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Coordination, focal points and voting in strategic situations: a natural experiment

Ganna Pogrebna · Pavlo R. Blavatskyy

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Abstract This paper studies coordination in a multi-stage elimination tournament with large monetary incentives and a diversified subject pool drawn from the adult British population. In the tournament, members of an *ad hoc* team earn money by answering general knowledge questions and then eliminate one contestant by plurality voting without prior communication. We find that in the early rounds of the tournament, contestants use a focal principle and coordinate on one of the multiple Nash equilibria in pure strategies by eliminating the weakest member of the team. However, in the later rounds, contestants switch to playing a mixed strategy Nash equilibrium.

Keywords Coordination · Focal point · Voting in strategic situations

JEL Classification C72 · C93 · D72

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G. Pogrebna (✉)
Institute for Social and Economic Research and Policy, Center for Decision Sciences,
Columbia University, 419 Schermerhorn Hall, New York, NY 10027, USA
e-mail: gp2240@columbia.edu

P.R. Blavatskyy
Institute for Empirical Research in Economics, University of Zurich, Winterthurerstrasse 30,
8006 Zurich, Switzerland
e-mail: pavlo.blavatskyy@iew.unizh.ch

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1 Introduction

Several experimental studies have shown that when faced with complex coordination problems presented in an abstract form, people often need to play the same game repeatedly in order to learn to coordinate with each other in the absence of communication (see e.g. Blume and Gneezy 2000). However, in the real world situations when strategies could be identified by labeling, people tend to choose solutions that appear to be salient, peculiar, noticeable, relevant or natural to them. These solutions have been first elucidated in the classic work of Thomas Schelling (1960) as "*focal point*[s] *for each person's expectation of what the other expects him to be expected to do*" (Schelling 1960: 57).[1] Experimental research has provided evidence that salience may become an effective coordination mechanism in strategic games with multiple equilibria (see e.g. Mehta et al. 1994a, 1994b).

We investigate coordination in a strategic situation with voting in the presence of a focal principle using data from a natural experiment of British Broadcasting Corporation (BBC) television show, *The Weakest Link*, with large monetary incentives and a diversified subject pool drawn from the adult British population.[2] This paper is related to two streams of literature: literature on voting in strategic situations and literature on decision making in game shows.

Much of the research in economics and psychology has concentrated on voting in strategic situations. At the theoretical level, several studies have analyzed coordination problems in elections with different information aggregation mechanisms. Particularly, Feddersen and Pesendorfer (1997) assess coordination in elections with fixed alternatives and show that the electoral rule is the main determinant of the equilibrium voting behavior. The impact of signaling on voting in strategic situations is explored in Lohman (1993) and Razin (2003). Piketty (2000) analyzes the coordination of voters in a repeated election with multiple candidates. Experimental studies on voting in strategic situations date back to Fiorina and Plott (1978) and focus on coordination, resource allocation and voting cycles (e.g. Eckel and Holt 1989; Holt and Anderson 1999). Even though the literature on voting in strategic situations offers many insights into the nature and mechanisms of the electoral process, to date, economic research has provided little guidance with regard to voting in strategic situations in the presence of a focal principle.

Television shows have long represented an appealing material for economic researchers. Particularly, Metrick (1995) argues that the television show is a suitable empirical resource for economists, since many of these shows are structured as well-defined decision problems or strategic games. Bennett and Hickman (1993) and Berk et al. (1996) use data from the television show *The Price is Right* to test for the optimal information updating and rational bidding strategies correspondingly. Gertner (1993), Metrick (1995), and Beetsma and Schotman (2001) use data from *Card Sharks*, *Jeopardy!* and *Lingo* respectively to measure individual risk attitudes. *The Weakest Link* television show has also attracted the attention of several researchers.[3]

[1] The theoretical framework of focal points has been further developed by Sugden (1995).

[2] In *The Weakest Link* contestants can earn up to £10,000 in every television episode. Therefore, contestants have considerably higher monetary incentives than in conventional laboratory experiments. Replicating this natural experiment in the laboratory would require a budget of at least £230,000. In *The Weakest Link* contestants vary greatly in their age, educational levels and occupations and come from all administrative areas of the UK, which makes them a more diversified sample of population compared with conventional subject pools of undergraduate students.

[3] For example, Levitt (2004) and Antonovics et al. (2005) examined discrimination in *The Weakest Link* using data from the American version of the show. By testing two theories of discrimination Levitt (2004) finds only

The Weakest Link is designed as an elimination tournament so that only one of nine contestants who participate in the game earns the monetary prize, which is accumulated by the team (the remaining contestants receive nothing). Members of the team have never met each other before the show. Contestants are eliminated from the tournament by plurality voting. Every contestant can vote against only one of her counterparts. Therefore, the action space is well-defined and common knowledge. The monetary prize is generated from correct answers to general knowledge questions. Contestants are heterogeneous in their ability to answer general knowledge questions. These abilities, as well as voting decisions of contestants, are observable in all rounds of the game. In every round the host of the show encourages the team to eliminate the weakest player.

Our first objective is to explore whether contestants coordinate successfully when making their voting decisions. Our second objective is to understand whether observed coordination (if any) could be attributed to learning or to the existence of the focal principle to eliminate the weakest contestant. Finally, we use econometric estimation to identify factors that influence individual voting decisions in the show.

We find that contestants behave differently at the beginning and at the end of the show. Starting from the first round of the game contestants succeed in coordinating on one of the multiple Nash equilibria in pure strategies. They eliminate the weakest opponent with an *overwhelming plurality*, which appears to be a focal principle (Schelling 1960). However, coordination rates decline as the game progresses. In the later rounds of *The Weakest Link*, contestants appear to play *strictly mixed* strategy Nash equilibrium. We also show that the main determinants of individual voting decisions in *The Weakest Link* are the relative rank of an opponent (in terms of ability to answer general knowledge questions), negative reciprocity (contestants tend to vote against these counterparts, who voted against them in previous rounds) and money lost by the opponent (due to incorrect answers).

The remainder of the paper is organized as follows. Section 2 describes the television show *The Weakest Link* and offers basic statistics of the data set. Section 3 provides game theoretical analysis of the show and explores coordination and its dynamics during the game. Section 4 presents an econometric analysis of the determinants of individual voting decisions. Section 5 concludes with a general discussion.

2 Description of the television show

2.1 Rules of the game

In the British version of *The Weakest Link*, nine contestants participate in every episode. Becoming a contestant requires applying by phone or e-mail to the BBC. Therefore, all contestants self-select into the television show and have some familiarity with the rules of the game when they apply for participation. Contestants come from different educational

very limited evidence of discriminative voting patterns against female and black contestants. However, he maintains that some contestants tend to discriminate against Hispanics and elderly. Levitt (2004) also argues that the behavior of *The Weakest Link* contestants is consistent with non-random voting. While Antonovics et al. (2005) obtain a similar result of non-discriminative voting against female and black contestants, they employ conditional logit analysis to show that women tend to discriminate against men in the early rounds of the show. Fevrier and Linnemer (2006) analyze a simplified strategic game similar to actual game played by three contestants when they vote in the last round of *The Weakest Link*. They identify two pure strategy Nash equilibria of the simplified game and argue that the voting patterns observed in the French version of *The Weakest Link* suggest that contestants coordinate on a payoff dominant equilibrium "*if it is not too risky*".

