Strengths of the "Weakest Link"?

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Abstract

The "Weakest Link" is a game show full of paradox. To increase the probability of winning, contestants should eliminate the strongest players. Yet, if it is anticipated that the best player is to be eliminated, participants do not answer questions correctly and nothing is gained. We solve a game that illustrates the Weakest Link tradeoffs and show that two equilibria coexist: an equilibrium in which players remain silent and a more entertaining equilibrium in which they give good answers whenever they can. We study the first wave of the Weakest Link show broadcast in France. Contestants vote against the weakest player and answer truthfully to the questions. They exhibit, however, myopic behavior as they do not use all the available information. The selection of one equilibrium or the other relies on how players coordinate in voting subgames. Three arguments are provided to explain observed behavior: Pareto domination, risk domination, and the "mise en scène" of the show.

Keywords: Coordination, Pareto and risk domination, vote, game show, field experiment.

***JEL* Classification:** C93, C72, D72, D80.

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1 Introduction

The recipe of a good quiz show usually involves one, two or more contestants, tricky questions, a dash of luck and a smack of knowledge. As a general rule, the winner is the one who performed best in answering questions. This general framework embraces games like “Who Wants to Be a Millionaire?”, “Jeopardy”, “The Price is Right”, “The Wheel of Fortune” and many others all around the air. “The Weakest Link ” is a new game show from the U.K. which differs in many respects from the other shows. It contains a succession of accumulation and elimination stages. In an accumulation phase, players attempt to find right answers to questions. The better they answer, the higher the jackpot rises. Each accumulation stage is followed by an elimination phase in which contestants vote one of them out. The purpose of the elimination is to select one and only one winner of the jackpot; all other players win nothing. Yet, when only two players remain a vote is no longer useful and the winner is the one who answers best to a final series of questions.

Because of the voting stages, the Weakest Link is a strategic game. It can be seen as a caricature of many real life events. One of them is the selection of the leaders in a political party. A political party has a lot of members working hard to promote its values. Yet, only a handful of them elected by the mass of the anonymous party members are at the top and enjoy both power and a comfortable life. Inside a firm a similar situation may occur: executives work together to improve profitability but they also judge one another and this leads to an informal ranking that helps some of them to reach higher levels in the firm hierarchy.

At first sight, even among purely selfish contestants, the accumulation phase seems to be of a common interest nature. Each player wants the jackpot to be as high as possible. The elimination stage, however, appears to be of a highly strategic nature. On the one hand a player wants to eliminate the worst contestants because they do not contribute much to the jackpot. But on the other hand any player has a higher probability to win the final contest if opposed to a weak antagonist. It seems unclear which incentive should prevail. When the game is coming to an end, however, it is more tempting to vote against the strongest player.[1] Contrary to the “You are the Weakest Link, goodbye” that punctuates each elimination stage, the weakest player should not be eliminated at the end. But if it is anticipated that the best player is to be eliminated no one wants to be this player. So contestants

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[1] This is the first reaction someone (at least an economist) has watching the show.

should try to answer very badly in the final stages of the game and rational players should use previous rounds information to assess who is the best, which means that in every round contestants should answer very badly and ultimately they should always give a wrong answer. In this case the jackpot remains empty and even the winner has nothing to win. If it is expected that the one who contributes the most to the common good is precisely the one who will not benefit from it, then no one contributes.

To understand better the game, we built the simplest game that seemed to get the gist of the Weakest Link tradeoffs. The game exhibits multiple equilibria. In the first equilibrium, no one answers correctly to any question ("mute equilibrium") and the eliminated player is selected at random. In the second equilibrium, people answer right if they can ("truthful equilibrium") and the weakest player is eliminated. Both are perfect bayesian equilibria, but they rely on a different equilibrium in the voting subgame. The mute equilibrium is built on the elimination of the strongest player, while the truthful equilibrium depends on the elimination of the weakest contestant. The truthful equilibrium exists even when two weak players face a strong one and when voting out the strongest is the Pareto dominant equilibrium of the subgame from the point of view of both weakest players. Consequently, the truthful equilibrium relies on the selection of the Pareto dominated equilibrium of the subgame.[2] Yet, the Pareto dominant equilibrium of the subgame is less stable in the sense of Harsanyi and Selten (1988) because it is risk-dominated[3]. The selection of the truthful equilibrium relies on a game-theoretical twist. Indeed, the truthful equilibrium Pareto dominates the mute equilibrium because in a truthful equilibrium any player has

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[2] Still only from the point of view of the two weak players, not taking into account the strongest player.

[3] See also Harsanyi (1995a) and Harsanyi (1995b).

a strictly positive probability to win a strictly positive jackpot, while in the mute equilibrium the jackpot is zero. The selection of the Pareto dominant equilibrium, however, relies on a coordination in the voting subgame on a Pareto dominated equilibrium of the subgame.

The aim of the paper is to confront game-theoretical predictions with the behavior of motivated individuals. We built a database containing all 36 Weakest Link shows broadcast in France during the summer 2001. The analysis of these data shows that contestants answer truthfully. Moreover, the strongest player is almost never voted out, instead the weakest link is eliminated most of the time. Therefore observed behavior is consistent with the truthful equilibrium.

The analysis of the Weakest Link game show provides an illustration of the issue of equilibrium selection in the presence of coordination failures. When the Pareto dominant equilibrium in one of the voting subgames is very risky, players coordinate on the risk dominant equilibrium of this subgame. On the other hand when the Pareto dominant equilibrium of the subgame is only slightly risky, players coordinate on this equilibrium. Besides risk-domination, it seems that the "mise en scène" of the show gives the players a focal point (Schelling (1960)). In particular, just before the teammates vote, Anne Robinson (the host) shrilly demands: "Who is not up to the standard of the rest of you? Who has lost the plot? Who is least likely to cope with the pressure? Who has stopped you from reaching a decent target? Who is not up to the standard of the team?" Even if it is just "cheap talk" as players can pick whoever they want, these sentences point in the direction of a focal point in the voting subgame.

When economists want to see how well game theory explains the behavior of individuals, they have two options: either construct a laboratory experiment or find real-life data. Most of the time, real-life data are not detailed enough to be useful. But when they are, their advantage over laboratory experiments is twofold. First, monetary incentives can be much larger. For instance, the total amount of money paid by TF1 to the winners of the 36 shows broadcast summed to more than 1 million of FF, clearly exceeding the budget available to most experimental economists. Second, even when the monetary incentives are the same, the preferences of an individual are better reflected by real life choices than in a laboratory setting. Many economists have collected such data and game shows[4] have been used on several occasions. In some recent papers, data from game shows are used as a natural experiment to test behavior towards risk (Gertner (1993) and Metrick (1995)) or rationality (Bennett and Hickman (1993), Berk, Hughson, and Vandezande (1996) and Tenorio and Cason (2002)). In Walker and Wooders (2001) data from professional tennis games are used to study mixed-strategy play and in Chiappori, Levitt, and Groseclose (2002) a similar approach is developed based on penalty kicks in soccer.

