Cognitive Performance in Competitive Environments: Evidence from a Natural Experiment*

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October 2014

Abstract

Competitive situations that involve cognitive performance are widespread in labor markets, schools, and organizations, including test taking, competition for promotion in firms, and others. This paper studies cognitive performance in a high-stakes competitive environment. The analysis takes advantage of a natural experiment which randomly allocates different emotional states across professional subjects competing in a cognitive task. The setting is a chess match where two players play an even number of chess games against each other alternating the color of the pieces. White pieces confer an advantage for winning a chess game and who starts the match with these pieces is randomly decided. We provide a theoretical model to guide the empirical analysis. The model shows that in this setting there is no rational reason why winning frequencies should be better than 50-50 in favor of the player drawing the white pieces in the first game. Yet, we find that observed frequencies are about 60-40. As predicted, we also find that psychological effects are stronger when the competing subjects are more similar in cognitive skills. We conclude that these elements affect cognitive performance in the face of experience, competition, and high stakes.

*We thank Luis Cabral, David De Meza, Leontxo García, Diego González-Díaz, Robert Östling, Pedro Rey-Biel, Yona Rubinstein, David Strömberg, Richard Thaler, Oscar Volij and participants in seminars at LSE, Bristol, Munich, Pisa, Stockholm IIES, Erasmus, Ben Gurion, Collegio Carlo Alberto, IMEBE and the Chess Grand Slam Final Bilbao-Shanghai for useful comments. Julio González-Díaz acknowledges financial support from the European Commission through a Marie Curie fellowship and from the Spanish Ministry for Science and Innovation and FEDER (ECO2008-03484-C02-02).

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1 Introduction

Economists have paid considerable attention to the relationship between perceptions and reasoning, and to emotions such as anxiety, disappointment, expectations-based reference points, and others. There is evidence that behavioral effects are in fact important for explaining a wide range of economic and social behavior.[1] Despite their potential importance, however, little is known about the relevance of these effects on cognitive performance. Do they exist? If so, do they persist in the face of experience, competition, and high stakes?

Understanding cognition is important. Numerous studies establish that measured cognitive ability is a strong predictor of schooling attainment, wages and a range of social behaviors (see, e.g., Neal and Johnson (1996), Heckman, Stixrud and Urzua (2006), McArdle, Smith and Willis (2009), and other references therein). Several studies in economics and sociology have also shown the importance of noncognitive skills in predicting occupational attainment and the schooling performance of children and adolescents. Heckman, Stixrud and Urzua (2006), for instance, review this literature and present an analysis of the effects of both cognitive and noncognitive skills on wages. They show that a model with one latent cognitive skill and one latent noncognitive skill explains a large array of diverse behaviors including schooling, work experience, occupational choice, and participation in various adolescent risky behaviors. In particular, for a variety of dimensions of behavior and for many labor market outcomes, a change in noncognitive skills from the lowest to the highest level has an effect on behavior that is comparable to or greater than a corresponding change in cognitive skills. An emerging body of literature also finds that "psychic" costs explain a range of economic and social behavior (see, e.g., Carneiro, Hansen, and Heckman (2003), Carneiro and Heckman (2003), Cunha, Heckman and Navarro (2005), Heckman, Lochner and Todd (2006)). This is important because there are numerous settings that represent competitive situations that involve cognitive performance (e.g., test taking, student competition in schools, competitions for promotion in certain firms and organizations, and others).

[1] Rabin (1998), Camerer (2003) and DellaVigna (2009) provide excellent surveys.

Also, besides social and economic outcomes, recent research is concerned with the general importance of cognitive ability on financial market outcomes.[2]

Thus, understanding the relationship between cognitive performance and psychological effects is an important question in the literature on human capital, cognition, schooling, and behavioral economics. This paper contributes to these strands of economics literature by studying the impact of psychological differences on cognitive performance in a competitive environment. The analysis takes advantage of the opportunity provided by a randomized natural experiment that, in effect, exogenously assigns different emotional states across subjects. To the best of our knowledge, it represents the first study on cognitive performance in a competitive setting that takes advantage of a natural experiment to evaluate the causal link from behavioral aspects to cognitive performance.

The randomized experiment we study comes from professional sports. Important elements of human behavior are starkly observable in these settings. As Rosen and Sanderson (2001) indicate, "if one of the attractions of sports is to see occasionally universal aspects of the human struggle in stark and dramatic forms, their attraction to economists is to illustrate universal economic principles in interesting and tractable ways." Thus, not surprisingly, a number of prominent findings in economics have been documented for the first time in sports settings. For instance, without attempting to be exhaustive, Ehrenberg and Bognano (1990) study incentive effects in golf tournaments, Szymanski (2000) studies discrimination using soccer data, Duggan and Levitt (2002) examines corruption in sumo wrestling, Garicano et al (2006) study social pressure as a determinant of corruption in a soccer setting, and Bhaskar (2009) and Romer (2006) study optimal decision making using cricket and football data.

Much like these sports settings, ours represents a valuable opportunity for studying an open question in the literature for a number of reasons:

First, the situation involves a tractable number of subjects (just two) competing at

[2]The evidence shows that cognitive ability is an important predictor of financial outcomes and suboptimal behavior (see, e.g., Agarwal and Mazumder (2013), Bertrand and Morse (2011), Gerardi, Goette and Meier (2010), Cole and Shastry (2009)).

a game that is considered the ultimate cognitive sport (chess). The game they play has complete information and involves no chance elements. The game is strictly competitive (or zero-sum). Pure conflict situations in which one person's gain is always identical to another's loss involve no potential elements of cooperation. As such they represent the cleanest possible setting to study competitive behavior. Subjects compete in the same setting and under identical circumstances and, as we will see in the next section, the only difference is the randomly determined order in which they complete a task.

Second, and most importantly, we take advantage of existing results in the literature (to be discussed below) that show that the *order* of competition generates differences in emotional states. Using the randomly assigned treatment and control of these emotional states across subjects we undertake the question we study. As is well known a randomized experiment is a powerful methodology not often available in the social sciences that ensures that the conditions for causal inference are satisfied (Manski, 1995).

Third, the setting involves professional subjects who are characterized by the highest degree of cognitive skills (comparable to the most advanced computers available today) at the specific competitive task they perform as professionals (playing chess). Thus, we can study if biases exist in the face of experience, competition and high stakes for these subjects. This is important because several papers have found that individuals with higher cognitive ability demonstrate *fewer* and *less extreme* cognitive biases that may lead to suboptimal behavior.[3] There is also a related literature suggesting that providing relative performance information affects performance (Azmat and Iriberri (2010)).

Fourth, direct measures of cognitive abilities are often lacking and can be measured only indirectly (through their correlation with other variables) in the literature. The setting in this paper provides a highly precise measure of the cognitive ability of the players at the task they perform. In particular, players have a rating according to what is called the "ELO rating method," and this rating estimates quite precisely the probability that one player will outperform the other at the task. This is a valuable advantage of the empirical setting.