Round 1		...	Round 7		Final	
A team of 9 contestants can earn money by answering general knowledge questions	9 members of the team eliminate one contestant by independent plurality voting	...	A team of 3 contestants can earn money by answering general knowledge questions	3 members of the team eliminate one contestant by independent plurality voting	2 contestants can earn money by answering general knowledge questions	The winner is determined in a general knowledge quiz
						time →
$t = 1$	$t = 2$	...	$t = 13$	$t = 14$	$t = 15$	$t = 16$

Fig. 1 Timing of the game

Table 1 Technology that converts correct answers into money

Number of correct answers given in a row up to this point	0	1	2	3	4	5	6	7	8	≥ 9
Amount of money that may be banked	£0	£20	£50	£100	£200	£300	£450	£600	£800	£1000

and professional backgrounds. They do not know the intellectual capabilities of each other before the game starts. There is, however, a preliminary two-hour session before the show when contestants are introduced to each other. The session is monitored and the possibility of conspiracy among contestants is excluded.

Every episode of the television show *The Weakest Link* consists of seven rounds and a final round. Figure 1 presents the chronological sequence of events.

In round $i \in \{1, \dots, 7\}$ there are $10 - i$ contestants who sequentially answer general knowledge questions at time $t = 2i - 1$. Table 1 presents the technology that converts correct answers to general knowledge questions into money. Every contestant can use this technology by saying "Bank!" when it is her turn to answer a question but before this question is actually asked. In this case, the sequence of correct answers given in a row is broken and the contestants have to build a new chain of correct answers from zero. If a contestant does not use the technology and answers a question incorrectly, all money accumulated in the chain is lost and the team has to start a new chain.

In round $i \in \{1, \dots, 7\}$ there is a limit of $190 - 10i$ seconds for answering general knowledge questions. The amount of money that can be earned in one round is limited to £1000. General knowledge questions increase in difficulty from round to round.

In round $i \in \{1, \dots, 7\}$ the remaining $10 - i$ members of the team eliminate one contestant at time $t = 2i$ (Fig. 1). Contestants cast votes simultaneously and independently from each other. Specifically, every contestant writes the name of her candidate for elimination on a plastic board, which is not visible to the others. When voting is over, contestants reveal their voting decisions. The contestant who received more votes than any other contestant is eliminated from the game as *the weakest link*. In other words, contestants are eliminated by plurality voting.

The game is very intense as contestants not only have to answer questions and keep track of money accumulated in the chain, but they also must pay attention to the performance of

Table 2 Selected descriptive statistics

Descriptive statistics	Value
Percent of female	41.11
Percent of male	58.89
Minimum age (years)	18
Maximum age (years)	84
Average age (years)	46
Average earnings (£)	2,330.60
Median earnings (£)	2,275.00
Standard deviation (£)	846.70

each other to make their voting decisions at the end of each of the seven rounds, until the number of contestants boils down to two. The tension is increased by the sarcastic remarks of the host, Anne Robinson, who has a reputation of "the rudest person on British television".[4]

Two contestants compete in the final round. At time $t = 15$ they accumulate additional money by answering general knowledge questions. The technology, presented in Table 1, is available to the finalists, however, any money banked is tripled and the time limit is 90 seconds. At $t = 16$, the winner is determined through the head-to-head general knowledge quiz of five questions per contestant.[5] The winner receives the total prize earned in the show. The other eight contestants leave with nothing.

2.2 Basic statistics

The data have been transcribed from BBC Prime *The Weakest Link* original broadcasts, aired between January 7, 2005 and October 21, 2005. Excluding repetitions, the sample contains a total of 100 television episodes. The resulting laboratory incorporates 4200 voting decisions made by 900 contestants. Table 2 presents selected descriptive statistics of the sample, revealing some characteristics of the contestants.

Contestants are recruited from all administrative regions of the United Kingdom. The majority of contestants are white adults, from 18 to 84 years old (with the average age of 46 years). 58.89% of contestants are male and 41.11% female. Even though contestants usually reveal their occupation at the beginning of the show and answer questions about their profession posed by the host during the game, it is difficult to deduce hard data from these self-reported characteristics.

One of the main advantages of *The Weakest Link* natural laboratory is that the stakes in the show are higher than in any standard laboratory experiment. Notably, prizes in the recorded sample ranged from £830.00 to £5,420.00 with an average of £2,330.60, median of £2,275.00 and standard deviation of £846.70 across 100 episodes.

3 Game theoretical analysis

In this section we provide a game theoretical analysis of the show. Our analysis can be divided into three main parts. First, we construct the relative ranking of contestants in terms

[4]Quoted from official website of *The Weakest Link* television show http://www.bbc.co.uk/weakestlink.

[5]If after ten questions both finalists have the same number of correct answers, the quiz continues until one contestant dominates the other by one correct answer.

Table 3 Relative difficulty of questions across rounds

Round r	1	2	3	4	5	6	7
Weight ω_r	0.0873	0.1920	0.2716	0.2904	0.3213	0.3339	0.4003

of ability to answer general knowledge questions during the show. This ranking allows us to incorporate heterogeneity of contestants in our theoretical analysis. Second, we consider Nash equilibria in pure strategies in the early rounds of the show and determine whether contestants coordinate on any of the available equilibria. Third, we calculate Nash equilibria in pure and mixed strategies in the later rounds of the show. We also explore whether behavior of contestants can be rationalized within our theoretical predictions.

3.1 Ranking of contestants

In *The Weakest Link* television show contestants are heterogeneous in their ability to answer general knowledge questions. In order to account for this heterogeneity we construct a measure of the relative ranking of contestants in each round of the game. This ranking is used in our game theoretical and econometric analysis below. The performance of every contestant $j \in \{1, \dots, 10 - i\}$ participating in the plurality voting in round $i \in \{1, \dots, 7\}$ is measured by index

$$C_j^i = \frac{\sum_{r=1}^{i} \omega_r a_j^r}{\sum_{r=1}^{i} \omega_r b_j^r}, \tag{1}$$

where a_j^r is a number of correct answers given by contestant j in round $r \in \{1, \dots, i\}$ and b_j^r is the total number of questions that contestant j was asked in round r.

During the show, the host warns contestants that the questions become more complex as the game progresses. In order to account for this feature of the game show design, we compute weights ω_r that capture the relative difficulty of questions across rounds, from the game show data. Weights ω_r are calculated as a fraction of incorrect answers given in round r by 300 contestants who participated in all seven rounds in our recorded sample of 100 television episodes, relative to the total number of questions that these contestants have received in round r. Table 3 demonstrates that obtained weights ω_r increase in r. In other words, our analysis confirms the claim of the game show host that questions become more difficult in the later rounds of the game. We incorporate weights ω_r in our index of contestants' performance (1) in order to account for the increased difficulty of questions towards the end of the show.