The issue of the selection or not of a Pareto-dominant but risk-dominated equilibrium has been analyzed in laboratory experiment several times. Cooper, DeJong, Forsythe, and Ross (1990) focus on coordination games with Pareto-rankable equilibria. They showed that a Pareto-dominant equilibrium is not always selected. They also show that dominated strategies are relevant as their presence influences equilibrium selection. Huyck, Battalio, and Beil (1990) also provide evidence that “coordination failure results from *strategic uncertainty*: some subject conclude that it is too “risky” to choose the payoff-dominant action”. The issue of communication in such coordination

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[4] More generally, the economics of television game shows is not to be neglected. These shows are numerous in all countries and the amount at stake can be huge both in terms of what the participants can win and in terms of advertising revenues for the diffusing channels.

games has been investigated by Aumann (1990) from a theoretical point of view and by both Cooper, DeJong, Forsythe, and Ross (1992) and Clark, Kay, and Sefton (2000) from an experimental point of view. Aumann argues that communication may not help players' coordination. Indeed, if, whatever a player's choice, his/her payoff is higher when the other plays the Pareto-dominant equilibrium strategy, then communication is not credible. This point of view has been experimentally comforted by Clark, Kay, and Sefton.

The paper is organized as follows: in section 2 we briefly present the rules of the Weakest Link. Section 3 describes the empirical facts that help to understand how people played in the Weakest Link game show in France. Section 4 introduces a simple way to model the Weakest Link as a game which equilibria are characterized in section 5. Section 6 confronts the theoretical analysis to the empirical facts. Section 7 concludes.

2 History and rules of the Weakest Link

The Weakest Link appeared on BBC Two in the summer of 2000 with 68 daily episodes. Such was its success that BBC One commissioned seven champions' league episodes and one hilarious bad losers' show. These prime time shows hit U.K.'s screens in the autumn. The Weakest Link continued to make a huge impact, and for the second series a staggering 90 episodes were commissioned for daytime and 21 shows for primetime. After its success in the U.K. the game has been exported to other countries. In the U.S. NBC has been broadcasting the show since April 2001 with Anne Robinson as host. The show is also transmitted (with home hosts) in Australia, Belgium, France, Germany, Ireland, Italy, the Netherlands, New-Zealand, Turkey and probably many other countries as well.

The structure of the game remains the same across countries only the number of players can vary.[5] TF1 (France) starts each game with 9 players. Contestants stand in a circle around the host.[6] They are strangers to each others but must work as a team to reach the maximum prize money. A game is made up of 9 rounds. Seven rounds divide in two stages: accumulation and elimination phases. Round 8 is an additional accumulation round and round 9 is a quiz-show contest between both remaining players to select the only winner.

In each accumulation stage, players are asked one after the other general knowledge questions. The goal in a round is for the team to answer enough questions correctly to reach the money target within the time limit. Each accumulation phase ends when either the time allocated[7] to it is over or when the money target is reached.[8] Players should take some risks to win more. Imagine that every correct answer is another link on a chain. Each new correct answer increases the value of the chain. If someone gets a question wrong he breaks the chain and the team must start building a new chain, starting from zero. But if someone says the word “Bank” before his/her question is asked, the money is safe and a brand new chain starts from zero.[9] The amount won in one round is added to the sum of money accumulated in

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[5] For instance 9 in the BBC Two original shows, 7 in subsequent BBC One shows, 8 in NBC shows.

[6] A woman most of the time: Anne Robinson on BBC and NBC, Laurence Boccolini on TF1.

[7] For the first round 2 minutes and 30 seconds are allocated to the players. Every next round is 10 seconds shorter than the last one. For instance, round 2 lasts 2 minutes and 20 seconds and round 8 lasts 1 minute and 20 seconds.

[8] A round ends if the team earned 15 000 FF.

[9] A one correct answer chain is worth 300 FF, a two correct answer chain 750, and the following are respectively worth 1 500, 3 000, 4 500, 7 500, 9 000, 12 000, and 15 000 FF. For instance, if a player says “bank” after his/her three preceding partners answered right 1 500 FF are won.

the previous rounds.

At the end of each round, each teammate votes to eliminate a fellow contestant. The player who obtains the highest number of votes against him/her is eliminated. In case of a tie, a crucial rule applies which we call the "strongest-link rule". This rule states that the player who is the "strongest-link"(the player who has the highest rate of good answers.[10]) chooses among the tied contestants the one he/she wants out. A "weakest link" is also defined but the main difference is that he/she has no prerogative unless being stigmatized by the host.

When only two players remain, they answer a last series of questions (round 8) which allows them to win more money. The amount of money accumulated in this round is multiplied by three and is added to the money won in the previous rounds. Finally to determine the winner of the jackpot each player answers five questions winning one point for a good answer. The winner is the one who scored best. If after the five questions they have the same score, then they continue answering questions until one answers well while the other is wrong. The winner takes all the jackpot and the losers have nothing.

Last but not least, the show is unusual because of the insistence with which the host bosses people around and tries to humiliate the candidates.[11]

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[10] In case of equality, the "strongest-link" is the one who put the highest amount of money in the bank. If equality persists the "strongest-link" is randomly selected.

[11] According to BBC Online (see `http://www.bbc.co.uk/weakestlink/index.shtml`): Anne Robinson is "a cross between Cruella de Vil, a dominatrix and a bossy school ma'am..." and that she "has also earned the title of the Rudest Woman on Television."

