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Exploring the capability to reason backwards: An experimental study with children, adolescents, and young adults

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ABSTRACT

This is the first study investigating the development of the capability to reason backwards in children, adolescents, and young adults aged 6 to 23 under controlled laboratory conditions. The experimental design employs a modified version of the race game. As in the original game, subjects need to apply backward analysis in order to solve the games. We find that subjects' capability to reason backwards improves with age, but that this process systematically differs across genders. Our repetition of the games indicates that differences exist also in learning between age groups and across genders.

1. Introduction

Dynamic decisions are of importance in many areas of daily life (e.g., sequential negotiations, health prevention, making arrangements for retirement, or investing in education). As long as one can assume that there is a last period, people need to apply some form of backward reasoning in order to calculate their optimal decision. At the least, backward induction is a fundamental assumption in modeling such decisions in economics. But are people capable of reasoning backwards?

Several experimental studies have reported what appear to be failures to apply backward induction. For example, in centipede games very few subjects play the subgame-perfect equilibrium strategy suggested by game theory and end the game at the first node (see McKelvey and Palfrey, 1992; Fey et al., 1996; Nagel and Tang, 1998; Parco et al., 2002; Rapoport et al., 2003; Bornstein et al., 2004). As this solution depends on common knowledge of selfishness and rationality, explanations such as the existence of social preferences or limited knowledge of rationality have been proposed. In a recent field experiment with chess players, Levitt et al. (2011) contrast the behavior in the centipede game with that in the race game. In the latter game the equilibrium can also be found by backward analysis,[1] but its game-theoretic solution is more

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[1] As Dufwenberg et al. (2010) and Levitt et al. (2011) point out, the race game does not require backward induction in a *strict* sense as a player does not need to solve for her opponent's optimal choice. To acknowledge the different approach that is required to solve the race game, we follow Gneezy et al. (2010) and use the terms "backward analysis" or "backward reasoning".

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robust than the solution of the centipede game. In the race game two players alternate in choosing numbers between 1 and an integer k. All chosen numbers are added up and the player who chooses a number that makes the sum equal to an integer m wins. Using this game has the advantage that the optimal strategy does not depend on beliefs about other players and, since it is a constant sum, winner-take-all game, it also does not depend on distributional or efficiency concerns. Some chess players in the study by Levitt et al. (2011) prove to be quite sophisticated in solving the race game with k equal to 9 or 10 and m equal to 100. But Levitt et al. (2011) observe no systematic relationship to the behavior in the centipede game. They conclude that the rather late stops in the centipede game are not driven by the subjects' inability to reason backwards.

In light of this evidence, two basic observations can be made: (i) a non-negligible share of people appears to be able to reason backwards; (ii) in the centipede game the frequency of equilibrium play depends on information about the opponents.

In this study we build on observation (i) and ask how differences in the ability to apply backward analysis evolve. We extend the previous research by focusing on the development of this capability among different age groups. In particular, using modified versions of the race game, we compare how these games are solved by children, adolescents, and young adults aged 6 to 23. Additionally, we study whether there are differences between these age groups regarding the improvement of their performance. Exploring the development of backward analysis skills is interesting in its own right. However, insights on these abilities may also have consequences for modeling inter-temporal decisions, which are often considered a game against a future self (see, e.g., Laibson, 1997; Diamond and Köszegi, 2003). Because many fundamental inter-temporal decisions are made early in life, for example planning a family or investing in education, it is important to learn how young people make such decisions.

Observation (ii) underlines the importance of selecting an appropriate experimental design to isolate the factors that influence the application of backward analysis. Because our focus is on the ability to reason backwards, we follow Levitt et al. (2011) in choosing the race game as an experimental paradigm. Additionally, to increase comparability between age groups, we opt for a design in which all subjects face the same computerized opponent (that plays the equilibrium strategy whenever possible).

The paper proceeds as follows. The next section surveys related literature from which we derive the hypotheses tested in the experiment. Section 3 presents the race games that were used in our study and Section 4 describes the experimental design. The results are provided in Section 5. Section 6 concludes.

2. Related literature and hypotheses

Our analyses are based on the race game which has been introduced to behavioral research in studies by Burks et al. (2009), Dufwenberg et al. (2010), and Gneezy et al. (2010). Employing two race games with k equal to 3 and 4 and m equal to 14 and 16, respectively, Gneezy et al. (2010) study whether, and how fast, subjects learn to reason backwards.[2] They observe that subjects only seem to apply this method after experiencing defeat. Dufwenberg et al. (2010) focus on learning transfers across games with k equal to 2 and m equal to 6 and 21. They report that experience with the shorter game improves performance in the longer one, though subjects seem to work "this analytic solution out in steps" (p. 141). Similar to the findings by Gneezy et al., their results suggest that cognitive limitations prevent subjects from reasoning backwards right from the beginning. In fact, based on a sample of 1000 trainee truckers, Burks et al. (2009) find a significantly positive relationship between performance in a race game (referred to as Hit 15), IQ measured by a nonverbal IQ test (Raven's matrices), and a test of quantitative literacy. Similarly, conducting an online survey with 422 students, Carpenter et al. (2013) observe a strong correlation between performance related to Hit 15 and two common measures for cognitive ability (i.e., Frederick's CRT and college entrance exam scores from the Scholastic Achievement Test and the American College Test). The results by Burks et al. also reveal that the ability to solve the race game is positively related to patience, to the willingness to take calculated risks, and to the truckers' perseverance on the job, among other things. This relationship to other economically important behavioral traits and behavior in the field further emphasizes the value of finding out more about the capability to reason backwards.

Based on previous research on the race game, we formulate two basic hypotheses regarding the capability to reason backwards which we test in our experiment. First, we expect subjects to solve initially at least some of the race games by reasoning backwards:

Hypothesis 1. Subjects are able to reason backwards, but to a limited degree.

Second, because previous studies suggest that subjects learn to reason backwards when games are played repeatedly, we also formulate a second hypothesis:

Hypothesis 2. The ability to reason backwards improves with repetition.

As there is no evidence on the occurrence of this capability in children and adolescents, we expect the two hypotheses to hold for all age groups employed in our study. Though, there might be differences across these groups regarding average performance in the race game and its improvement.

[2] In their notation the games are called $G(15, 3)$ and $G(17, 4)$.