[3] Benjamin, Brown and Shapiro (2013) and Frederick (2005), for instance, document this phenomenon for high school and college students, respectively, using different measures of intelligence and cognitive ability.

Finally, the setting concerns high-stakes decisions that subjects are familiar with, that really affect them, to which they are used, and that take place in their own real-life environment. In this sense, it involves a set of useful characteristics in terms of stakes, familiarity and nature of the environment. And from the perspective of observing and measuring behavior, a comprehensive dataset is available where choices, outcomes, and treatments are cleanly measured.

From the theoretical point of view, this paper also contains a contribution to the game theoretical literature on repeated interactions. In our setting, a match consists in the repeated play of a given stage game but, differently from standard repeated games, the total payoff that players obtain may not be a sum or an average of the payoffs in each period. The existing literature has studied the case of binary outcomes: in each stage game one player wins and the other loses (see Walker, Wooders and Amir (2011)), but we are aware of no study with more than two outcomes. The presence of a third outcome in our context (win, lose, tie) brings in, among other aspects, the issue of how to chose risk during the match.[4] Our results regarding optimal play are, in addition, important for the interpretation of the empirical results.

The rest of the paper is structured as follows. Section 2 describes the natural experiment. Section 3 develops a formal model of the specific task the subjects undertake. The model allows us to identify the conditions under which we may be able to conclude whether behavioral effects have an impact on cognitive performance. Section 4 describes the data. Section 5 presents the main empirical evidence and Section 6 concludes.

2 The Natural Experiment

In a *chess match*, two players play an even number of *chess games*, typically about 6 to 10 games, against each other. Games are generally played one per day, with one or two rest days during the duration of the match. The basic procedure establishes that the two players *alternate* the colors of the pieces with which they play. In the first game, one player plays with the white pieces and the other with the black pieces. In the second

[4] See, for instance, Cabral (2002, 2003), Hvide (2002) and Hvide and Krnstiansen (2003).

game, the colors are reversed, and so on. Who plays with the white pieces in the first game is *randomly* determined, and this is the only procedural difference between the two players. According to the rules of FIDE (the Fédération Internationale d'Échecs, the world governing body of chess), the order is decided randomly under the supervision of a referee. This random draw of colors, which is typically conducted publicly during the opening ceremony of the match, requires that the player who wins the draw will play the first game with the white pieces. Therefore, the fact that players have no choice of order or color of the pieces makes it an ideal randomized experiment for empirically establishing causality.

The explicit randomization mechanism used to determine which player begins with the white pieces in a sequence of games where both players have exactly the *same* opportunities to play the *same* number of games with the *same* colors, have the *same* stakes, are in the *same* setting and where all other circumstances are identical, suggests that we should expect both players to have, ceteris paribus, exactly the *same* probability of winning the match. That is, absent behavioral effects associated with the order of colors, there is no rational reason why observed winning frequencies should be different from 50-50.[5] Yet, we find that this is not the case. As anticipation of the results, what we find instead is that winning probabilities are about 60-40 in favor of the player who plays with the white pieces in the first and in all the odd games of the match.

As will be discussed in more detail later, playing with the white pieces is advantageous in a chess game. This means that, ceteris paribus, the player playing with the white pieces in the odd games of the match is randomly allocated a greater likelihood to be *leading* during the course of the match. Conversely, his opponent, who plays with the white pieces in the even games of the match, is more likely to be *lagging.* Hence, this natural experiment shares the same design used recently in the literature to study the relevance of emotional or psychological states in understanding the behavior of subjects performing *noncognitive* tasks in competitive environments. See Genakos and Pagliero (2012), Pope and Schweitzer (2011), and Apesteguia and Palacios-Huerta (2010) for evidence from weightlifting, professionals playing golf and penalty kicks in soccer, re-

[5]In Section 3 we qualify this statement.

spectively. Our study, therefore, extends this research to the area of *cognitive* tasks in a competitive environment using the same type of randomly determined asymmetry in emotional states.

Finally, it seems appropriate to quote a reflection by Osborne and Rubinstein (1994, p. 6, italics added) who were the first to identify the research potential of this specific natural setting (chess) to contribute to our understanding of bounded rationality, including the relationship between cognitive abilities and behavioral effects:

"When we talk in real life about games we often focus on the asymmetry between individuals in their abilities. For example, some players may have a clearer perception of a situation or have a greater ability to analyze it. These differences, which are so critical in real life, are missing from game theory in its current form. To illustrate the consequences of this fact, consider the game of chess. In an actual play of chess the players may differ in their knowledge of the legal moves and in their analytical abilities. In contrast, when chess is modeled using current game theory it is assumed that the players' knowledge of the rules is perfect and their ability to analyze it ideal. Results we prove [...] imply that chess is a trivial game for "rational" players: an algorithm exists that can be used to "solve" the game. This algorithm defines a pair of strategies, one for each player, that leads to an "equilibrium" outcome with the property that a player who follows this strategy can be sure that the outcome will be at least as good as the equilibrium outcome no matter what strategy the other player uses. The existence of such strategies (first proven by Zermelo (1913)) suggests that chess is uninteresting because it has only one possible outcome. Nevertheless, chess remains a very popular and interesting game. Its equilibrium outcome is yet to be calculated; currently it is impossible to do so using the algorithm. Even if White, for example, is shown one day to have a winning strategy, it may *not* be possible for a human being to implement that strategy. Thus, while the abstract model of chess allows us to deduce a significant fact about the game, at the same time it omits the *most important determinant* of the outcome of an actual play of chess: the players' "abilities." Modeling asymmetries in abilities and in *perceptions* of a situation by different players is a fascinating challenge for future research, which models of "bounded rationality" have begun to tackle."

To the best of our knowledge, no previous research has taken the opportunity that this setting provides to study these aspects.

3 A Rational Model of a Match

A chess match is a nontrivial setting in which it is not possible to attribute differences in performance, if any, without first understanding what is the role that rational elements may play in behavior. So, what is the role that these elements play in a chess match? Under what conditions may we conclude that behavioral effects have an impact on cognitive performance? In this section we provide a formal analysis that answers these questions. To do so first recall that the randomly determined color of pieces generates one very specific type of asymmetry between the players. As is well known, playing with white pieces confers a strategic advantage in a chess game (in the sample we will study, 30 percent of the chess games were won by the players with the white pieces and 17 percent by the player with the black pieces; the rest are draws). Hence, as indicated earlier, what the random draw of colors means is that players who begin playing with the white pieces are randomly given a greater opportunity to *lead* in the match (conversely, those with the black pieces are given a greater opportunity to *lag* in the match); and this is the same type of randomly determined asymmetry that is present in previous studies. Second, we note that a chess match is a dynamic tournament. This means that, in principle, it is possible that players may not have the same effort conditions during the match and/or may choose to take a different amount of risk depending on their leading/lagging state in the score. In empirical studies in the literature the task was effortless and risk did not play any role since the outcome of the task (e.g., score or not) was binary. But in a chess game risk matters since there are three possible outcomes (either player may win the game or they may tie). This rational aspect merits a careful analysis and in what follows we try to understand the role that it plays. In this respect, our theoretical results not only serve the purpose of making our empirical analysis well founded, but also represents a contribution to the literature on equilibrium play in matches which, to date, has studied binary outcomes (see Walker, Wooders, and

Amir (2011)). Before formally studying risk, we briefly discuss the role that another rational element might have: differential effort conditions during the match.