3 Facts

In order to learn how people play, we watched carefully all game shows broadcast in France during the summer of 2001.[12]

At the beginning of the show, contestants are invited to briefly present themselves by declining their first name and their age.[13] For each show, we noted all the answers of each player (if the answer was right, wrong and/or if "banked" was said as well as all the votes and the identity of both the strongest and weakest link). Table 1 presents summary statistics about the 36 shows.[14] The show is equally accessible to women and men, and contestants are distributed on a wide range of age (from 18 to 79 with an average of 40). A total of 324 people participated. Over all questions, the average rate of good answers is 0.62 (for a rate of good answers round by round see tables 15 to 22 in appendix D). The winner received on average about 30 000 FF (with a minimum gain of 10 000 FF and a maximum of about 54 000 FF while the median gain is 28 000 FF). The total amount distributed for the 36 shows comes to more than 1 million (1 053 600) of French Francs. Of course, it would not have been conceivable to generate such data in an experimental

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[12] That is, all the shows broadcast in France in the first wave of the game. In all we watched 36 shows. Each show is one hour long. To watch the shows, we used the facilities provided by the Institut National de l'Audiovisuel (INA) and its department l'Inathèque de France located inside the Bibliothèque nationale de France. This section is responsable for the running of legal deposit of radio and television, defined by law on June 20 1992. It gathers all broadcasts of French radio and television programs. We are very grateful to these institutions for their help. TV programs are recorded on DVD so we have had all the opportunity to comfortably watch them.

[13] They also give a residence area (either a town or a province) and a professional occupation.

[14] Tables 15 to 22 in appendix D provide the same information round by round both for the excluded player and for the remaining players.

Table 1: Summary statistics

Variable	Gender	Age	Rate	Gain
Mean	0.52	39.4	0.62	29 267
St. dev.	0.5	14.5	0.21	12 233
min	0	18	0	10 200
max	1	79	1	54 450
N	324	324	324	36

Gender=0 for a female and Gender=1 for a male, "Rate" is the average rate of good answers for all round, "Gain" is the amount of money in FF won by the winner (6.55957 FF =1 €).

context.

Age and gender do not seem to determine the identity of the winner. For example, 45% ($\sigma = 0.5$) of the shows have been won by a woman and 47.5% ($\sigma = 0.5$) of the players are women. In the same spirit, the average player is 39 years old ($\sigma = 14$) when the winner is on average 36 years old ($\sigma = 10$). Tables 15 to 22 in appendix D confirm this round by round and table 7 shows that, indeed, age and gender do not have a significant influence on the probability of being eliminated after any round.

3.1 Who is culled?

A key moment in the game is the vote. How do players coordinate themselves to vote one of them out? Table 2 presents round by round how many votes the player eliminated in round t received in round t' (with $t' \leq t$).[15] For instance, the line beginning by "Eliminated 2" means that, on average, the player voted out in round 2 received 0.58 votes in round 1 and 3.97 in round 2. Of course, coordination is not perfect and the eliminated player of one round does not

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[15] No player has ever voted against himself/herself.

Table 2: Number of votes received on average by the players

Round →	R1	R2	R3	R4	R5	R6	R7
Eliminated 1	5.00	-	-	-	-	-	-
Eliminated 2	0.58	3.97	-	-	-	-	-
Eliminated 3	0.53	0.78	4.10	-	-	-	-
Eliminated 4	0.39	0.61	0.75	3.50	-	-	-
Eliminated 5	0.55	0.53	0.55	0.67	2.86	-	-
Eliminated 6	0.50	0.50	0.52	0.47	0.64	2.34	-
Eliminated 7	0.44	0.69	0.55	0.50	0.52	0.50	1.90
Finalist	0.53	0.50	0.25	0.55	0.58	0.72	0.58
Winner	0.39	0.41	0.25	0.30	0.36	0.44	0.52
Total of the votes	9.00	8.00	7.00	6.00	5.00	4.00	3.00

Table 3: Number of ties for each round

Round →	R1	R2	R3	R4	R5	R6	R7
Number of ties	5	8	6	7	12	11	4
Percentage of ties	13.9	22.2	16.7	19.4	33.3	30.6	11.1

systematically receive all the votes. Coordination, however, is rather good in the sense that the excluded player receives significantly more votes than the other players. In particular, only the eliminated player receives more than one vote on average. Another way to look at the coordination of the voters is to compute the number of times a tie occurred. Table 3 shows that while most of the time no tie occurs, the number of ties is not negligible. In particular, in rounds 5 and 6 where a tie occurred in one third of the shows. A tie underlines the key role played by the contestant who managed to be the strongest link. The advantage of being the strongest link is stressed by table 4 which shows, for each round, the number of times the strongest link

Table 4: Elimination or not of the strongest link

	Eliminated	Not eliminated
round 1	0	36
round 2	0	36
round 3	1	35
round 4	2	34
round 5	3	33
round 6	2	34
round 7	5	31

has been voted out. Clearly it does not happen very often. The strongest link position seems slightly less comfortable in round 7. Yet, it should be noted that among the 5 cases where the strongest link has been eliminated in round 7, all players answered identically well twice. Moreover, table 21 of appendix D as well as figure 1 show that on average the eliminated players in round 7 answered correctly one question over two, while his/her opponents enjoyed a rate of good answers of 68%.

The position of the weakest player is less enviable as shown in table 5 even if he/she is far from being systematically eliminated. Table 6 shows, however, that on average the group of the weakest players receives most of the votes.[16] In each round, the players that answered less well than the average received more votes than their fellow contestants who answered better than the average.

To sum up, descriptive statistics presented in table 4, 5 and 6 show that a contestant who answers well is less likely to be voted out than a player who answers badly. Good players are rewarded rather than punished by their

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[16] A player belongs in the weak group if his/her rate of good answers is lower (resp. larger) than (for a given show) the average rate of good answers of the round.

Table 5: Elimination or not of one weakest link

	Eliminated	Not eliminated
round 1	24	12
round 2	21	15
round 3	21	15
round 4	21	15
round 5	23	13
round 6	24	12
round 7	21	15

Table 6: Average number of votes received by each type

Round →	R1	R2	R3	R4	R5	R6	R7
Weaker players	7.66	6.61	6.14	4.83	3.64	2.92	1.89
Stronger players	1.33	1.39	0.86	1.17	1.36	1.08	1.11
Sum	9.00	8.00	7.00	6.00	5.00	4.00	3.00

fellow contestants.

A further insight is given by figure 1 where the (average) rate of good answers is plotted for each round and for each category of eliminated player. For example, the "out-2" curve shows the average rate of good answers for the players eliminated after round 2. The rate of good answers of a player dramatically decreases the very round in which he/she is eliminated. So clearly, the eliminated player has (on average) the worst performance in his/her fatal round.[17] On the contrary, the winner always performs very well (he/she has, on average, the best rate of good answers in every round). The loser of the final round also experiences a dramatic fall in his/her rate of good answers in

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[17] This fall can be interpreted as a selection bias. If the players vote the worst player out, he/she has to have a significant lower rate of good answers.