The rank of contestant j in round i is denoted by $X1_j^i \in \{1, \dots, 10 - i\}$. It is assigned in descending order based on index (1), i.e. the contestant with the highest index C_j^i ($i \in \{1, \dots, i\}$) receives the highest rank (rank 1). If several contestants have the same index C_j^i, which is frequently observed in early rounds of the game ($i \leq 4$), they are assigned an average shared rank.

3.2 Pure strategy equilibria in the early rounds

Proposition 1 *In round $i \in \{1, \dots, 5\}$ any voting profile, where $j \in \{4, \dots, 9 - i\}$ contestants vote against the same person and no more than $j - 3$ remaining contestants vote against another person, constitutes a pure strategy Nash equilibrium independent of the prize in the game and relative probabilities of winning for different contestants.*

Proof Even if one contestant changes her vote, at least $j-1$ contestants will vote against the same person, and no more than $j-2$ remaining contestants will vote against another person. Therefore, the outcome of plurality voting remains unchanged and none of the contestants has an incentive to change her vote. □

Intuitively, when an *overwhelming plurality* of contestants vote against the same person, such voting profile constitutes an equilibrium because no one can change the outcome (of plurality voting) by switching her vote. An *overwhelming plurality* is formed when one of the candidates for elimination has a three-vote lead. By definition, an *overwhelming plurality* cannot be formed in rounds 6 and 7. For example, consider round 6 with 4 contestants. When three contestants vote against the fourth contestant, one of them may have an incentive to deviate and cast her vote against the same contestant, who has been eliminated by the fourth contestant. The plurality vote then becomes tied and the expected payoff for the contestant who deviated can be higher than her payoff from eliminating the fourth contestant with certainty. Therefore, equilibria identified in Proposition 1 cannot be observed in rounds 6 and 7.

3.3 Coordination and focal principle in the early rounds

Obviously, there are many possible ways to form an *overwhelming plurality* in every round $i \in \{1, \ldots, 5\}$. However, since the title of the television show is *The Weakest Link*, the focal principle is to vote against the weakest opponent (Schelling 1960). Moreover, the host repeatedly encourages contestants "to have the courage to eliminate the weakest link." Thus, the voting profiles when an *overwhelming plurality* votes against the weakest opponent strike out as the focal equilibria on which contestants can easily coordinate.

Table 4 shows the number of television episodes when an *overwhelming plurality* of contestants vote against the same person and the distribution of such episodes according to the rank of the contestant who is eliminated. In other words, Table 4 presents cases, when an observed voting profile in round $i \in \{1, \ldots, 5\}$ satisfies the conditions of Proposition 1. Apparently, when an *overwhelming plurality* of contestants vote against one person, they vote against the opponent with the lowest rank.[6] For example, in round 1 contestants have formed an *overwhelming plurality* in 73 television episodes. In 66 of these episodes (90%) they have voted against the weakest contestant (ranked 9). Thus, among all possible equilibria identified in Proposition 1, contestants manage to play the focal equilibria when they coordinate

Table 4 Outcomes of the *overwhelming plurality* voting in rounds 1–5

Round	Total episodes	Episodes when the plurality votes against the contestant ranked...								
		1	2	3	4	5	6	7	8	9
1	73	0	0	0	0	0	2	3	2	66
2	50	0	0	0	0	2	2	6	40	
3	42	0	0	0	1	1	8	32		
4	45	1	2	2	5	6	29			
5	19	0	2	1	4	12				

[6]Low ability contestants have a higher probability of being eliminated and therefore, contestants end up in a truth-revelation equilibrium, i.e. high ability players have no incentive to misrepresent their type by deliberately answering general knowledge questions incorrectly.

on voting against the weakest opponent, even without explicit pre-play communication or learning in early rounds.

Table 4 shows that pure strategy equilibria identified in Proposition 1 are played less often as the game progresses.[7] For example, in round 5 contestants manage to form an overwhelming plurality only in 19 television episodes. In 12 of these episodes (63%) contestants coordinate on voting against the lowest ranked contestant. Thus, not only do the instances of successful coordination tend to decline but also the relative frequency of coordination on focal equilibria decreases, as the game progresses.

Apparently, from the first round, contestants succeed in playing pure strategy equilibria identified in Proposition 1 (particularly, focal equilibria). However, contestants do not remain in these equilibria. In the later rounds of the game, the majority of observed voting profiles do not satisfy the conditions of Proposition 1. This suggests that as the game progresses, contestants start to think more strategically when casting their votes and eliminate strong opponents to secure a win in the final. To investigate this possibility we conduct a game theoretical analysis of the later rounds of the game.

3.4 Equilibria in the last round

To understand voting behavior in the later rounds of the game, we analyze the last round (round 7).[8] In round 7 there are three contestants left in the game. For simplicity, we will refer to a contestant who is ranked $j \in \{1, 2, 3\}$ in round 7 as contestant j. The left panel of Fig. 2, Fig. 3 and Fig. 4 shows the cumulative distribution function of a monetary payoff (in British pounds) that, respectively, contestant 1, contestant 2 and contestant 3 received in 100 television episodes of our recorded sample. The right panel of Fig. 2, Fig. 3 and Fig. 4 shows the certainty equivalent of a corresponding stochastic payoff ($x \geq 0$) on the left panel. The certainty equivalents are calculated using CRRA utility function $u(x) = x^{1-r}/(1-r)$ for a plausible range of the coefficients of relative risk aversion $r \in [-2, 1)$.

Let π_j^k be the expected utility of a payoff for contestant $j \in \{1, 2, 3\}$ if contestant $k \in \{1, 2, 3\}$, $k \neq j$, is eliminated in round 7. Notice that the right panel of Fig. 2 shows monetary outcomes with utilities π_1^2 and π_1^3 given CRRA utility function and various coefficients of relative risk aversion $r \in [-2, 1)$. Similarly, the right panel of Fig. 3 (Fig. 4) shows monetary outcomes with utilities π_2^1 and π_2^3 (π_3^1 and π_3^2).

A quick inspection of the right panels of Fig. 2, Fig. 3 and Fig. 4 reveals that actual payoffs in round 7 satisfy condition (2) for plausible risk attitudes of contestants.[9]

$$\pi_1^3 \leq \pi_1^2 < 2\pi_1^3, \quad \pi_2^3 < \pi_2^1 \leq 2\pi_2^3, \quad \pi_3^2 < \pi_3^1 < 2\pi_3^2. \tag{2}$$

In round 7 (at $t = 14$) contestants play the game that is presented in the normal form on Fig. 5. Notation S_j^k denotes an action of contestant $j \in \{1, 2, 3\}$ when she votes against contestant $k \in \{1, 2, 3\}$, $k \neq j$. In case of a tie, e.g. when contestant 1 votes against contestant 2,

[7] For pure strategy equilibria identified in Proposition 1 Table 4 shows an upper bound on their frequency of play. Some of the voting profiles counted in Table 4 can be also the result of equilibrium voting when one or several contestants randomize their vote.

