if we are going to make any predictions at all.) Conversely, if Player 1 in this tree chooses Up at the first decision node, then this clearly implies that Player 1 is *not* anticipating what Player 2 is going to do. But notice: Up looks superficially more attractive than Down in that the set of eight payoffs in the top half of the tree (8, 13, 16, 8, 6, 20, 6, 18) look more attractive than the set of eight payoffs in the bottom half of the tree (15, 17, 2, 4, 20, 8, 8, 0). In fact if the eight numbers in each half were equally likely we can see that the Up set dominates the Down set. This can be seen more clearly if we arrange them in order: Up has (20, 18, 16, 13, 8, 8, 6, 6) while Down has (20, 17, 15, 8, 8, 4, 2, 0). So Up is superficially more attractive, but is only so if Player 2 does not think ahead and anticipate what Player 2 is going to do.

We have a very clear test. In this tree, Down is the correct decision for Player 1 at the first decision node. Contrariwise, Up is the wrong decision, and implies that Player 1 is *not* thinking ahead to what Player 2 is going to do. These predictions come from the structure of the tree. We call a tree which has the appropriate structure a tree with the *dominance property*. What we mean by this is that one decision at the first decision node appears to be optimal if Player l does not think ahead to what Player 2 is going to do, whereas the other decision is in fact optimal if Player 1 does think ahead and eliminate the payoffs which Player 2's future decision will avoid (assuming throughout that both players' preference functionals satisfy dominance). This simple property enables us to test whether players do indeed think about the other player or not.

## 3. The experiment

The experiment was computerised and implemented at the laboratory of **EXEC**, the Centre for Experimental Economics at the University of York. When the subjects arrived, they were given written Instructions (see the Appendix), and the first ten minutes of the experiment were allocated to them reading the Instructions. Then a PowerPoint presentation was played at a predetermined speed on their individual and screened computer terminals – repeating the Instructions and giving more details as well as examples of the tree. At this point, the subjects had the opportunity to ask any questions. It was impressed on them that there was no time constraint.

A total of 52 subjects participated in the experiment – divided into 26 pairs. In each pair, one player was chosen to be Player 1 and the other Player 2. Neither player knew the identity of the other player, and there was no way that they could communicate to each other. All pairs were given four separate attempts at the tree, the intention being to see if experience affected behaviour. For each pair and on each attempt, the set of payoffs was different – though all the trees had the dominance property – which we defined and discussed earlier. In addition, all payoff sets had two further properties. Let us suppose that Up (Down) is the correct decision at the first decision node. Then the first further property was that the arithmetic mean of the 8 payoffs in the bottom (top) half of the tree was at least £2.50 higher than the arithmetic mean of the 8 payoffs in the top (bottom) half of the tree. The second further property was that the expected payoff playing Up (Down) at the first decision node was always at least £2.50 more than the expected payoff playing Down (Up) at the first decision node. So the incorrect decision appeared to quite a lot better than the correct one (for those players not thinking ahead to what the other player would do), while the expected payoff from the correct decision was quite a lot larger than the expected payoff from the incorrect decision. All the payoffs were integers in the range from 0 (pounds sterling) to 20 (pounds sterling). Moreover, the branches of the tree were randomly changed from tree to tree so that the correct decisions at the various nodes varied from tree to tree. After completing all four attempts, the two subjects in a pair independently called over an experimenter and each subject was paid in cash a randomly chosen one of the payoffs on the four attempts at the experiment. (We should note that the use of this *random lottery incentive mechanism* should not create problems in this particular experiment as the whole experiment is driven by dominance – so changing expected wealth through the experiment should not affect behaviour.) The subjects completed a very brief questionnaire and signed a receipt.