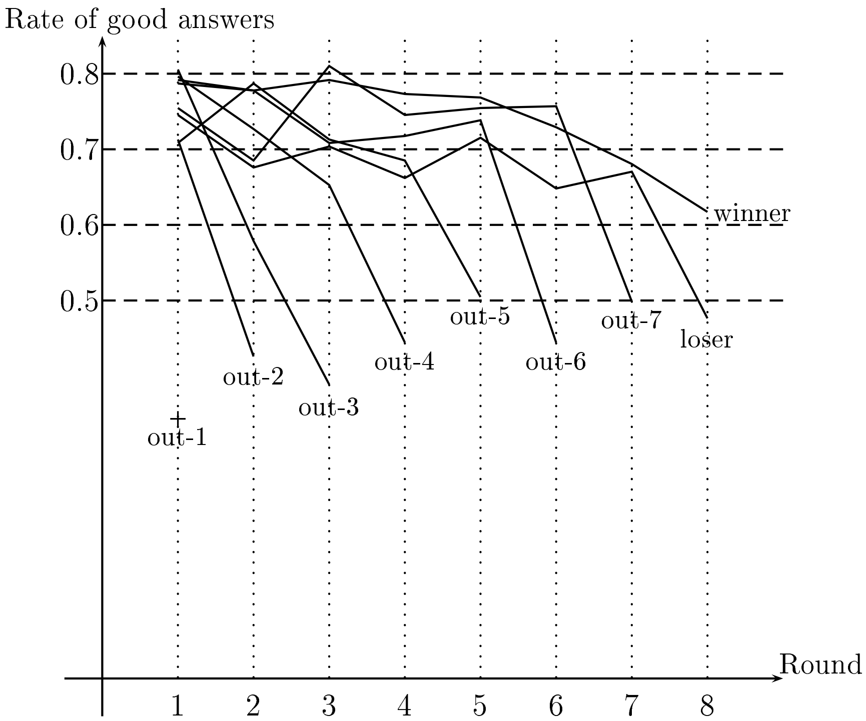

Figure 1: Round by round rate of good answers

round 8 from which he/she does not recover in round 9 where he/she loses.[18]

The player eliminated after round 7 seems better than the loser of the final during the first six rounds. This fact may lead people that watch the show to think that the "strongest player" is eliminated before the final round. Yet this is not entirely true as the winner of the game is (also) the best one and he/she is not eliminated. And more importantly, the loser of the final performs significantly better than him/her in round 7. To conclude, figure 1 shows that the finalists are the players who did not experience a dramatic fall in their performances.

The previous descriptive analysis is confirmed by the estimation of a

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[18] The rate of good answers of round 9 are not reported here, as questions are of a different kind in this round.

multinomial Logit model which shows that **contestants are myopic and poor players are voted out**. When one individual has to chose one alternative among n, the probability that the alternative i is chosen is estimated by a multinomial Logit. In the Weakest Link the team has to chose one player to eliminate among n, a convenient way to model the probabilities is to consider McFadden's multinomial logit model. The explanatory variables are the rates of good answers of each player for each round as well as age and gender. Let n denote the number of players still in the game at the end of round $t = 9 - n + 1$, let r_i denote the history of the rates of good answers for player i, $r_i = (r_{i1}, r_{i2}, \ldots, r_{it})$, let $r = (r_1, \ldots, r_n)$ the history of all players, and finally let a_i denote the age of player i and s_i his/her gender. Let $\beta = (\beta_1, \beta_2, \ldots, \beta_t)$ (resp. α_1, and α_2) be the list of t parameters associated to the rates of good answers in rounds 1 to t (resp. age, and gender).

The conditional probability p_i that individual i is eliminated, given a certain history r, is:

$$p_i = \frac{e^{\beta . r_i + \alpha_1 a_i + \alpha_2 s_i}}{\displaystyle\sum_{k=1}^{n} e^{\beta . r_k + \alpha_1 a_k + \alpha_2 s_k}}$$

We estimated the parameters β and α by the maximum likelihood method. The results are summarized in table 7 where the significative estimations (at the 5% level) are typeset in bold. Clearly age and sex do not influence the probability (age is only significative in round 5 while sex never is). As the diagonal shows, the probability of being voted out is decreasing with the rate of good answers in the current round. Moreover (except in round 3) only the rate of good answers in the current round influences the probability which shows that contestants are myopic, in the sense that round-t elimination probability only depends on round-t performances and not on past performances. This is a kind of bounded rationality as the players should

Table 7: Probability of being eliminated

	round 1	round 2	round 3	round 4	round 5	round 6	round 7
	$\beta\,(\sigma)$	$\beta\,(\sigma)$	$\beta\,(\sigma)$	$\beta\,(\sigma)$	$\beta\,(\sigma)$	$\beta\,(\sigma)$	$\beta\,(\sigma)$
β_1	$-$**5.12(1.15)**	$-0.63(0.86)$	$0.73(0.98)$	$0.84(0.85)$	$-0.29(0.83)$	$0.96(1.46)$	$0.35(1.39)$
β_2	-	$-$**3.8(1.36)**	$-$**1.99(0.81)**	$-0.03(0.87)$	$0.27(1.07)$	$0.75(1.24)$	$-0.10(1.05)$
β_3	-	-	$-$**4.60(1.34)**	$-0.97(0.94)$	$-0.49(0.87)$	$-0.67(1.01)$	$1.11(1.02)$
β_4	-	-	-	$-$**3.50(0.93)**	$0.13(0.89)$	$0.24(1.12)$	$0.71(1.43)$
β_5	-	-	-	-	$-$**4.02(1.11)**	$0.99(1.19)$	$0.26(1.73)$
β_6	-	-	-	-	-	$-$**4.96(1.78)**	$1.40(1.14)$
β_7	-	-	-	-	-	-	$-$**3.46(1.45)**
α_1	$0.01(0.02)$	$0.02(0.013)$	$0.02(0.02)$	$0.02(0.01)$	**0.03(0.01)**	$0.03(0.02)$	$0.00(0.02)$
α_2	$-0.29(0.44)$	$0.3(0.48)$	$-0.15(0.45)$	$-0.65(0.54)$	$0.73(0.64)$	$-0.62(0.59)$	$-0.22(0.55)$

use all the available information to evaluate the strength of their opponent.[19] This myopia is maintained by the structure of the game show: in particular all statistics used to stigmatize some players, the definitions of the weakest and strongest links are based only on the current round performances.

3.2 Is there a strategic lie?

The structure of the game is such that it could be rewarding not to give a right answer even when one knows it. Our feeling, however, is that it does not happen: **Contestants answer truthfully**. What did convince us of that? *First, casual observation* shows that people take time to find an answer,[20] and are disappointed when they do not give a right answer. Moreover, after their elimination,[21] they often say that they could not find an easy answer and that they cannot forgive themselves or that they complain another player was

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[19] However, as they are not allowed to take notes, it is only human that they do not remember very well what happened in the previous rounds.