[8] Analysis of round 6 follows a similar logic. However, it is mathematically cumbersome and does not provide additional insights to the economic intuition.

[9] The first inequality in condition (2) holds when the strongest contestant is not very risk-averse ($r \leq 0.27$). Otherwise, $\pi_1^3 \geq \pi_1^2$ and equilibrium 2 presented in Table 5 (where the strongest and the weakest contestants vote against the second ranked contestant) is not sustainable. The last inequality in (2) holds when the weakest contestant is not extremely risk-seeking ($r \geq -1.35$). Otherwise, equilibrium 2 presented in Table 5 does not exist.

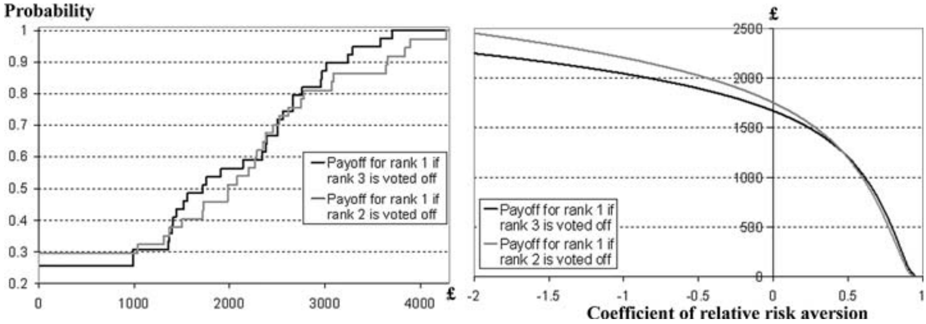

Fig. 2 Cumulative distribution function of the payoff for contestant who is ranked 1 (*left panel*) and a certainty equivalent payoff for CRRA utility function (*right panel*)

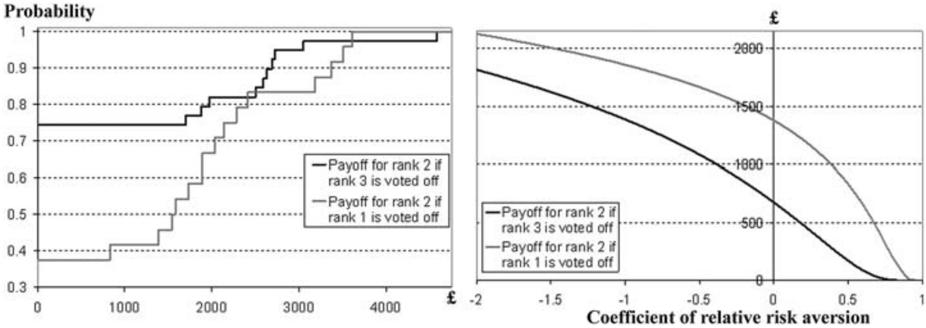

Fig. 3 Cumulative distribution function of the payoff for contestant who is ranked 2 (*left panel*) and a certainty equivalent payoff for CRRA utility function (*right panel*)

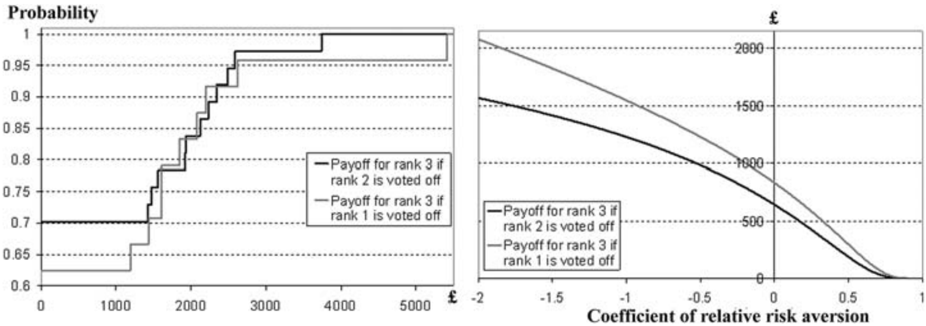

Fig. 4 Cumulative distribution function of the payoff for contestant who is ranked 3 (*left panel*) and a certainty equivalent payoff for CRRA utility function (*right panel*)

contestant 2 votes against contestant 3 and contestant 3 votes against contestant 1, we assume that every contestant has equal chance of being eliminated (with probability 1/3).[10]

[10]In our recorded sample there were 8 instances of voting ties in round 7 and contestant 1 was eliminated in 1 case, contestant 2—in 5 cases, and contestant 3—in 2 cases. Actual tie-breaking rule of *The Weakest Link*

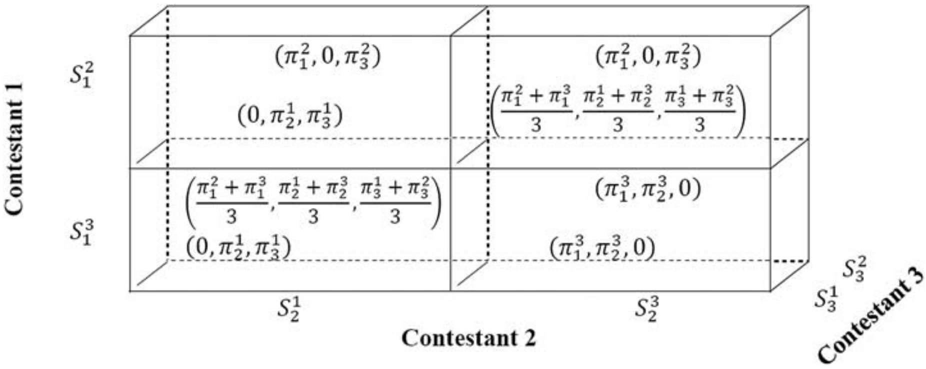

Fig. 5 Normal form game representation of voting in round 7

The payoffs are presented in vector form on Fig. 5 with a convention that the first number is the payoff of contestant 1 and the last number is the payoff of contestant 3.

Proposition 2 *The game presented in the normal form on* Fig. 5 *with parameters that satisfy condition* (2) *has only four Nash equilibria that are presented in* Table 5.

Proof The situation when two contestants vote against each other and the remaining contestant randomizes cannot be an equilibrium because the remaining contestant is better off by voting with probability 1 against the contestant whom she would like to eliminate. The situation when two contestants vote against different people and the remaining contestant randomizes also cannot constitute an equilibrium. The latter contestant is better off by voting with probability 1 against the contestant who votes against her. The situation when two contestants vote against the third contestant and the latter randomizes is a Nash equilibrium, provided that the third contestant randomizes in such a way that neither of the first two contestants has an incentive to change her vote. This yields equilibria 1–3 in Table 5.