## 4. The results of the experiment

Let us start with the second decision nodes and the decisions of the subjects who were Player 2. In the 26 pairs, 25 took the correct decision (the dominating one) on the first attempt, 25 on the second, 24 on the third and 24 on the fourth. It is interesting to note that in 23 of the pairs, Player 2 always took the correct decision, while there was one Player 2 who took the incorrect decision on one attempt, another Player 2 who took the incorrect decision on two attempts, and one Player 2 who managed to take the incorrect decision on three attempts. The conclusion is that the vast majority of the Player 2's took the correct decision, though one is left wondering about the three Player 2's who managed to take incorrect decisions. (It is interesting to look at the detailed data. The one Player 2 who took the incorrect decision on one attempt did so by going for (0,4) instead of (10,12), where we list the equally likely outcomes for each of the two choices, putting first the one near the top of the tree. This seems to be quite a major mistake. The Player 2 who took 2 incorrect decisions went for (20,13) instead of (14,20) and went for (7,19) instead of (9,20). These errors look relatively minor. The Player 2 who took the incorrect decision on 3 attempts went for (19,3) instead of (6,20), for (20,6) instead of (20,10) and for (5,1) instead of (20,2). While at least one of these could be classified as a minor error, at least one is major. It is difficult to find explanations for some of these decisions.)

Let us now turn to the crucial decisions from the point of view of the hypothesis we want to test: the decisions of the Player 1's. Of the 26 pairs, only 5 took the correct decision on the first attempt, 9 on the second, 9 on the third and 9 on the fourth. While it could be argued that there was some improvement between the first and the second, it is difficult to see any further improvement with experience. We must admit that we had expected to see such an improvement – because in the vast majority of the pairs Player 2 took the correct decision – and so Player 1 (if he or she had wanted to be) could have been in no doubt about the rationality of Player 2. If we combine together the data from all 4 attempts, we see that just 32 out of 104 first decisions were correct. This is 30.8%. A test of the null hypothesis that the first decision was taken at random is rejected at 1% (with a t-statistic equal to 4.25) with the departure being in the wrong direction – implying that the subjects were more likely to take the incorrect decision rather than the correct decision. The conclusion seems to be clear – the Player 1's do not think ahead and anticipate the Player 2's decision as Game Theory would have us believe.

An alternative story – perhaps one in keeping with present thinking about player's beliefs in games – is that Player 1 assumes that Player 2 will choose at random. Given that, in all the trees in the experiment, if Up (Down) is the correct decision then the mean of the bottom (top) half of the tree was considerably more than the mean of the top (bottom) half of the tree, this may be a reassuring story. The problem with this story, though, is that the structure of the trees in our experiment leaves no doubt for uncertainty about what Player 2 might do. Why might Player 1 believe that Player 2 will choose the dominated choice? Why might Player 1 be in any doubt about what Player 2 is going to do?

We should note that these aggregate figures hide some individual variations – it is clear that some players always think about the other player while others never do: of the 26 Player 1's, 10 never made a correct decision, 7 made a correct decision only once, 4 only twice, 3 three times and just 2 got the decision correct every time. Again one can reject the null hypothesis that all Player 1's chose at random – in favour of the hypothesis that they are more likely to take the incorrect decision. However, perhaps a better conclusion is that a minority of the Player 1's did think about the other player while the majority did not.

## 5. Some more formal analysis

While the key results of the experiment appear to be stark in their message, it may be useful to do a little formal analysis. Let us define the following variables: *d* denoting the decision (of either Player 1 or Player 2) and taking the values 0 for an incorrect decision and 1 for a correct one; *a* for the attempt number, taking values 1, 2, 3 and 4; *n* for the decision node number, taking the values 1 for the node at which Player 1 takes a decision and 2 for the node at which Player 2 takes a decision. We carried out a probit analysis and found the following, where *Z* denotes the latent variable such that $d = 1$ if $Z > 0$ and $d = 0$ if $Z \leq 0$ (and where the numbers in parentheses are t-ratios):

$$\begin{array}{llll} Z = -2.71 + 0.053a + 2.08n & ll = -87.0 & n = 208 \\ \quad\quad (6.6) \quad\quad (0.5) \quad\quad (8.8) & & \end{array} \tag{1}$$