[20] Remember that a fixed number of seconds is given for all the questions of a round, so that if one take more time to answer less time is available for his/her teammates.

[21] When a player is eliminated, he/she is interviewed during a few seconds and gives his/her opinion about what happened.

clearly weaker and should have been voted out. Yet, casual observation can be misleading. Our second point is more objective: *the structure of the game allows us to perform a statistical test* to find if contestants answer truthfully or not. Indeed, during round 8 (when only two players remain) someone who knows the right answer has no incentive to conceal it as there is no further elimination stage. Moreover, gains accumulated during round 8 are multiplied by 3. Therefore we compared the rates of good answers between any two successive rounds for the 2×36 players that reached round 8. These 72 players are the 36 winners and the 36 players who lose in round 9.

A statistical test (detailed in appendix A) shows that the rates are not statistically different between round t and $t+1$ for $1 \leq t \leq 6$, either for the winners, or the losers or the pair. Yet q_7 and q_8 are statistically different for the population of losers plus winners. But as figure 1 shows this difference is mainly due to the poor performance of the (soon-to-be) losers. For the winners, q_7 is not statistically different from q_8. In any case the fact that q_8 is strictly lower than q_7 is incompatible with the hypothesis that players lie in round 7 and answer truthfully in round 8.[22] All these elements allow us to conclude that, indeed, contestants answer truthfully.

3.3 Test of heterogeneity

The empirical results obtained so far could be consistent with a model where all contestants are homogeneous. A model in which all players have the same ability to know the answer to a question. If all contestants were alike, there would no longer be any incentives to vote the player who answers best

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[22] The lower rate of good answers in round 8 can be attributable to tiredness. In round 8 players have less time and as they are only two they do have to answer more frequently which means that they do not have time to rest between two questions. Moreover, players who reached round 8 do no longer fear a vote.

out. There would still exist a coordination problem in the voting game, but the previous analysis shows that the players coordinate themselves on voting against the weakest player.

A key issue is then to determine if the players are heterogeneous or homogeneous in their ability to answer the questions. After having watched 36 game shows, we are convinced that players are indeed heterogeneous. Some are clearly very weak while others are quite strong. This kind of casual observation can, however, be misleading. Moreover, if the players are heterogeneous at the beginning of the game, are they still heterogeneous at round 7 after 6 eliminations? One could imagine that after the first 4 or 5 eliminations, the remaining players are rather homogeneous in strength than heterogeneous; the dilemma between voting against the weakest or the strongest would vanish.

One way to prove heterogeneity, is to show that even among the winners there are differences in their abilities. We use a standard panel data test approach[23] to show that the hypothesis that all winners have the same ability to correctly answer the questions is rejected by the data. Details can be found in appendix B.

4 Model

As the contestants do not seem to vote how they intuitively should, it is important to evaluate their behavior in a game-theoretic framework. To achieve this goal, we analyse a simplified version of the Weakest Link game show. Mainly, we focus our attention on the last rounds (7, 8 and 9) of the game show. The main strategic effects present inside the Weakest Link can be summarized in the following **four stage three person game**. In

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[23] See Hsiao (1986), chapter 2.

order to cope with the heterogeneity of the players, we assume that each player can be either strong or weak. A strong player knows the answer of a question with probability θ_H, while a weak player knows it with probability θ_L with $0 < \theta_L < \theta_H < 1$. Each player knows his/her own strength but ignores the ability of the others. He/She only knows that a contestant is weak with probability ρ and strong with probability $1 - \rho$. **In the first stage**, one question is asked sequentially to each player. Questions and answers are public. For instance, player 3 (to whom the last question is asked) knows before answering his/her question if player 1 and 2 answered well or not. If a contestant knows the answer he/she decides to give the right answer or to give a wrong answer. Let h denote the history of the responses[24] for instance $h = (1, 0, 0)$ means that the first player answered correctly while the second and third gave a wrong answer. Let $m = f(h)$ denote the accumulated gain for a history h, where f is an increasing function in the number of good answers, with $f((0, 0, 0)) \geq 0$. At the end of stage one, the player who performed best is said to be the "strongest link". In case of equal performances, one player is randomly chosen among the best ones but (as in the real game) his/her identity is hidden until after the vote. **Stage two** implements a vote. Players vote simultaneously against one of their partners. The contestant who receives more votes is eliminated. In case every player receives one vote, it is to the strongest link to decide who is eliminated.[25] **In stage three** the remaining two players try to accumulate the more money they can in the jackpot by answering correctly to questions. **Stage four** determines who wins the jackpot. It is assumed that a weak (resp. strong) player wins the jackpot against another weak (resp. strong) player with probability one half, and a weak (resp. strong) player wins

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[24] Formally, $h \in \{(0,0,0), (1,0,0), (0,1,0), (0,0,1), (1,1,0), (1,0,1), (0,1,1), (1,1,1)\}$.

[25] The strongest link can eliminate the player he voted against or any other player.

against a strong (resp. weak) player with probability K (resp. $1-K$) with $0 < K < \frac{1}{2}$.

The resolution of the game goes backward. Stage 4 is not strategic. Obviously the best strategy in stage 3 is to give the right answer every time one knows it. Stage 2 (the voting game) is more tedious. Let x denote the probability of being weak that one player attributes to another one. To understand players' incentives we have to calculate players' expected gains just before the vote. The expected amount won at stage 3 is a function $g(\theta_i, \theta_j)$ depending on the abilities of each remaining player. In particular let G_{LL} (resp. G_{LH} and resp. G_{HH}) denote the expected gain when both players are weak (resp. one is weak the other strong and resp. both are strong). It is assumed that (on average) more able players win more, that is, $G_{LL} < G_{LH} < G_{HH}$.

Therefore, if a player is weak his/her expected gain if he/she reaches the endgame against a player who is weak with probability x is:

$$G_L(x) = \frac{1}{2} x (G_{LL} + m) + K (1-x)(G_{LH} + m),$$

while if he/she is strong the expected gain is:

$$G_H(x) = (1-K) x (G_{LH} + m) + \frac{1}{2}(1-x)(G_{HH} + m).$$

As the above expressions show, we can by choosing the money unit, normalize G_{LH} to 1 which leads to the following expected gains[26]:

$$\begin{aligned} G_L(x) &= (1+m) K + \frac{1}{2}\left[G_{LL} - (2(1+m)K - m)\right] x, \\ G_H(x) &= \frac{1}{2}(G_{HH} + m) + \frac{1}{2}\left[(2(1+m)(1-K) - m) - G_{HH}\right] x. \end{aligned}$$

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[26] To save on notations we do not change the name of the variables after the normalization.