With respect to the idea that players can exert different effort during the match depending on the score, the design by FIDE of the typical chess match intends to ensure that all the games in the match are played under *identical* conditions and, in particular, that players have sufficient time to fully recover from the physical effort they exert: no more than one game is played each day and rest days are scattered during the duration of the match to ensure that players can play every single game in perfect physical conditions. Consistent with FIDE's objective, we know of no chess player who has ever argued that differences in physical effort may play a role in a match.

A more important consideration is the fact that players may choose the risk they take during the match depending on the score. The role of strategic risk taking is, in general, not trivial and requires a formal analysis, which we provide below.[6] Interestingly, the analysis shows that the possibility of strategic risk taking is not neutral: it favors the player who starts the match playing with the *black* pieces. That is, absent behavioral effects we should find that this player significantly wins *more* often a chess match.

The basic intuition for this result is the following. Lagging in the score may induce a player to choose to lower his expected performance by taking risks that he would otherwise not take in exchange for a greater probability to win a game and catch up in the score. Hence, the possibility of taking more risks and having more variable outcomes (e.g., increasing the chance of both winning *and* losing in exchange for a lower chance of tying) is an instrument at the disposal of the lagging player. This instrument, if anything, could help counteract the potential disadvantages given by the random determination of the colors. Clearly, the leading player can also tailor the risk he takes to the advantage that he has in the match and play more conservative strategies. However, no matter how conservative the leading player is, the lagging player can *always* drive the game into a win-lose lottery where the probability of winning is greater than if he had not chosen to take the additional risk.

[6] See Genakos and Pagliero (2012) for an important paper that studies weightlifting, which is a unique setting where it is easy to separate effort from risk taking.

This insight is not new; in fact, it is well known in the literature in economics on the strategic choice of risk (variance and covariance) in dynamic competitive situations. See, for instance, Cabral (2002, 2003), Hvide (2002) and Hvide and Krinstiansen (2003). It basically has the following implication:

- If the empirical evidence shows that the player who starts the match playing with the *black* pieces exhibits significantly greater cognitive performance, we will not be able to conclude whether or not behavioral effects are present in the data. His greater winning frequency may simply reflect the advantage that strategic risk taking confers in a rational model.

- However, if the empirical evidence shows that the player who starts the match playing with the *white* pieces performs better than his opponent, we will be able to conclude that psychological effects are present in the data. And, since strategic risk taking favors the player who starts with the black pieces, the difference in performance will represent a *lower bound* on the actual impact of these effects on cognitive performance.

In what follows, we adapt the insights from this literature to a match and formally show how in fact the possibility of choosing the risk that is taken during a match favors the lagging player. We present two models. The first one, which is a particular case of the second, shows the basic intuition for the result.

PRELIMINARIES. Consider a chess game between two identical players: white and black. Suppose that the players cannot adapt the risk they take (they can only take "safe" actions), and let W denote the probability that the player with the white pieces (white) wins and L be the probability that the player with the black pieces (black) wins. Hence, $1 - W - L$ is the probability that the game ends in a draw. As indicated earlier, in chess it is strategically advantageous to play with the white pieces. This means that $W > L$. Empirically, this is strongly confirmed. For instance, for the more than 165,000 chess games in our dataset where both players have an ELO rating above 2,500, we have $W = 0.28$ and $L = 0.18$.

Consider next a chess match of T games, where T is an even number. In game 1, Player 1 plays with the white pieces and Player 2 with the black ones. In subsequent games the colors are alternated. Since a chess match is a constant-sum game, then, without loss of generality, we can assume that the utilities for each of the players are 1 if winning the match, 0 if losing, and 0.5 if they tie.[7]

In a typical chess game, the first mover advantage gives the player with the white pieces *more* control over how "risky" the game will be. This is because he has more control over the type of "opening" that will be played. Although there is not much discussion about this assumption in the chess community, chess is too complex to provide a theoretical foundation for it. Nevertheless, it is relatively straightforward to confirm the view of expert players about this asymmetry in the "technology" for risk taking, and also to provide evidence supporting this assumption.

For instance, former world champion Vladimir Kramnik (June 2011, interviewed after the Candidates Matches to qualify to challenge the reigning world champion, italics added): "My white games were all pretty complicated, tense and full of fight. I am responsible for my white games, and I was always trying to find a way to fight with white, even if I did not get an advantage. But *with black it is very difficult and incredibly risky to start avoiding drawish lines from the very beginning,* because it can easily just cost you a point in a very stupid way [...] get a bad position, lose the game, lose the match and feel like an idiot? I didn't do it [...]. It is a difficult decision which can easily backfire at this level."

With respect to empirical evidence, we may look, for instance, at performance in a *game* conditioning on lagging in the score in the match. As argued earlier, because of strategic risk taking, the expected performance of a player should decrease when he is lagging. It turns out this is in fact the case. What is important, however, is whether it decreases by a significantly greater amount when the black player is lagging. And indeed this is what happens: the decrease in performance turns out to be around twice as large (from about 10-16 percent for black to about 5-7 percent for white).[8] Hence,

[7]Since both players are identical, we can represent their preferences by the same utility functions. Moreover, without loss of generality, these utilities can be normalized so that the utility of a win is 1 and the utility of a loss is 0. Then, since we are in a constant-sum game, the utility of a tie has to be 0.5.

[8]The expected performance is simply the number of points a player is expected to achieve in the current game, i.e., his expected score, which can be computed as:

$$1 \times \text{"prob. of winning"} + 0.5 \times \text{"prob. of a draw"} + 0 \times \text{"prob. of losing"}.$$

consistent with Kramnik's statement, the data show that it is more difficult to take risks with the black pieces than with the white pieces. In other words, the "technology" for risk-return trade-off is worse for the player with black pieces than for the player with white pieces.

In what follows we study two models which incorporate the aforementioned property. Importantly, it turns out that this assumption is sufficient (but not necessary) for the results. For the sake of exposition, we develop both models within the chess terminology, but the results apply to repeated interaction models in any other setting in which the stage games have three possible outcomes (win, lose, and tie).