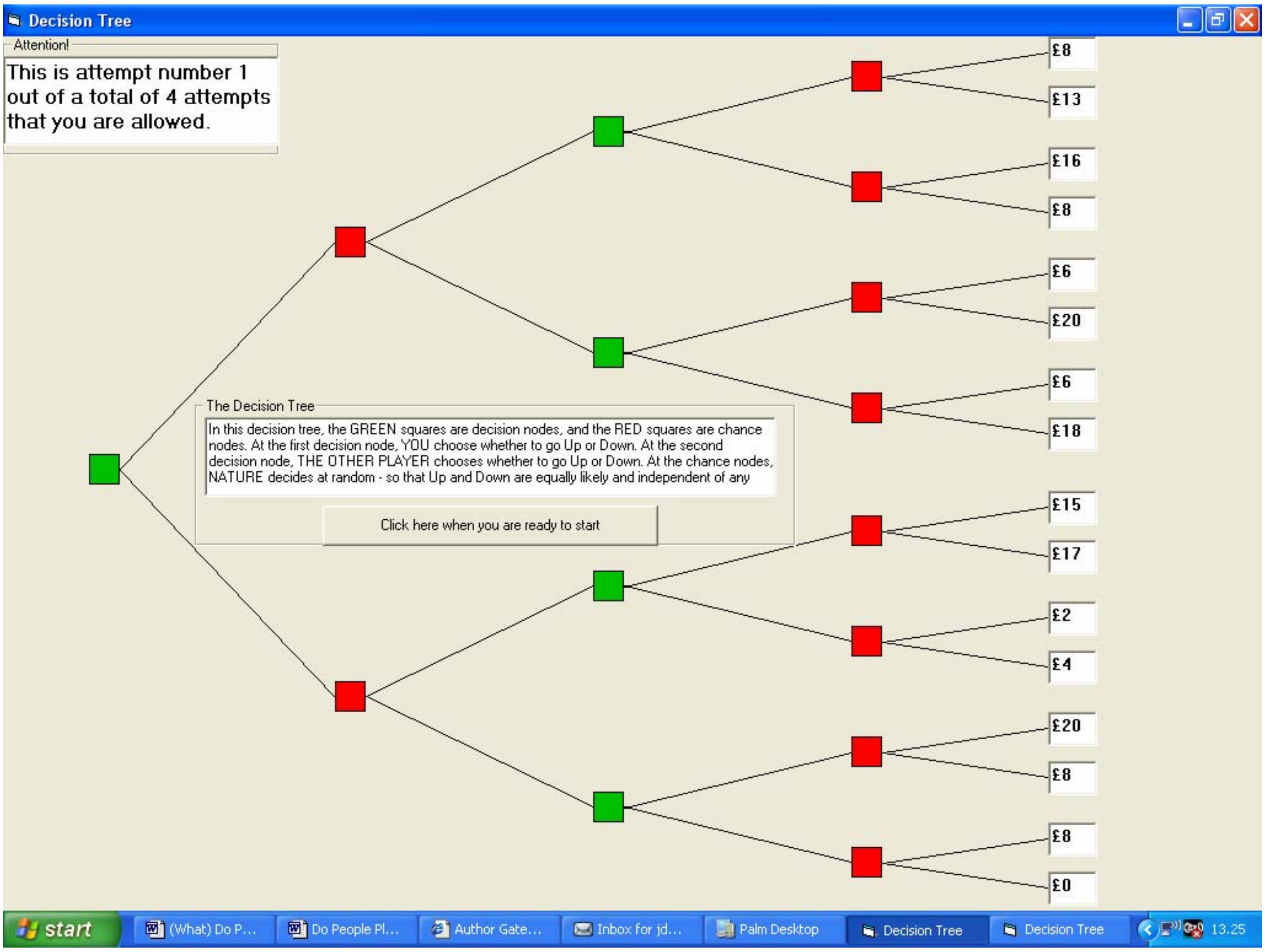
The variable *a* has a positive sign (indicating that subjects are more likely to make a correct decision the more experience they have) but it is not significant. The variable *n* is significant – and this reflects the fact that almost all subjects' decisions respected dominance at the second decision node.