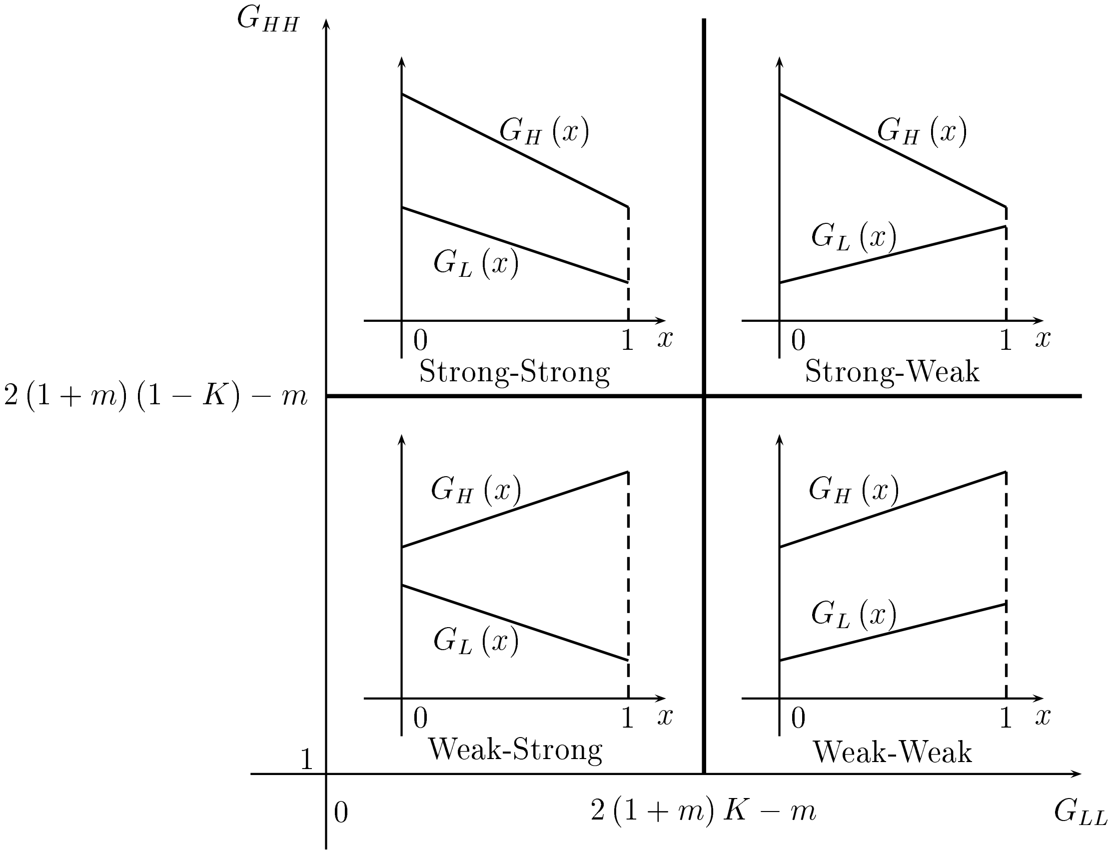

Figure 2: Expected gain for a H (resp. L) player facing a player who is weak with probability x.

Both $G_L(x)$ and $G_H(x)$ are linear functions of x but depending on the parameter values they can be either increasing or decreasing with the probability x that one's opponent in the endgame is weak. Yet it is always true that $G_H(x) > G_L(x)$.[27] Figure 2 shows these functions in the (G_{LL}, G_{HH}) space. Depending on the parameter values four cases can occur. When the slope of $G_q(x)$ $(q = H,\ L)$ is increasing (resp. decreasing), that means that a player of type q prefers to play the endgame against a type L (resp. H).

First, in the area $0 \leq G_{LL} \leq 2(1+m)K - m$ and $1 \leq G_{HH} \leq 2(1+m)$ $(1-K)-m$, which is called "Weak-Strong", players prefer dissimilarity. A strong player prefers to play the endgame against a weak opponent[28] while

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[27] Indeed, it is easy to check that $G_{HH} > 1$ and $K < 1/2$ imply $G_H(0) > G_L(0)$ and that $G_{LL} < 1$ and $1 - K > 1/2$ imply $G_H(1) > G_L(1)$.

[28] Indeed, G_{HH} is not sufficiently larger than $G_{LH} = 1$ and a type H prefers to maximize

a weak player prefers to be matched with a strong player.[29]

Second, in the area $0 \leq G_{LL} \leq 2(1+m)K - m$ and $2(1+m)(1-K) - m \leq G_{HH}$ (denoted "Strong-Strong"), players are pro-strong. Indeed, both types of player prefer to play against a strong opponent.

Third, if $2(1+m)K - m \leq G_{LL}$ and $1 \leq G_{HH} \leq 2(1+m)(1-K) - m$ ("Weak-Weak"), players are pro-weak. A weak, as well as a strong player, prefers to play against a weak contestant.

Finally, if $2(1+m)K - m \leq G_{LL}$ and $2(1+m)(1-K) - m \leq G_{HH}$ ("Strong-Weak"), both types prefer similarity. A weak player prefers to play against a weak opponent, while a strong one prefers to be matched against a strong one.

It is readily confirmed that $K < 1/2$ implies $2(1+m)K - m < 1$ and $2(1+m)(1-K) - m > 1$; the Weak-Weak and Strong-Weak cases always exist. Now, if K is too low ($K < \frac{m}{1+m}\frac{1}{2}$) or similarly m is too large ($m > \frac{2K}{1-2K}$), then the Weak-Strong and Strong-Strong cases disappear as $2(1+m)K - m < 0$.

The intuition is that in the Strong-Strong case the equilibrium of the vote subgame should be one where the weakest is eliminated (and therefore one where everyone does his/her best to answer right). On the contrary, in the Weak-Weak case the strongest is expected to be eliminated in equilibrium (and therefore it is expected that no one answers correctly). This intuition is only partially true because of the voting game. Indeed, in the Weak-Weak case equilibria exist where the strongest player is not eliminated. The following complete-information game helps to understand this unexpected result, which relies on the "strongest-link rule". Three players denoted A,

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the probability of winning rather than the gain in case of a win.

[29] For a type L, G_{LL} is too low compared to $G_{LH} = 1$ and a type L sacrifices the probability of winning in order to win more in case of a win.