MODEL 1: The Simple Version

In this first model we assume that white has *all* the control over the risk involved in the game. We will relax this assumption in the general model later by assuming that the black player also has some control over the risk. We assume that the white player can increase his probability of winning by taking a risky action. This action increases his probability of winning by $R_w > 0$ and his probability of losing by αR_w, with $\alpha > 1$.[9]

The table below shows the expected score for each player when lagging and when the match is tied for various cases: all ELO levels and those with a minimum ELO rating of 2500, and for any differences in ELO ratings between the players ("No ELO diff") and for relatively even matches in which the difference in ratings is less than 100 points ("Max ELO diff 100"). Performance loss denotes the relative change in the expected score.

	Expected score of black			
	All ELO levels		Minimum ELO: 2500	
	No ELO diff.	Max. ELO diff. 100	No ELO diff.	Max. ELO diff. 100
Match tied	0.455	0.449	0.447	0.443
Black lagging	0.381	0.403	0.374	0.395
Performance loss	**16.3%**	**10.2%**	**16.3%**	**10.8%**

	Expected score of white			
	All ELO levels		Minimum ELO: 2500	
	No ELO diff.	Max. ELO diff. 100	No ELO diff.	Max. ELO diff. 100
Match tied	0.545	0.551	0.553	0.557
White lagging	0.505	0.524	0.515	0.531
Performance loss	**7.3%**	**4.9%**	**6.9%**	**4.7%**

[9]Clearly, it must be the case that $W + L + (1+\alpha)R_w \leq 1$.

First, we note that Player 2 can guarantee for himself an expected payoff of at least 0.5 just by mimicking in the even games the choices made by Player 1 in the odd games. Actually, it turns out that Player 2 can do strictly better than 0.5. Intuitively, this is because he can benefit from the fact that he has more information when he has to make his choices concerning risk.

Proposition 1. *Consider a match consisting of $T = 2$ games. Then, optimal play in this match leads to a higher expected payoff for Player 2 than for Player 1.*

Proof. We solve the game backwards. We start in Period 2, where Player 2 plays with the white pieces. If Player 2 lost the first game, he can only get a positive payoff by winning the second game, so he chooses the risky action. If the first game was a draw then, since the utility for a tie in the match is 0.5, Player 2 plays safe. That is, he does not want to transfer probability from the probability of drawing to the probability of winning if this entails transferring an even greater probability from the probability of drawing to the probability of losing (recall that $\alpha > 1$). If Player 2 won the first game he just wants to minimize the probability of losing the second game, so he plays safe.

We look now at Period 1. We find that the expected payoff for Player 1 is less than 0.5 regardless of his action. The expected payoff for Player 1 if he chooses the safe action is:

$$W\big(1-(W+R_w)+\frac{W+R_w}{2}\big)+(1-W-L)(L+\frac{1-W-L}{2})+\frac{L^2}{2},$$

and this reduces to $\frac{1}{2}(1-WR_w)$, which is less than 0.5. His expected payoff when choosing the risky action is:

$$(W+R_w)(1-W-R_w+\frac{W+R_w}{2})+\big(1-W-L-(1+\alpha)R_w\big)(L+\frac{1-W-L}{2})+\frac{(L+\alpha R_w)L}{2},$$

and this reduces to $\frac{1}{2}\big(1-R_w^2-Rw(\alpha(1-W)-(1-W-L))\big)$, which is also less than 0.5 (recall that $\alpha > 1$). □

Corollary 1. *In a match consisting of T games, the expected payoff for Player 2 is greater than the expected payoff for Player 1.*

Proof. We already know that Player 2 can get an expected payoff of 0.5 simply by mimicking the actions of Player 1 in the previous game. Assume now that he always follows the mimicking strategy except in game T in the following case: If the score is tied at the end of game $T-2$, then he plays risky in game T if he lost game $T-1$ and plays safe otherwise. Proposition 1 implies that this is a profitable deviation from the mimicking strategy and, therefore, its expected payoff for player 2 is greater than 0.5. □

Note that in none of the above results we used the fact that $W > L$. Since Player 2 is the only one who can choose risk in Period 2, he is also the only one who can make an informed choice of risk. This "informational rent" is enough to give him an edge in the match. We show in the general model below that if *both* players have some control over risk in *both* periods, then the empirical fact that $W > L$ is crucial to prove that Player 2 has an advantage.

Model 2: The General Model

At a given game, both players can increase the probability of winning by taking a risky action. A risky action by white increases his probability of winning by $R_w > 0$ and his probability of losing by αR_w, with $\alpha > 1$. Similarly, a risky action by black increases his probability of winning by $R_b \geq 0$ and his probability of losing by αR_b.[10] As noted earlier, in chess white has *at least as much* control over how "risky" a chess game is, that is $R_w \geq R_b$. We find below that this is a *sufficient* condition to obtain that Player 2 has an advantage in a match. Further, this condition is not necessary.

Note that since $W > L$ and $\alpha > 1$ the following two conditions are satisfied when $R_w \geq R_b$:

C1: $R_b < \frac{W}{L} R_w$.

C2: $R_b < R_w + \frac{R_w(\alpha-1)(1-W-R_b)}{L+R_w}$.

[10]Clearly, it has to be the case that $W + R_w + \alpha R_b + L + R_b + \alpha R_w \leq 1$.

We show next that these two conditions suffice to give Player 2 an advantage in a two-game match. The intuition is that, although both players can control risk in both periods, the possibility of choosing a risky strategy is particularly valuable when a player is lagging in the score. Since $W > L$, Player 2 is more likely to be lagging in the score than Player 1 and, hence, he is the one more likely to benefit from risk taking in Period 2.

Proposition 2. *Consider a match with $T = 2$ games. When C1 and C2 are satisfied, optimal play leads to a higher expected payoff for Player 2. In particular, a sufficient condition for this result is that $R_w \geq R_b$.*[11]

Proof. We solve the game backwards starting with Period 2. We distinguish three cases.

Case 1. Suppose Player 1 won game 1. Then, in game 2, Player 1 is indifferent between a victory and a draw, so he plays safe. Player 2 is indifferent between a loss and a draw, so he plays risky. The expected utility for Player 1 in this case is:

$$u_1 = \frac{1}{2}(W + R_w) + 1(1 - (W + R_w)).$$

Case 2. Suppose Player 1 lost game 1. Following the above reasoning, Player 1 plays risky in game 2 and Player 2 plays safe. The expected utility for Player 1 in this case is:

$$u_2 = \frac{1}{2}(L + R_b).$$

Case 3. Suppose that game 1 was a draw. Then, in game 2, since the utility for a tie in the match is 0.5, both players play safe. That is, they do not want to transfer probability from the probability of drawing to the probability of winning if it entails transferring an even greater probability from the probability of drawing to the probability of losing (recall that $\alpha > 1$). The expected utility for Player 1 in this case is:

$$u_3 = 1L + \frac{1}{2}(1 - (W + L)).$$

[11]Note that, when $R_b = 0$, conditions **C1** and **C2** are trivially satisfied and this result reduces to Proposition 1 in Model 1.