The situation when one contestant votes against one of her opponents with probability 1 and two remaining contestants randomize cannot be an equilibrium. The contestant, against whom the first player casts her vote, is better off by voting with probability 1 against the first player. Thus, the only remaining possibility is that all three contestants play *strictly mixed* strategies and this leads to equilibrium 4 in Table 5. □

Four equilibria presented in Table 5 cannot be ranked according to the payoff dominance (e.g. Harsanyi and Selten 1988). In equilibria 1, 2 and 3, correspondingly, contestant 1, 2 and 3 is eliminated with certainty and receives zero payoff. In equilibrium 4, all contestants receive positive expected payoff but at least one contestant can receive a strictly better payoff in equilibria 1–3 (contestants 2 and 3 receive the best possible payoff in equilibrium 1 and contestant 1—in equilibrium 2).[11]

states that the deciding vote belongs to the contestant who: 1) gave the smallest number of incorrect answers in the last round; 2) gave a higher number of correct answers in the last round; 3) banked more money for the team.

[11] This result appears to be at odds with the findings of Fevrier and Linnemer (2006) who identify a payoff dominant equilibrium. However, Fevrier and Linnemer (2006) consider a simplified strategic game similar to

Table 5 Four possible Nash equilibria in round 7

Equilibria	Action of contestant 1	Action of contestant 2	Action of contestant 3
1	Any (pure or mixed)	S_2^1	S_3^1
2	S_1^2	S_2^1 with probability $p \in \left[0, \frac{2\pi_3^2-\pi_3^1}{2\pi_3^1-\pi_3^2}\right]$	S_3^2
3	S_1^3	S_2^3	S_3^1 with probability $r \in \left[\frac{3(\pi_1^2-\pi_1^3)}{2\pi_1^2-\pi_1^3}, \frac{2\pi_2^3-\pi_2^1}{2\pi_2^1-\pi_2^3}\right]$
4	S_1^2 with probability $\tilde{q} = \dfrac{\frac{2\pi_3^1-\pi_3^2}{2\pi_3^2-\pi_3^1}\left(1-\frac{2\pi_1^2-\pi_1^3}{2\pi_1^3-\pi_1^2}\left(1-\frac{2\pi_2^3-\pi_2^1}{2\pi_2^1-\pi_2^3}\right)\right)}{1+\frac{2\pi_1^2-\pi_1^3 2\pi_2^3-\pi_2^1 2\pi_3^1-\pi_3^2}{2\pi_1^3-\pi_1^2 2\pi_2^1-\pi_2^3 2\pi_3^2-\pi_3^1}}$	S_2^3 with probability $\tilde{p} = \left[\dfrac{\frac{2\pi_1^2-\pi_1^3}{2\pi_1^3-\pi_1^2}\left(1-\frac{2\pi_2^3-\pi_2^1}{2\pi_2^1-\pi_2^3}\left(1-\frac{2\pi_3^1-\pi_3^2}{2\pi_3^2-\pi_3^1}\right)\right)}{1+\frac{2\pi_1^2-\pi_1^3 2\pi_2^3-\pi_2^1 2\pi_3^1-\pi_3^2}{1+\frac{2\pi_1^2-\pi_1^3 2\pi_2^3-\pi_2^1 2\pi_3^1-\pi_3^2}{2\pi_1^3-\pi_1^2 2\pi_2^1-\pi_2^3 2\pi_3^2-\pi_3^1}}}\right]$	S_3^1 with probability $\tilde{r} = \dfrac{\frac{2\pi_2^3-\pi_2^1}{2\pi_2^1-\pi_2^3}\left(1-\frac{2\pi_3^1-\pi_3^2}{2\pi_3^2-\pi_3^1}\left(1-\frac{2\pi_1^2-\pi_1^3}{2\pi_1^3}\right)\right)}{1+\frac{2\pi_1^2-\pi_1^3 2\pi_2^3-\pi_2^1 2\pi_3^1-\pi_3^2}{2\pi_1^3-\pi_1^2 2\pi_2^1-\pi_2^3 2\pi_3^2-\pi_3^1}}$

Table 6 Theoretically possible voting profiles in round 7: observed frequency in the data and a predicted frequency of occurrence in equilibria 1–4

Voting profile[a]	Observed	Predicted frequency in equilibria...			
	frequency	1	2	3	4
211	12%	$\theta_1 \in [0, 1]$	0	0	$\tilde{q}(1-\tilde{p})\tilde{r}$
311	11%	$1-\theta_1$	0	0	$(1-\tilde{q})(1-\tilde{p})\tilde{r}$
212	11%	0	$\theta_2 \in \left[0, \frac{2\pi_3^2-\pi_3^1}{2\pi_3^1-\pi_3^2}\right]$	0	$\tilde{q}(1-\tilde{p})(1-\tilde{r})$
232	21%	0	$1-\theta_2$	0	$\tilde{q}\tilde{p}(1-\tilde{r})$
331	15%	0	0	$\theta_3 \in \left[3\frac{\pi_1^2-\pi_1^3}{2\pi_1^2-\pi_1^3}, \frac{2\pi_2^3-\pi_2^1}{2\pi_2^1-\pi_2^3}\right]$	$(1-\tilde{q})\tilde{p}\tilde{r}$
332	22%	0	0	$1-\theta_3$	$(1-\tilde{q})\tilde{p}(1-\tilde{r})$
231	4%	0	0	0	$\tilde{q}\tilde{p}\tilde{r}$
312	4%	0	0	0	$(1-\tilde{q})(1-\tilde{p})(1-\tilde{r})$

[a]The first number denotes the rank of contestant against whom contestant 1 casts her vote, and the last number denotes the rank of contestant against whom contestant 3 casts her vote

3.5 Voting profiles in the last round

Assuming that contestants play one of the four Nash equilibria identified in Table 5 in all episodes, in this section we identify an equilibrium they are most likely to play given voting profiles observed in our recorded sample. Theoretically, it is possible to observe eight voting profiles in round 7, all being listed in the first column of Table 6. The second column of Table 6 shows the percentage of episodes with a corresponding observed voting profile in round 7.

According to Table 6, in 92% of all episodes two contestants vote against the same opponent. In particular, they vote against the strongest contestant in 23% of all episodes, against the second ranked contestant—in 32% of all games, and against the weakest contestant—in 37% of all episodes. Even though the weakest contestant is eliminated with the highest probability, frequencies of being eliminated are similar across all three contestants. The results of a set of Fisher's exact tests (Fisher 1922) suggest that the differences between propensities of being eliminated between contestant 1 and 2 ($p = 0.20$) and contestant 2 and contestant 3 ($p = 0.55$) are not statistically significant. However, contestant 3 has a statistically significantly higher chance of being eliminated compared with contestant 1 ($p = 0.04$).[12] These results indicate that even though contestants fail to coordinate on voting off the weakest counterpart in round 7 in the majority of episodes in our sample, relatively weaker contestants (contestant 2 and contestant 3) are more likely to be eliminated than the strongest contestant (contestant 1).

the voting game played by three contestants in round 7 of *The Weakest Link*. We show that equilibria of the original game played by *The Weakest Link* contestants in round 7 cannot be ranked according to the payoff dominance criterion.