B, C, vote in order to eliminate one of them. Player A is a strong player while both B and C are weak. Assume then that A is the strongest-link. As in the Weak-Weak case, B and C prefer to remain together rather than to play against A while A is indifferent between continuing with either B or C. The following strategies form a Nash equilibrium: B votes against C, C votes against B and A randomly votes against B or C. In case of a tie, A eliminates the player who voted against him. If B (resp. C) deviates to vote against A at best it only creates a tie which leads to his/her elimination. Of course there also exists a more "intuitive" equilibrium where B and C vote against A. The point is that two issues are at stake: on the one hand individual reward matters but on the other hand there is a coordination problem in the voting game. The above argument extends to our model. In the next section we characterize under which conditions a truthful equilibrium exists (where every players who knows the answer, replies correctly) and when a mute equilibrium exists (where no player answers correctly).

5 Equilibria

As it is usual in signaling games we should expect to find many equilibria. Moreover our game has a multi-sender multi-receiver stage followed by a voting stage which should lead to an even greater richness. We restrict our attention to establish when one of the two "extreme" equilibria exist. More formally, we restrict our analysis to equilibria where the decision to answer right or wrong to a question is independent from the history of past answers.

Proposition 1. *A mute (perfect bayesian) equilibrium does always exist.*

Proof. The equilibrium strategies are the following: no one answers correctly.

If no one gives a correct answer, players believe (using Bayes rule) that each of his/her opponent is weak with probability ρ and vote randomly. If some one deviates and gives a good answer, this out of equilibrium event has a zero probability and Bayes rule does not apply. Therefore we suppose that the other players do not change their a priori beliefs but vote against him/her. It is readily confirmed that the above strategies form a Nash equilibrium of the game for any value of the parameters. $\square$

The existence of a mute equilibrium is both intuitive and striking. It is intuitive and it was our fear when we first saw the game. In particular, it seems to be the natural issue of the game when parameters lie in the Weak-Weak case. This equilibrium is, however, striking in the Strong-Strong situation because for this range of parameter values, both types are pro-strong. In that case, the mute equilibrium depends crucially on the out-of-equilibrium beliefs. Finally, this equilibrium is at odd with observation because players do answer correctly to many questions.

Next, we characterize when a truthful equilibrium exists. Let us assume that everyone tries to answer correctly. Let λ_0 (resp. λ_1) denote the probability of being weak after a wrong (resp. good) answer.[30] If it is an equilibrium of the voting game to vote against the (apparent) weakest, then it is straightforward that a truthful equilibrium exists. Therefore, the analysis reduces to the analysis of the voting game.

Proposition 2. *A truthful (perfect bayesian) equilibrium does exist if* $G_L(\lambda_1) \geq \frac{3}{4}G_L(\lambda_0)$ *and* $G_H(\lambda_1) \geq \frac{3}{4}G_H(\lambda_0)$.

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[30] That is:

$$\lambda_0 = \frac{\rho(1-\theta_L)}{\rho(1-\theta_L)+(1-\rho)(1-\theta_H)} \text{ and } \lambda_1 = \frac{\rho\theta_L}{\rho\theta_L+(1-\rho)\theta_H}$$

Proof. The equilibrium strategies are the following: everyone answers correctly if he/she knows the answer. In the voting game, four situations can occur depending on the history of good answers. 1) If everyone answered correctly; players vote randomly. 2) If only one player gave a wrong answer; this player votes randomly with probability $\frac{1}{2}$ against each others, and the others vote against him/her. In case of a tie the strongest-link votes against the other player who gave a good answer. 3) If two players gave a wrong answer; they vote against each other and the third player votes randomly. In case of a tie, the strongest-link votes against the one that voted against him/her. 4) If no one answered correctly; players vote randomly.

It is readily confirmed that the above strategies form a Nash equilibrium of the game for any value of the parameters in cases one, three and four. Only case two has to be examined in details.

The player who did not answer has no incentive to deviate. Consider A who gave a good answer. Player A is of type T, $T = L, H$. He/she can vote against the player who made a mistake (denoted C) which gives him/her an expected gain of:

$$G_T(\lambda_1)$$

Or he/she can vote against the other player who also gave a good answer (denoted B) which gives him/her an expected gain of:

$$\frac{1}{2}G_T(\lambda_0) + \frac{1}{2}\frac{1}{2}G_T(\lambda_0) = \frac{3}{4}G_T(\lambda_0)$$

Indeed, with probability $\frac{1}{2}$ both A and C vote against B, while with probability $\frac{1}{2}$ a tie occurs as A votes against B, B against C and C against A. In that case, A is the strongest link with probability $\frac{1}{2}$ and eliminates B, while B is the strongest link with probability $\frac{1}{2}$ and eliminates A.

Therefore, player A does not deviate if and only if :

$$G_T(\lambda_1) \geq \frac{3}{4}G_T(\lambda_0)$$

Finally, if the above condition is true, players vote against the (apparent) weakest which induces them to answer truthfully. □

When is the condition $G_T(\lambda_1) \geq \frac{3}{4} G_T(\lambda_0)$ $(T = L, H)$ fulfilled? First, this condition is true when λ_0 is close enough to λ_1 which occurs when the observation of a good or a bad answer is not very informative on players' types. Either because types are very similar (θ_L close to θ_H) or because the population is "dominated" by one type (ρ close to 0 or ρ close to 1). Next, when λ_0 and λ_1 are not close to each other, this condition (for $T = L$) can still be true if G_{LL} is low enough and (for $T = H$) if G_{HH} is large enough, so both types of players are willing to play against a strong opponent. Corollary 1 makes these existing conditions more precise. Let $\overline{G_{LL}} = 2K \frac{1+3\lambda_0-4\lambda_1}{3\lambda_0-4\lambda_1}$ and $\underline{G_{HH}} = 2(1-K)\frac{3\lambda_0-4\lambda_1}{1+3\lambda_0-4\lambda_1}$.