We move now to Period 1. We can compute the expected utilities for each combination of strategy profiles of the players in period 1. Let u_{SR} denote the expected utility of Player 1 when he plays safe and Player 2 plays risky and similarly the other utilities. Then:

$$\begin{aligned}
u_{SS} &= Wu_1 + Lu_2 + (1 - W - L)u_3 \\
u_{RR} &= (W + R_w + \alpha R_b)u_1 + (L + \alpha R_w + R_b)u_2 \\
&\qquad + (1 - (W + L + (1 + \alpha)(R_w + R_b)))u_3 \\
u_{RS} &= (W + R_w)u_1 + (L + \alpha R_w)u_2 + (1 - ((W + R_w) + (L + \alpha R_w)))u_3 \\
u_{SR} &= (W + \alpha R_b)u_1 + (L + R_b)u_2 + (1 - ((W + \alpha R_b) + (L + R_b)))u_3
\end{aligned}$$

We now show that, given Period 2's optimal behavior, Player 2 can ensure for himself an expected utility higher than 0.5 by playing safe in period 1. Then, whatever Player 2's optimal choice is in period 1, it also gives him an expected payoff higher than 0.5. We compute the utilities of Player 1 with his two actions in period 1 when player 2 is playing safe. First, u_{SS} reduces to $\frac{1}{2}(1 + R_b L - R_w W)$, which is less than 0.5 when **C1** is satisfied. Second, u_{RS} reduces to

$$u_{RS} = \frac{1}{2}\big(1 + L(R_b - R_w) - R_w^2 + R_w(1 + (\alpha - 1)W + \alpha(-1 + R_b))\big),$$

which after some algebra can be rewritten as:

$$u_{RS} = \frac{1}{2}\big(1 - (L + R_w)(R_w - R_b) - R_w((\alpha - 1)(1 - W - R_b))\big),$$

which is less than 0.5 when **C2** is satisfied. □

Note that $R_w \geq R_b$ is a *sufficient* condition for the above results and that it is clear from conditions **C1** and **C2** that Player 2 will also have an advantage *even* in some cases where $R_w < R_b$. In other words, $R_w \geq R_b$ is by no means a necessary condition. This is because the "informational rent" that Player 2 always has is independent of which player has greater control over risk in a game.

These results show that rational effects operate in this setting in favor of Player 2. This means, as indicated earlier, that we would only be able to conclude that psychological effects are a significant determinant of cognitive performance if the empirical evidence goes in the *opposite* direction, that is if it shows that Player 1 significantly outperforms Player 2. In that case we can conclude that the observed differences in cognitive performance are caused by emotional effects resulting from the consequences of the playing order, and that the quantitative impact of these effects is at least as large as the difference in average winning frequencies.

4 Data

The dataset comes from *Chessbase*'s megabases, which are the most comprehensive databases in chess. They have detailed data on about 5 million games beginning in the XVIth century. We study *all* the matches during the period 1970-2010, namely about 511 matches with over 3,000 chess games. We select these four decades since 1970 is the year when FIDE adopted the ELO rating system; that is, the year after which records on the cognitive ability of the players at this task, as measured by this rating, exist. The dataset is comprehensive as it includes *all* matches classified as such in Chessbase's megabases that perfectly fit the randomized experiment described in Section 2.[12]

A valuable characteristic of the data set is that we have a reliable measure of the cognitive ability of the players performing the tasks is a valuable characteristic of the dataset. Players have a rating according to the ELO rating method, and the difference between two players' ELO ratings is functionally related to an estimate of the probability that one of the players will beat the other should they play a chess game. Nowadays, the top 10 players in the world typically have an ELO rating between 2,750 and 2,850 points, the top 100 players a rating above 2,650, and players with a rating above 2,500 points are professionals who have the title of Grandmaster, which is the highest title

[12]As such, it does not include matches played versus a computer, matches without a perfect alternation of colors, or matches where there is an incumbent who wins in case of a tie. We also exclude two observations of matches in which various games were played in the same day without the standard rest time between games.

that a player can achieve.

5 Empirical Evidence

5.1 Initial Evidence for Professionals

In order to have an initial sense of the evidence, we begin by studying all matches where players have an ELO rating above 2,500 and the rating difference between the players is no greater than 100 points. These players are professionals and the stakes in the matches they are involved in are high. Further, a match with an ELO difference above 100 points between the two players is a quite uneven match where the strong player is expected to with a very high probability regardless of other factors. This sample concerns 197 matches with a total of 1,319 chess games.

As one would expect from the random treatment, the average quality of the players that begin with the white pieces (mean = 2,620.1, std. deviation = 62.1) and the average quality of the players that begin with the black pieces (mean = 2,616.7, std. deviation = 57.4) are statistically identical (p-value = 0.56).

Figure 1 shows the proportions of matches won by the player who begins playing the first game with the white pieces and by the player who begins with the black ones.

[Figure 1 here]

If the order had no effect on the outcome of a match, these proportions should be statistically identical. Yet, there is a significant and quantitatively important difference: the player who begins playing the first game with the white pieces wins 57.4 percent of the time. This is statistically different from 50 percent at the five percent significance level (p-value = 0.046). The formal analysis in the previous section allows us to conclude that this difference in performance or "average treatment effect" arising from the randomly determined difference in the order of play can be attributed exclusively to psychological effects resulting from the consequences of the playing order.

In Figure 2 we split the data into "Elite" versus "Non-Elite" matches, and in matches for the World Championship versus other matches. "Elite" matches are those played by players with an ELO rating above 2,600, and World Championship matches are matches belonging to the World Championship cycles organized by FIDE. These are two intuitive ways of selecting arguably more important matches, where the stakes are higher, and players are more skilled and have a deeper preparation.

[Figure 2 here]

We find that for Elite matches winning frequencies are 62-38 and for World Championship matches 67-33. These frequencies are statistically different from 50-50 at standard significance levels (for Elite matches p-value $= 0.021$, for World Championship matches p-value $= 0.005$). Thus, the magnitude and the significance of the effects increase when considering Elite and World Championship matches.

5.2 Regression Results for the Complete Sample

This subsection first reports the complete set of results for the three different samples of professionals studied earlier: first for professionals with a rating above 2,500, and second and third for the subsamples of Elite and World Championship matches. In each case we consider two different specifications, one with no restriction on the rating difference, and another with a maximum difference of 100 ELO points between the players. The most complete specification is, of course, the first column in the table (professionals with no restriction in rating differences).

[Table 1 here]

The results confirm the initial evidence presented in the previous figures: the effect of starting the match playing with the white pieces is positive and strongly significant in each of the regressions, typically with p-values < 0.01 and even p-values < 0.001. Further, the impact is greater in magnitude and statistically more significant in the more important matches (Elite and World Championship). As expected, the difference in ELO ratings between the players also has a positive and significant impact in the probability of winning a match in every regression specification.