The experimental software recorded the time *t* to take each decision. However, the inclusion of this variable did not improve the explanation significantly. Nor did the inclusion of the small number of demographic variables that we collected in a questionnaire at the end of the experiment: age, sex, degree and year of degree. All these variables proved insignificant.

## 6. Conclusions

The main conclusion seems to be stark: the majority of Player 1's were not anticipating the decision that Player 2 would take. This conclusion is particularly strong for two reasons: first, there was no conflict of interest between the two players; second, there could have been no doubt in the minds of the Player 1's as to what Player 2 would do – as the whole experiment is driven by dominance. As long as all the players' preferences respected dominance, *and all players assumed that the other player's preferences respected dominance*, then the future decision was clear. In this case Player 1's best decision is clear. Given that many Player 1's did the wrong thing, we are left with just the one conclusion: players do not think about what the other player will do.

Figure 1: An example of the tree as viewed by Player 1

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## INSTRUCTIONS

Welcome to this experiment. It is an experiment on the economics of dynamic decision making under risk. The Economic and Social Research Council of the UK (ESRC) has provided the funds to finance this research. The instructions are straightforward, and if you follow them carefully you may earn a considerable amount of money which will be paid to you in cash immediately after the end of the experiment. Please read the instructions carefully and take as much time as you need. There are no right or wrong ways to complete the experiment, but what you do will have implications for what you are paid at the end of the experiment. There is no participation fee for this experiment – what you are paid at the end depends partly on the decisions that you take during the experiment, partly on the decisions taken by someone else and partly on chance. At the end of the experiment you will be asked to sign a receipt for any payment that you received, and to acknowledge that you participated voluntarily in the experiment. The results of the experiment will be used for the purpose of academic research and will be published in such a way that your anonymity will be preserved.

### *The Other Player*

You will be doing this experiment with another player. You will not know who this other player is, and he or she will not know who you are. The other player is one of the other participants in this session of the experiment and is present in this same room. Even at the end of the experiment, you will not know who the other player was, and he or she will not know who you were. In these instructions, we refer to you and the other player as Player 1 and Player 2, not necessarily respectively. Player 1 takes the first decision and Player 2 the second. You will be told at the beginning of the experiment whether you are Player 1 or Player 2.

### *The Experiment*

The experiment concerns a *Decision Tree*. This decision tree is simply a short sequence of decisions to be taken by you and the other player, interlaced with moves taken by Nature. Nature is a random device, representing risk, whose behaviour will be explained to you shortly. Each sequence of decisions by you and the other player and moves by Nature leads to a payoff, which is an amount of money. You will be allowed several attempts at the decision tree. On each attempt there will be a payoff, denominated in money. Your payment for participating in this experiment will be one of these payoffs – chosen at random from the set of payoffs on the various attempts that you will have completed. The payoffs of the other player will be exactly the same as you. You and the other player have common interests.

### *The Decision Tree*

The *Decision Tree* is characterised by a sequence of *decision* and *chance* **nodes**. At each node there two subsequent paths to follow: Up and Down. At each *decision node* **you or the other player** will have to take a *decision* - in each case whether to go Up or Down. At each *chance node* a chance device - which we call **Nature** - will determine whether Up or Down is chosen. Nature operates in a totally random way – so that Up and Down are equally likely and independent of any past moves either by you or Nature. In total there are *two* decision nodes and *two* chance nodes, starting with a *decision* node and then alternating the two types until the final *chance* node. So the entire sequence is: decision, chance, decision, chance. At the first decision node, Player 1 takes the decision; while at the second node, Player 2 takes the decision. After the second and final chance node is played out you will arrive at an *end node*. Each *end node* has associated with it a *payoff* - an amount of money. The payoffs associated with each end node are written in the end nodes.

### *Nature*

'Nature' is our way of describing a totally random device. It is important that you understand what this means. At any chance node, when Nature moves, it moves in such a way that Up or Down are equally likely and independent of any moves made by you or by Nature at any time. This means that it is impossible to predict what Nature is going to do and the only information on which you can work is simply that Up and Down are equally likely. It may be useful to you to note that the way that Nature is implemented on the computer is through using the random number generating mechanism of the computer software. Even with this knowledge you are unable to predict any move of Nature.