[12]The results of Fisher's exact test (Fisher 1922) remain the same even if we take into account 8 instances of voting ties, where contestant 1 was eliminated once, contestant 2–5 times, and contestant 3—twice. Since the weakest contestant has approximately the same or greater propensity of being eliminated compared with her stronger counterparts, strong contestants do not have any apparent reason to misinterpret their types by deliberately answering general knowledge questions incorrectly.

Several voting profiles (e.g. "232" and "332") are observed often (on average, in every fifth game), whereas other voting profiles (e.g. "231" and "312") are observed rarely (on average, in every 25th game). The likelihood of observing different voting profiles depends on a particular equilibrium from Table 5 that contestants choose to play in round 7. Therefore, we can infer which equilibria contestants are most likely to play in round 7 from the observed frequencies of occurrence of various voting profiles.

The third column of Table 6 shows that if contestants play equilibrium 1 from Table 5, they coordinate on this equilibrium in no more than 23% of all episodes. Similarly, if contestants play equilibria 2 and 3 from Table 5, they coordinate on these equilibria in no more than 32% and 37% of all episodes correspondingly (e.g. the fourth and the fifth column of Table 6). Therefore, it appears that in the majority of episodes in our sample contestants do not play one of equilibria 1–3.

In equilibrium 4 from Table 5 all three contestants play *strictly mixed* strategies and therefore, every theoretically possible voting profile can be observed in this equilibrium. The predicted frequency of every voting profile in equilibrium 4 is presented in the last column of Table 6. It turns out that when contestants play equilibrium 4, they coordinate on this equilibrium in up to 60% of all episodes.[13] In particular, as many as 60% of observed voting profiles can result from equilibrium 4 play when the strongest contestant plays S_1^2 with probability $\tilde{q} = 0.49$, contestant 2 plays S_2^3 with probability $\tilde{p} = 0.85$ and the weakest contestant plays S_3^1 with probability $\tilde{r} = 0.16$.

Is it possible to justify such (or similar) mixed strategies by actual payoffs that contestants with plausible risk attitudes face in the show? To answer this question, we estimate the coefficients of relative risk aversion $r_1 \in [-2, 1)$ for every contestant $j \in \{1, 2, 3\}$ such that:

(a) payoffs π_j^k are calculated as the expected utility from stochastic payoffs presented on the left panel of Fig. 2, Fig. 3, and Fig. 4 using CRRA utility function;
(b) optimal strategies of contestants in equilibrium 4 are calculated using formulas in the last row of Table 5;
(c) the predicted frequency of every voting profile that is theoretically possible in round 7 is calculated using formulas in the last column of Table 6;
(d) the number of episodes consistent with equilibrium 4 play is calculated as the highest number $n \in \{1, \dots, 100\}$ such that every voting profile listed in Table 6 is observed with frequency at least as high as its predicted frequency multiplied by $n/100$;
(e) the number of episodes consistent with equilibrium 4 play is maximized.

The estimated coefficients of relative risk aversions are $r_1 = 0.57$, $r_2 = 1.90$ and $r_3 = 0.68$, correspondingly for contestant 1, 2 and 3. Given these risk attitudes and stochastic payoffs presented on the left panel of Fig. 2, Fig. 3, and Fig. 4, the strongest contestant plays S_1^2 with probability $\tilde{q} = 0.49$, contestant 2 plays S_2^3 with probability $\tilde{p} = 0.89$ and the weakest contestant plays S_3^1 with probability $\tilde{r} = 0.05$. Observed voting profiles in 51% of all episodes are then consistent with assumption that contestants play equilibrium 4 in round 7.

To summarize, observed voting profiles of contestants suggest that if contestants play one of the four Nash equilibria identified in Table 5 in all episodes, they are most likely to play equilibrium 4 in round 7. In particular, equilibrium 4 is apparently played in every second

[13] To calculate a maximum number of episodes in which contestants can coordinate on equilibrium 4, we need to multiply the predicted frequency of voting profiles from the last column of Table 6 on the fraction of episodes in which contestants play equilibrium 4 and search for the highest possible fraction such that for every voting profile the predicted frequency of occurrence does not exceed an actually observed frequency.

episode if we assume that the strongest and the weakest contestants are slightly risk averse (with coefficients of relative risk aversion $r_1 = 0.57$ and $r_3 = 0.68$ respectively) and the second ranked contestant is highly risk seeking (with a coefficient of relative risk aversion $r_2 = -1.90$). However, there appears to be no obvious explanation why the second ranked contestant has such a different risk attitude from the other two contestants.

The left panel of Fig. 3 shows that the second ranked contestant has a strong incentive to vote against the strongest opponent—contestant 2 faces only 23% chance of earning the final prize if the weakest opponent is eliminated. However, the second column of Table 6 shows that contestant 2 votes against contestant 1 (the strongest opponent) only in 38% of all episodes. To explain such behavior within expected utility theory, we need to assume that contestant 2 is risk seeking. However, in more general non-expected utility theories, such as cumulative prospect theory (e.g. Tversky and Kahneman 1992) or rank-dependent expected utility theory (e.g. Quiggin 1982), behavior of contestant 2 can be explained not only by risk seeking behavior but also by overweighting of small probabilities of large outcomes.

There is a robust finding in economics and psychology that people distort probabilities: they tend to overweigh small probabilities and underweigh large probabilities (e.g. Kahneman and Tversky 1979; Gonzalez and Wu 1999).To investigate the latter possibility, we assume that all three contestants evaluate stochastic payoffs x_j^x presented on the left panel of Fig. 2, Fig. 3, and Fig. 4 according to formula

$$\pi_j^k = \sum_x v(x) \cdot \left[w\left(\text{prob}\{x_j^x \geq x\}\right) - w\left(\text{prob}\{x_j^x > x\}\right)\right]$$

of cumulative prospect theory (e.g. Tversky and Kahneman 1992) with value function $v(x) = x^\alpha$ and so-called Quiggin's probability weighting function $w(p) = p^\gamma/(p^\gamma + (1-p)^\gamma)^{\frac{1}{\gamma}}$. Coefficients $\alpha > 0$ and $\gamma > 0$ are estimated according to steps (b)–(e) explained above. These coefficients are constant for all three contestants. Note that expected utility theory (with power utility function) is a special case of cumulative prospect theory when coefficient γ equals one.

Obtained estimates of the parameters of cumulative prospect theory are $\alpha = 0.52$ and $\gamma = 0.88$. These estimates are similar to the parameterizations of cumulative prospect theory that are typically found in numerous experimental studies (e.g. Blavatskyy 2005). With these estimated parameters, contestant 1 plays S_1^2 with probability $\tilde{q} = 0.49$, contestant 2 plays S_2^3 with probability $\tilde{p} = 0.86$ and the weakest contestant plays S_3^1 with probability $\tilde{r} = 0.11$. Given such mixed strategies, 56% of observed voting profiles are consistent with equilibrium 4 play.