In Table 2 we report the main results. In the first two columns we consider *all* the matches in Chessbase's megabase *regardless* of the ELO level of the players (with no upper bound on the ELO difference and with a maximum of a 100 point difference, respectively). These are the most general specifications. For the sake of potential interest, in the next four columns we report the case of two minimum ELO levels (2,200 and 2,400).

[Table 2 here]

The results continue to confirm the strongly significant effect (p-values < 0.01) of starting the match playing with the white pieces. Similarly, and not surprisingly, the difference in ELO ratings continues to have a positive and significant impact on the probability of winning a match. The same results arise in columns three to six for the two minimum ELO levels. We also note that a small percentage of matches (not included in the sample) ended up tied. The same results are obtained in the corresponding ordered probit regressions with the three outcomes (win, loss, tie) when these matches are included. These results are reported in the Appendix.

5.3 Additional Testable Implications

We next take advantage of the opportunity provided by the fact that it is possible to measure with a high degree of precision the cognitive ability of the players to study the following testable prediction: given the undoubted role that other factors may play in determining the winner of a chess match, it should be the case that the psychological advantage of beginning with the white pieces significantly contributes to determining the outcome of a match *only* in relatively symmetric matches. That is, the more similar in cognitive strength two players are, the greater the effect should be. In other words, beginning with the white pieces should presumably tip the balance only when other factors are relatively similar, and the effect should steadily decrease as players are more different in their cognitive skills. We test this implication in Figure 3, which reports the evidence for the sample of matches studied in Subsection 5.1.

[Figure 3 here]

Consistent with the hypothesis, we find that *only* in matches between players of similar cognitive ability are there significant differences in performance. And as predicted we also find that the size of the effect increases when players are more similar in cognitive skills.[13]

6 Concluding Remarks

Competitive situations that involve cognitive performance are widespread in labor markets, education, and organizations, including test taking, student competition in schools, competition for promotion in firms, and numerous other settings. This paper contributes to the theoretical and empirical literature on dynamic competitive situations, which shows that incorporating behavioral elements arising from the *state* of the competition may offer significant insights about human behavior that otherwise will be lost. The literature has found that these emotional states are important for explaining the behavior of professional subjects performing non-cognitive tasks such as golf and soccer. The results in this paper show that they are also important for professionals performing competitive cognitive tasks.

Understanding all aspects of "competition" is central to economics, and understanding the effects of cognitive and noncognitive abilities is also important in areas ranging from cognitive psychology to neuroscience.

We have studied the impact of randomly allocated emotional differences on cognitive decision making in a competitive situation involving high stakes, sophisticated players, and elaborate decision processes. Previous research has also found that individuals with higher cognitive ability tend to exhibit *fewer* and *less extreme* cognitive biases that may lead to suboptimal behavior. Thus, an open question for future research is the extent to which these effects are important in other parts of the distribution of cognitive abilities and in tasks and settings with lower stakes. In schools, for instance, there is evidence

[13]This result may also explain the earlier finding showing that the effect is stronger for Elite and World Championship matches. These are matches where players have a deeper preparation and hence, conditional on their rating, their deeper preparation makes them more similar in cognitive skills during their matches.

suggestion that providing relative performance information has an impact on future performance (Azmat and Iriberri (2010)).

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A Appendix: Ordered Probit Regressions

Tables A1 and A2 report the results of the ordered probit regressions when considering the matches that ended up tied. The set of outcomes is: Win, Loss, Tie.

[Tables A1 and A2 here]

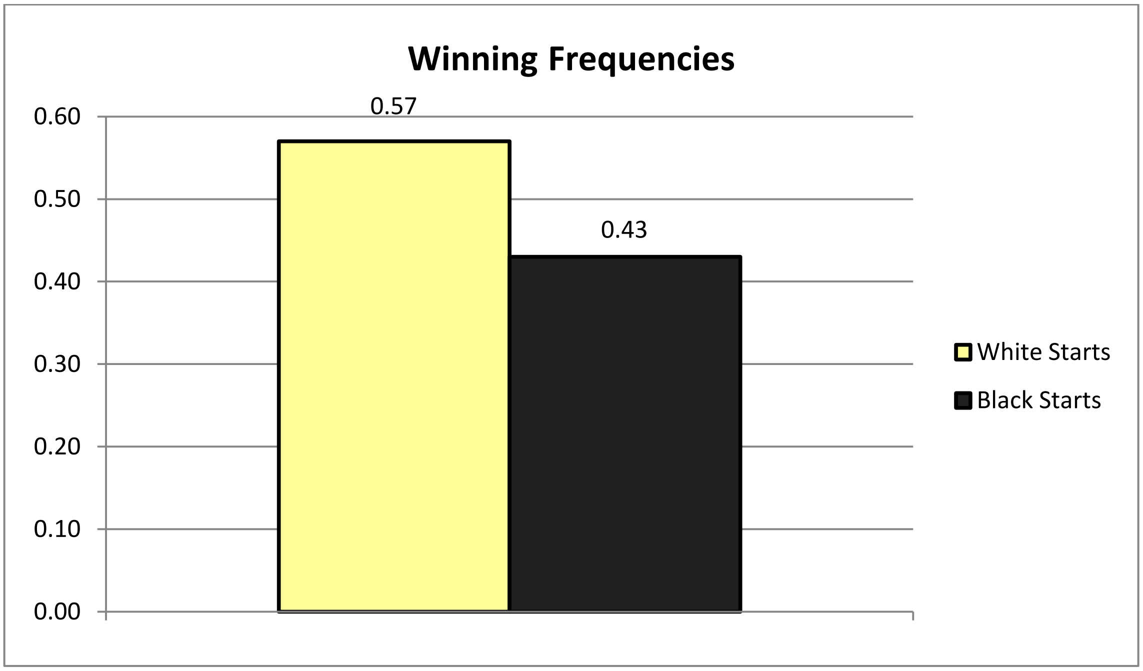

Fig. 1.