### *The Various Attempts*

You and the other person will be allowed several attempts at the tree. You and the other person will stay together throughout these attempts, and Player 1 will always decide first; while Player 2 will always decide second. The several attempts are all independent of each other. In particular, the moves by Nature in one attempt are independent of the moves by Nature in other attempts. Moreover, there is no reason why your and the other person's moves should not be independent – but those decisions are entirely up to you and the other person: your decisions on any one attempt are not in any way constrained by what you decided on other attempts. Your decisions are entirely up to you – though obviously your payment will depend on what you decide. The basic *structure* of the tree will remain the same from attempt to attempt, in the sense that there will always be a decision node, then a chance node, then a decision node, then a chance node and then a payoff node, in each attempt. Moreover, Nature will always behave completely randomly. **The one thing that will differ from attempt to attempt is the set of payoffs. You should therefore carefully check the set of payoffs on each attempt.**

### *Your Payment for Participating in the Experiment*

As we have already remarked, you and the other person will be allowed several attempts at the tree. The precise number of attempts will be told to you when you start the experiment, and you will be reminded throughout of how many attempts you have done and how many remain to be done. On each attempt there will be a *payoff*, denominated in money. Your payment for the experiment will be a randomly chosen one of these payoffs. For example, suppose you are allowed 5 attempts at the tree. There will be 5 payoffs – one for each attempt. At the end of the experiment, you will be invited to call over one of the experimenters. He or she will have 5 cards, numbered from 1 to 5. These cards will be shuffled and you will be invited to pick one of the cards (obviously without seeing the number written on it). The number on the card that you pick will be noted and you will be paid the payoff on that numbered attempt. The same procedure will be followed to determine the payment of the other player. As we said before, you have precisely the same interests as the other player. In no way are you in competition.

### *How the Experiment will Proceed*

The experiment will begin with a PowerPoint presentation of these Instructions. Then you will turn to the experiment itself. The opening screen displays the **EXEC** logo. When you are told to start you should click on the **EXEC** logo. You will then be told how many attempts at the tree you will be allowed. The decision tree will then be displayed. You should study this carefully, and particularly the various possible end (payoff) nodes. You will end up at one of these payoff nodes in any one attempt. You and the other player will then be invited to work through the tree, starting at the left-hand node, which is a decision node. At the first decision node, Player 1 will be asked to indicate whether he or she wants to move Up or Down and then Player 1 will be asked to confirm the decision by clicking on the button "Click here to confirm"; that decision will then be implemented, with the part of the tree that the decision has excluded turning grey to indicate that that part is no longer available. At the second decision node, Player 2 will be asked to indicate whether he or she wants to move Up or Down and then Player 2 will be asked to confirm the decision by clicking on the button "Click here to confirm"; that decision will then be implemented, with the part of the tree that the decision has excluded turning grey to indicate that that part is no longer available. At each chance node, you will be asked to get Nature to move by clicking on the button "Click here to get Nature to move"; you will then be told the move by Nature, and it will be implemented, with the part of the tree that Nature's move has excluded turning grey to indicate that it is no longer available. After the second and final move by Nature, you will see that only one end (payoff) node remains available. This is the payoff for that attempt.

### *The end of the experiment*

After you have completed all the attempts, the **EXEC** logo will once again be displayed, along with a message informing you that the experiment is over. The message will also list the payoffs on the various attempts At this point, you should call over one of the experimenters. He or she will then carry out the procedure described above for determining your payment for the experiment. He or she will ask you to complete a brief questionnaire and will pay you your payment. You will be asked to sign a receipt for the payment.

### *Other*

If there is any aspect of these instructions about which you are not clear, please ask the Experimenter. It is clearly in your interests to understand these instructions as fully as possible. Please also feel free to call the Experimenter at any time.

## THANK YOU FOR YOUR PARTICIPATION