To summarize, among four Nash equilibria presented in Table 5, only a *strictly mixed* equilibrium 4 can explain more than one half of voting profiles observed in round 7. Moreover, contestants can play a *strictly mixed* equilibrium without having large differences in risk attitudes if they evaluate stochastic payoffs according to cumulative prospect theory rather than expected utility theory. Estimated parameterization of cumulative prospect theory for *The Weakest Link* contestants is in line with those found in other experimental studies.[14]

[14] The behavior of contestant 2 in round 7 can also be explained by assuming that contestant 2 is irrational. For example, since *The Weakest Link* is broadcasted on national television, contestant 2 might be concerned about her reputation and, therefore, might be less prone to vote against her strongest opponent.

4 Determinants of individual voting decisions

So far we have explored coordination dynamics during *The Weakest Link* television show. We have also provided several game theoretical explanations to the behavior of contestants. In this section we determine factors that influence individual voting decisions of contestants using an econometric estimation.

In round $i \in \{1, \ldots, 7\}$ each of $10 - i$ contestants has to vote against one of $9 - i$ opponents. In order to identify the determinants of individual voting decisions in *The Weakest Link* television show, it is necessary to take into account two streams of explanatory variables. First, one needs to control for the personal characteristics of $10-i$ contestants making voting decisions. Second, it is also important to consider the attributes of the voting alternatives, represented in *The Weakest Link* by the characteristics of $9 - i$ opponents, who may be eliminated. Therefore, a conditional logit model (Green 2003: 723) is particularly appropriate to investigate factors that influence individual voting decisions.[15]

Let $Y_j^i \in \{1, \ldots, 9 - i\}$ be a discrete variable that denotes the voting decision of $j \in \{1, \ldots, 10-i\}$ contestant in round $i \in \{1, \ldots, 7\}$. We estimate model (3), where $X1, \ldots, X7$ are explanatory variables described below.

$$\text{prob}(Y_j^i = m) = \frac{\exp\{\beta_1 X1_m^i + \beta_2 X2_{jm}^i + \cdots + \beta_7 X7_{jm}^i\}}{\sum_{k=1}^{9-i} \exp\{\beta_1 X1_k^i + \beta_2 X2_{jk}^i + \cdots + \beta_7 X7_{jk}^i\}},$$
$$m \in \{1, \ldots, 9-i\}, \quad j \in \{1, \ldots, 10-i\}, \quad i \in \{1, \ldots, 7\}, \quad k \in \{1, \ldots, 9-i\}. \quad (3)$$

The Weakest Link is an elimination tournament, where contestants are heterogeneous in their ability to answer general knowledge questions. Therefore, a natural candidate for an explanatory variable is a relative ranking of contestants in terms of their ability to answer general knowledge questions. In our econometric analysis we use relative ranking of contestant j in round i denoted by $X1_j^i \in \{1, \ldots, 10 - i\}$ from Sect. 3.1.

To control for discrimination in our sample we construct two explanatory variables. Difference in ranks $X2_{jk}^i = |X1_j^i - X1_k^i|$ is used to investigate if different types of contestants (in terms of ability to answer general knowledge questions) discriminate against each other i.e. whether a high ability contestant j votes against a low ability contestant k in round i or vice versa. Gender dummy $X3_{jk}^i \in \{0, 1\}$ is used to test for gender discrimination. Variable $X3_{jk}^i$ equals one if contestants j and k differ in gender and equals zero otherwise.

In *The Weakest Link* contestants may adopt a *tit for tat* strategy and vote against the opponent who voted against them in previous rounds. Variable $X4_{jk}^i \in \{0, \ldots, i - 1\}$ counts how many times contestant k voted against contestant j in rounds preceding round $i \neq 1$. We use this variable to control for contestants reciprocating the actions of their counterparts. Specifically, variable $X4_{jk}^i$ captures negative reciprocity.

In order to convert correct answers to general knowledge questions into money, contestants have to use technology presented in Table 1. The use of this technology can result in two types of ex-post mistakes. First, when a contestant banks and answers her question correctly, she misses an opportunity to exploit non-decreasing returns to scale, embedded in Table 1. To control for contestants penalizing premature banking, we use explanatory variable $X5_j^i$ that shows the amount of money banked by contestant j in round i. Second, when a contestant does not bank and fails to answer her question correctly, the previously

[15] Conditional logit has also been employed in the analysis of discrimination in *The Weakest Link* television show by Antonovics et al. (2005).

Table 7 Estimated conditional logit model of individual voting decisions

Variable	Round 1 coefficient (standard error)	Round 2 coefficient (standard error)	Round 3 coefficient (standard error)	Round 4 coefficient (standard error)	Round 5 coefficient (standard error)	Round 6 coefficient (standard error)	Round 7 coefficient (standard error)
Rank ($X1$)	0.6634***	0.5755***	0.5453***	0.5024***	0.4485***	0.3325***	0.2028*
	(0.0326)	(0.0269)	(0.0290)	(0.0320)	(0.0411)	(0.0527)	(0.0931)
Difference	0.0444	0.0497	0.0491	0.1201**	−0.0674	−0.1896*	−0.1493
in ranks ($X2$)	(0.0338)	(0.0306)	(0.0370)	(0.0427)	(0.056)	(0.0789)	(0.1490)
Gender ($X3$)	−0.2141*	0.0033	0.1982*	−0.0636	−0.2658*	−0.1540	−0.0100
	(0.0839)	(0.0876)	(0.0946)	(0.0999)	(0.1094)	(0.1261)	(0.1816)
Negative re-	–	0.4637***	0.4009**	0.8312***	0.4541***	0.1633	0.6437***
ciprocity ($X4$)		(0.0496)	(0.1534)	(0.1303)	(0.1271)	(0.1256)	(0.1668)
Money	0.0358	−0.0544	0.1341*	0.0571	−0.0895	−0.0619	−0.0965
banked ($X5$)	(0.0188)	(0.0390)	(0.0599)	(0.0599)	(0.0742)	(0.0764)	(0.1139)
Money lost	0.3664***	0.4088***	0.8203***	0.3612**	0.5972***	0.0642	0.3556
($X6$)	(0.0441)	(0.0684)	(0.1014)	(0.1120)	(0.1613)	(0.1433)	(0.3311)
Distance	0.0177	0.0237	0.0647**	0.0700**	0.0894**	0.0557	0.0271
($X7$)	(0.0224)	(0.0229)	(0.0241)	(0.0262)	(0.0296)	(0.0343)	(0.0472)
Observations	900	800	700	600	500	400	300
Log-likelihood	−1142.7	−1022.3	−865.9	−749.3	−576.5	−410.4	−194.0
MacFadden pseudo R^2	0.3894	0.3433	0.3096	0.2241	0.1683	0.0661	0.0670
Veall and Zimmermann R^2	0.7669	0.6998	0.6294	0.476	0.3395	0.1228	0.0950

*Significant at 0.05 significance level

**Significant at 0.01 significance level

***Significant at 0.001 significance level

accumulated chain of correct answers is lost. To control for contestants penalizing foregone banking opportunities, variable $X6_j^i$ measures the amount of money that could have been banked by contestant j in round i, had the contestant j banked before every question she answered incorrectly.