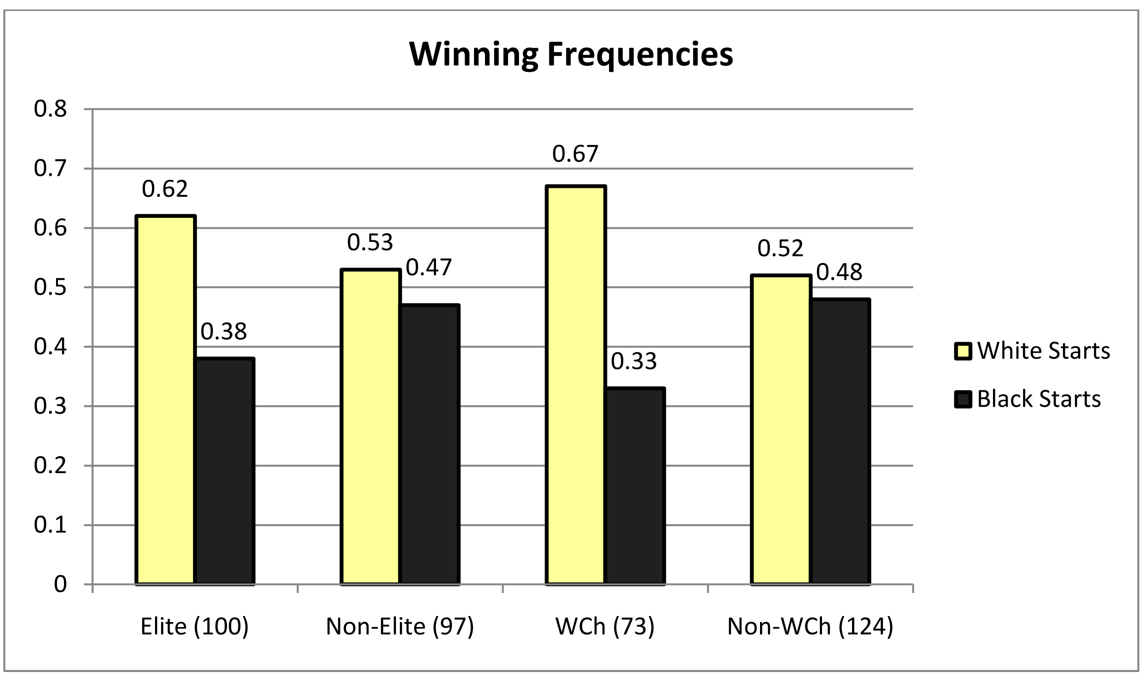

Fig. 2. The number of matches in each category are reported in parenthesis. The *p*-values of the proportions Chi-square tests are 0.02 (Elite matches), 0.68 (Non-Elite matches), 0.004 (World Championship matches) and 0.79 (Non-World Championship matches).

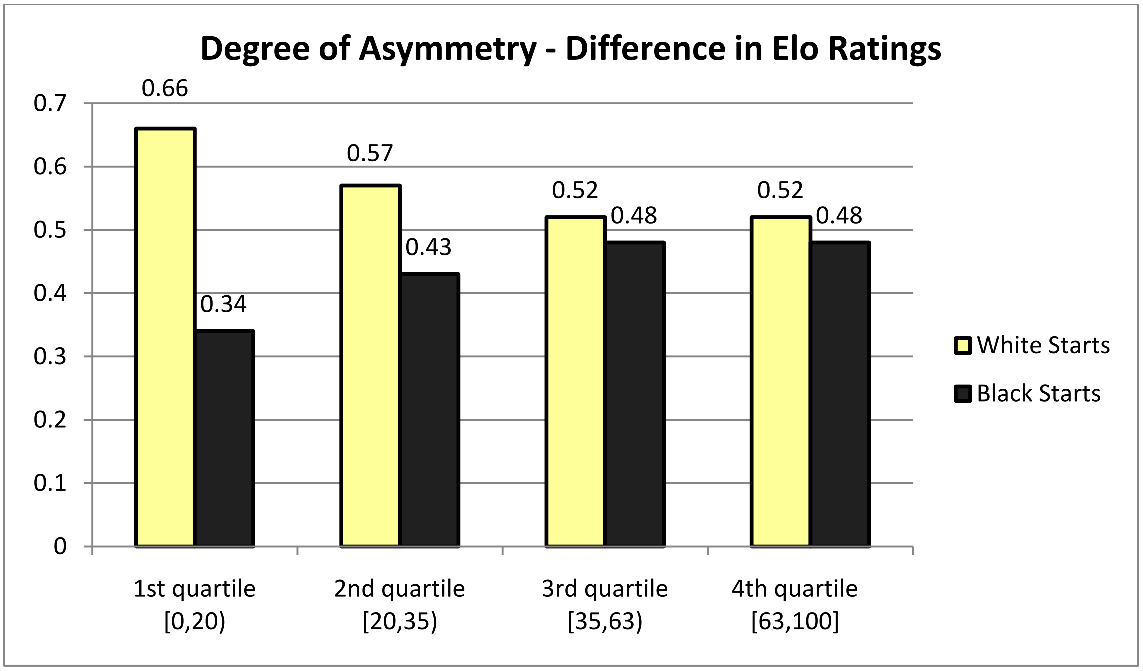

Fig. 3. Matches are sorted by the difference in ELO ratings between the two players, and then they are divided into four intervals (quartiles). The endpoint of the first interval is chosen so that it cuts off the lowest 25% of the sorted ELO differences. Similarly, the other endpoints cut off 50%, 75% and 100% respectively. The intervals are reported below each quartile. The number of matches in each quartile is 61, 42, 46 and 48 respectively. These differences in the number of matches across the intervals comes from the discreetness of the ELO ratings, which until the late 1999 moved in increments of 5 points. The *p*-values of the proportions Chi-square test are 0.02 (quartile 1), 0.44 (quartile 2), 0.88 (quartile 3) and 0.88 (quartile 4).

Table 1- Probit Regressions for Winners of a Chess Match

	Minimum ELO: 2500		ELITE Matches Minimum ELO: 2600		World Championship Matches	
Intercept	-0.120 (15.89)	-0.170 (16.68)	-0.284 (22.80)	-0.300 (23.10)	-0.376 (28.07)	-0.391 (29.27)
Starts with white pieces	**0.238**** **(0.129)**	**0.340***** **(0.134)**	**0.568***** **(0.190)**	**0.598***** **(0.192)**	**0.753***** **(0.224)**	**0.782***** **(0.226)**
Rounds	-0.000 (0.021)	0.000 (0.022)	-0.000 (0.030)	0.000 (0.031)	-0.000 (0.039)	-0.000 (0.040)
Year	-0.000 (0.0079)	0.000 (0.0083)	-0.000 (0.013)	0.000 (0.013)	-0.000 (0.016)	-0.000 (0.017)
ELO difference	**0.012***** **(0.001)**	**0.012***** **(0.001)**	**0.015***** **(0.0025)**	**0.013***** **(0.002)**	**0.012***** **(0.002)**	**0.011***** **(0.003)**
Player's ELO	0.000 (0.001)	0.000 (0.001)	0.000 (0.003)	-0.000 (0.003)	-0.000 (0.003)	-0.000 (0.003)
Maximum ELO Difference	None	100	None	100	None	100
N (matches)	234	197	116	100	79	73
Log-Likelihood	-252.15	-234.12	-116.25	-114.35	-83.19	-81.99
Akaike Information Criterion	516.29	480.24	244.51	240.69	178.38	175.97

Notes: *** denotes significant at the 1 percent significance level, ** at the 5 percent level, and * at the 10 percent level. The independent variables are the following: "Starts with white pieces" is a dummy variable that equals 1 if the player started playing the first game in the match with the white pieces; "Rounds" is the number of rounds in the match; "ELO difference" is the difference in ELO points with respect to the opponent at the time the match takes place; "Maximum ELO difference" is the maximum ELO difference between the players in the sample; "ELO points" are the ELO points of the player; and "Year" is the year the match takes place.

Table 2- Probit Regressions for Winners of a Chess Match

	Minimum ELO: None		**Minimum ELO: 2200**		**Minimum ELO: 2400**	
Intercept	-0.101 (11.50)	-0.130 (13.05)	-0.120 (11.96)	-0.128 (13.33)	-0.128 (14.01)	-0.162 (15.03)
Starts with white pieces	**0.202***** **(0.094)**	**0.260***** **(0.106)**	**0.240***** **(0.098)**	**0.256**** **(0.108)**	**0.257**** **(0.112)**	**0.324***** **(0.119)**
Rounds	-0.000 (0.015)	0.000 (0.017)	-0.000 (0.016)	-0.000 (0.017)	-0.000 (0.017)	-0.000 (0.019)
Year	-0.000 (0.005)	0.000 (0.006)	-0.000 (0.006)	-0.000 (0.006)	-0.000 (0.006)	-0.000 (0.007)
ELO difference	**0.008***** **(0.000)**	**0.012***** **(0.001)**	**0.009***** **(0.000)**	**0.011***** **(0.001)**	**0.011***** **(0.001)**	**0.012***** **(0.001)**
ELO points	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.0000 (0.000)	-0.000 (0.000)
Maximum ELO Difference	None	100	None	100	None	100
N (matches)	438	314	414	303	315	252
Log-Likelihood	-465.62	-376.30	-434.89	-361.93	-335.55	-300.61
Akaike Information Criterion	943.24	764.61	881.79	735.86	683.11	613.23

Notes: *** denotes significant at the 1 percent significance level, ** at the 5 percent level, and * at the 10 percent level. The independent variables are the following: “Starts with white pieces” is a dummy variable that equals 1 if the player started playing the first game in the match with the white pieces; “Rounds” is the number of rounds in the match; “ELO difference” is the difference in ELO points with respect to the opponent at the time the match takes place; “Maximum ELO difference” is the maximum ELO difference between the players in the sample; “ELO points” are the ELO points of the player; and “Year” is the year the match takes place.

Table A1- Ordered Probit Regressions for Winners of a Chess Match

	Minimum ELO: 2500		**ELITE Matches Minimum ELO: 2600**		**World Championship Matches**	
Starts with white pieces	**0.250** (0.110)**	**0.338*** (0.115)**	**0.603*** (0.161)**	**0.618*** (0.162)**	**0.703*** (0.209)**	**0.740*** (0.212)**
Rounds	-0.000 (0.016)	-0.000 (0.017)	-0.000 (0.022)	-0.000 (0.022)	-0.000 (0.031)	0.000 (0.031)
Year	-0.000 (0.001)	-0.000 (0.001)	-0.000 (0.002)	-0.000 (0.005)	-0.000 (0.004)	-0.000 (0.006)
ELO difference	**0.010*** (0.001)**	**0.010*** (0.001)**	**0.014*** (0.002)**	**0.012*** (0.002)**	**0.012*** (0.002)**	**0.011*** (0.003)**
ELO points	-0.000 (0.001)	0.000 (0.001)	-0.000 (0.002)	0.000 (0.004)	0.000 (0.003)	0.000 (0.004)
Loss/Tie	-0.069*** (0.000)	-0.026*** (0.000)	0.085*** (0.000)	0.082*** (0.000)	0.271*** (0.000)	0.115*** (0.001)
Tie/Win	0.317*** (0.044)	0.363*** (0.046)	0.511*** (0.068)	0.514*** (0.068)	0.430*** (0.001)	0.276*** (0.000)
Maximum ELO Difference	None	100	None	100	None	100
N (matches)	267	228	133	117	83	77
Log-Likelihood	-446.23	-413.88	-212.18	-208.66	-114.18	-123.91
Akaike Information Criterion	906.47	841.75	438.36	431.33	242.35	257.82

Notes: *** denotes significant at the 1 percent significance level, ** at the 5 percent level, and * at the 10 percent level. The independent variables are the following: "Starts with white pieces" is a dummy variable that equals 1 if the player started playing the first game in the match with the white pieces; "Rounds" is the number of rounds in the match; "ELO difference" is the difference in ELO points points with respect to the opponent at the time the match takes place; "Maximum ELO difference" is the maximum ELO difference between the players in the sample; "ELO points" are the ELO points of the player; and "Year" is the year the match takes place. "Loss/Tie" and "Tie/Win" are the corresponding threshold parameters of the ordered probit.

Table A2-Ordered Probit Regressions for Winners of a Chess Match

	Minimum ELO: None		**Minimum ELO: 2200**		**Minimum ELO: 2400**	
Starts with white pieces	**0.112* (0.077)**	**0.191** (0.089)**	**0.138* (0.080)**	**0.187** (0.091)**	**0.219** (0.093)**	**0.252*** (0.099)**
Rounds	0.000 (0.011)	0.000 (0.013)	-0.001 (0.012)	0.000 (0.013)	-0.000 (0.014)	-0.000 (0.015)
Year	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
ELO difference	**0.006*** (0.000)**	**0.008*** (0.000)**	**0.006*** (0.000)**	**0.009*** (0.000)**	**0.008*** (0.000)**	**0.009*** (0.001)**
ELO points	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Loss /Tie	-0.160*** (0.000)	-0.111*** (0.000)	-0.925*** (0.000)	-0.105*** (0.000)	-0.404*** (0.000)	-0.283*** (0.000)
Tie /Win	0.276*** (0.034)	0.308*** (0.037)	-0.495*** (0.034)	0.302*** (0.037)	0.012 (0.039)	0.136*** (0.041)
Maximum ELO Difference	None	100	None	100	None	100
N (matches)	511	369	481	354	364	296
Log-Likelihood	-895.74	-690.44	-837.48	-657	-625.47	-552.88
Akaike Information Criterion	1805.48	1394.88	1688.97	1328.23	1264.94	1119.77

Notes: *** denotes significant at the 1 percent significance level, ** at the 5 percent level, and * at the 10 percent level. The independent variables are the following: “Starts with white pieces” is a dummy variable that equals 1 if the player started playing the first game in the match with the white pieces; “Rounds” is the number of rounds in the match; “ELO difference” is the difference in ELO points with respect to the opponent at the time the match takes place; “Maximum ELO difference” is the maximum ELO difference between the players in the sample; “ELO points” are the ELO points of the player; and “Year” is the year the match takes place. “Loss/Tie” and “Tie/Win” are the corresponding threshold parameters of the ordered probit.