Contestants stand in a semi-circle in front of the host during the show. To control for the effect of the distance among contestants, we use variable $X7_{jk}^i \in \{1, \dots, 8\}$. This variable measures physical distance between contestant j and contestant k in round i. Specifically, $X7_{jk}^i = 1$ denotes a minimum distance between contestants i.e. when contestant j stands next to contestant k in round i. $X7_{jk}^i = 8$ denotes a maximum distance between contestants i.e. when contestants j and k stand at the opposite ends of the podium.

We estimate model (3) separately for every round $i \in \{1, \dots, 7\}$. Estimation was conducted in the Matlab 6.5 package.[16] The results are presented in Table 7.

[16] Program files and data are available from authors on request.

Table 7 shows that the only variable which is highly statistically significant in all rounds is the rank of the opponent ($X1$). Contestants tend to vote against the opponents who show a relatively low ability to answer general knowledge questions. We do not find evidence that contestants systematically discriminate against opponents of different ability or gender (Table 7). Moreover, difference in ranks ($X2$) is statistically significant with a negative sign in round 6 and gender dummy ($X3$) is statistically significant with a negative sign in rounds 1 and 5. This means that sometimes contestants are more likely to vote against their counterparts with a similar ability or the same gender.

Table 7 shows that an important determinant of individual voting decisions is negative reciprocity ($X4$). In all rounds except round 6, contestants are more likely to vote against those who voted against them in previous rounds. In other words, contestants seem to play *tit for tat* strategies. Except for round 3, we do not find any evidence that contestants vote against opponents who engage in premature banking. However, in the first five rounds of the game there is clear evidence that contestants vote against those opponents who missed a banking opportunity and by answering their question incorrectly lost the team money. There is some evidence of a distance effect in the intermediate rounds of the game ($3 \leq i \leq 5$). In these rounds contestants are more likely to vote against opponents who stand farther away from them on the podium.

Interestingly, Table 7 also shows that the fit of the estimated conditional logit model (3) sharply deteriorates in the last rounds of the game. For example, Veall and Zimmermann R^2 decreases from 0.3395 in round 5 to 0.1228 in round 6 and 0.0950 in round 7. In particular, in rounds $i = 6, 7$ the minimized log-likelihood of model (3) is almost identical to the log-likelihood $L_0 = -N \cdot \ln(9 - i)$ of a restricted model when all coefficients $\beta_1, \dots, \beta_7$ are set to zero, i.e. when contestants make voting decisions at random. This provides additional support for our results in Sect. 3 that while contestants play pure strategies and eliminate weak teammates at the beginning of the game, they gradually switch to behaviorally mixed strategies at the end of the game.

5 Discussion

The Weakest Link offers a unique natural laboratory to study coordination in strategic situations. This television show is structured as a well-defined non-cooperative game with high monetary incentives and a diverse subject pool. Contestants have finitely many pure voting strategies (they can vote against only one of their counterparts). Relative abilities of contestants to answer general knowledge questions are observable in all rounds of the game.

At the beginning of the game when the decision problem is sufficiently complex the behavior of contestants in *The Weakest Link* is consistent with coordination in the presence of labeling. There are multiple pure strategy Nash equilibria when an *overwhelming plurality* of contestants vote against the same opponent. Contestants have an incentive to coordinate on some equilibrium and one equilibrium (voting off the weakest player) serves as a focal point.

We find that contestants successfully coordinate on voting off the weakest teammate starting from the first round of the game, even though they do not engage in prior communication and do not have an opportunity to learn. In addition, we observe that when making their voting decisions, contestants primarily take into account the relative rank of the opponent, whether this opponent has voted against them in the previous rounds, and how efficiently this opponent uses the technology that converts correct answers into money.

We also find that at the end of the game when the decision problem is relatively simple, contestants fail to coordinate on the focal point in the majority of television episodes in our sample as well as tend to randomize between voting against strong and weak opponents. The majority of observed voting profiles at the end of the game can be explained by *strictly mixed* strategy Nash equilibrium.

Experimental evidence on mixed strategy play in the Nash equilibrium is inconclusive. On the one hand, O'Neill (1987) and McCabe et al. (2000) find that subjects generally follow Nash mixed strategies. On the other hand, Rapoport and Boebel (1992), Mookherjee and Sopher (1994) find little experimental evidence of resorting to mixed strategies in the Nash equilibrium. However, non-experimental data from the real world are generally consistent with the Nash mixed-strategy equilibrium, though such investigations are quite rare (Chiappori et al. 2002). Walker and Wooders (2001) and Chiappori et al. (2002) find that data from tennis and soccer tournaments are consistent with the hypothesis that players adopt Nash equilibrium mixed strategies. The results of this natural experiment support these findings and suggest that *The Weakest Link* contestants are most likely to play a *strictly mixed* Nash equilibrium in the last voting round of the game.

However, the majority of observed voting profiles can be rationalized through the Nash equilibrium play only when contestants, modeled as expected utility maximizers, differ substantially in their risk attitudes. Apparently *The Weakest Link* contestants systematically overestimate their relative chances of winning when facing the strongest opponent. This overweighting of small probabilities of large outcomes is remarkably captured by cumulative prospect theory (or rank-dependent expected utility theory).

The results of this paper indicate that behavior in strategic situations in a natural experiment, conducted on television, is generally consistent with experimental evidence that people use salience principles to coordinate in the absence of communication when the decision problem is sufficiently complex. This similarity appears to be especially striking given high monetary stakes, subject pool effects, observable heterogeneity, and larger number of players as well as other factors that distinguish natural experiments in television shows from the laboratory studies.

Even though we use a television show setting to explore the effect of focal points on voting in strategic situations, obtained results may provide some guidance in application to the political arena. Particularly, our findings may be generalized to explain the differences in electoral behavior of voters in political systems with many and few political parties. On the one hand, our analysis indicates that observable party characteristics provide sufficient guidance for the voters in a multi-party system to produce efficient coordination in the first round of the voting process. Such coordination is especially apparent in representative democracies, where many parties compete in the elections, but only few key players gain the control of the government. Our results may suggest that in multi-party systems, large groups of voters tend to use certain identifiers of political parties as focal points, which foster coordination in complex decision problems. On the other hand, our analysis indicates that in political systems with few parties when the decision problem is relatively simple, voters do not rely on focal principles and approach electoral decisions in a different manner. Exploring the possible impact of focal points on electoral behavior is an interesting endeavor for future research.

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