Corollary 1. *If λ_0 and λ_1 are relatively close, then a truthful equilibrium exists in the extended game for any values of the expected gains G_{HH} and G_{LL}. If not, then a truthful equilibrium exists if G_{HH} is large enough and/or G_{LL} is low enough. More formally:*

1. *If $\lambda_0 \leq \dfrac{4}{3}\lambda_1 + \dfrac{2}{3}\dfrac{K}{1-2K}$, then a truthful (perfect bayesian) equilibrium exists.*

2. *If $\dfrac{4}{3}\lambda_1 + \dfrac{2}{3}\dfrac{K}{1-2K} \leq \lambda_0 \leq \dfrac{4}{3}\lambda_1 + \dfrac{1}{3}\dfrac{1}{2(1-2K)-1}$, then a truthful (perfect bayesian) equilibrium exists for any $G_{HH} \geq 1$ and $G_{LL} \leq (1+m)\overline{G_{LL}} - m$.*

3. *If $\dfrac{4}{3}\lambda_1 + \dfrac{1}{3}\dfrac{1}{2(1-2K)-1} \leq \lambda_0$, then a truthful (perfect bayesian) equilibrium exists for any $G_{HH} \geq (1+m)\underline{G_{HH}} - m$ and $G_{LL} \leq (1+m)\overline{G_{LL}} - m$.*

Proof. See appendix C ☐

In particular a consequence of corollary 1 is that if $K \geq \frac{3}{8}$, then $\frac{2}{3}\frac{K}{1-2K} \geq 1$ and therefore λ_0 is always lower than $\frac{4}{3}\lambda_1 + \frac{2}{3}\frac{K}{1-2K}$ and a truthful equilibrium exists for any values of $G_{HH} \geq 1$ and $G_{LL} \leq 1$.

When both the mute and the truthful equilibrium exist it seems natural to select the truthful equilibrium which Pareto dominates the mute equilibrium. The credibility of one equilibrium, however, relies on how the players behave in the voting subgame. As shown in the proofs of proposition 2 and 2, if it is believed that players will coordinate on voting out the strongest player, then the equilibrium is mute. On the other hand, if it is believed that players will coordinate on voting out the weakest player, then the equilibrium is truthful. Therefore, we now study the coordination issue in the voting subgame.

The voting subgame is critical only in two cases: when there is only one good answer and when there is only one bad answer. Table 8 shows the normal form of the voting game, denoted G_{100}, when only one player answered correctly. It is a game between the two players who gave a wrong answer as it is assumed that the player who answered well votes randomly (1/2-1/2) against one of the other two. The strategies available to a player are fairly simple: either voting against the other player who got wrong or voting against the player who gave a good answer. As a player can be of two types these strategies are denoted 00, 01, 10 and 11. The strategy 01 means that if he/she is of type L (resp. H), the player votes against the player with a wrong (resp. good) answer. In each cell, the first line is the payoff of the row-player of type L, the second line the payoff of the row-player of type H, the third line the payoff of the column-player of type L and the last line the payoff of the column-player of type H.

In the remaining of this section, we restrict our attention to the case where the truthful equilibrium exists ($\frac{3}{4}G_T(\lambda_0) \leq G_T(\lambda_1)$) and to the Weak-Weak

	00	01	10	11
00	$\begin{pmatrix} 1/2\, G_L(\lambda_1) \\ 1/2\, G_H(\lambda_1) \\ 1/2\, G_L(\lambda_1) \\ 1/2\, G_H(\lambda_1) \end{pmatrix}$	$\begin{pmatrix} \left(\frac{2+\lambda_0}{2}\right) G_L(\lambda_1) \\ \left(\frac{2+\lambda_0}{2}\right) G_H(\lambda_1) \\ 1/2\, G_L(\lambda_1) \\ 0 \end{pmatrix}$	$\begin{pmatrix} \frac{(1+\lambda_0)}{2} G_L(\lambda_1) \\ \frac{(1+\lambda_0)}{2} G_H(\lambda_1) \\ 0 \\ 1/2\, G_H(\lambda_1) \end{pmatrix}$	$\begin{pmatrix} G_L(\lambda_1) \\ G_H(\lambda_1) \\ 0 \\ 0 \end{pmatrix}$
01	$\begin{pmatrix} 1/2\, G_L(\lambda_1) \\ 0 \\ \left(\frac{2+\lambda_0}{2}\right) G_L(\lambda_1) \\ \left(\frac{2+\lambda_0}{2}\right) G_H(\lambda_1) \end{pmatrix}$	$\begin{pmatrix} \left(\frac{2+\lambda_0}{2}\right) G_L(\lambda_1) \\ (1-\lambda_0)\, G_H(\lambda_0) \\ \left(\frac{2+\lambda_0}{2}\right) G_L(\lambda_1) \\ (1-\lambda_0)\, G_H(\lambda_0) \end{pmatrix}$	$\begin{pmatrix} \frac{(1+\lambda_0)}{2} G_L(\lambda_1) \\ \lambda_0 G_H(\lambda_0) \\ (1-\lambda_0)\, G_L(\lambda_0) \\ \left(\frac{2+\lambda_0}{2}\right) G_H(\lambda_1) \end{pmatrix}$	$\begin{pmatrix} G_L(\lambda_1) \\ G_H(\lambda_0) \\ (1-\lambda_0)\, G_L(\lambda_0) \\ (1-\lambda_0)\, G_H(\lambda_0) \end{pmatrix}$
10	$\begin{pmatrix} 0 \\ 1/2\, G_H(\lambda_1) \\ \frac{(1+\lambda_0)}{2} G_L(\lambda_1) \\ \frac{(1+\lambda_0)}{2} G_H(\lambda_1) \end{pmatrix}$	$\begin{pmatrix} (1-\lambda_0)\, G_L(\lambda_0) \\ \left(\frac{2+\lambda_0}{2}\right) G_H(\lambda_1) \\ \frac{(1+\lambda_0)}{2} G_L(\lambda_1) \\ \lambda_0 G_H(\lambda_0) \end{pmatrix}$	$\begin{pmatrix} \lambda_0 G_L(\lambda_0) \\ \frac{(1+\lambda_0)}{2} G_H(\lambda_1) \\ \lambda_0 G_L(\lambda_0) \\ \frac{(1+\lambda_0)}{2} G_H(\lambda_1) \end{pmatrix}$	$\begin{pmatrix} G_L(\lambda_0) \\ G_H(\lambda_1) \\ \lambda_0 G_L(\lambda_0) \\ \lambda_0 G_H(\lambda_0) \end{pmatrix}$
11	$\begin{pmatrix} 0 \\ 0 \\ G_L(\lambda_1) \\ G_H(\lambda_1) \end{pmatrix}$	$\begin{pmatrix} (1-\lambda_0)\, G_L(\lambda_0) \\ (1-\lambda_0)\, G_H(\lambda_0) \\ G_L(\lambda_1) \\ G_H(\lambda_0) \end{pmatrix}$	$\begin{pmatrix} \lambda_0 G_L(\lambda_0) \\ \lambda_0 G_H(\lambda_0) \\ G_L(\lambda_0) \\ G_H(\lambda_1) \end{pmatrix}$	$\begin{pmatrix} G_L(\lambda_0) \\ G_H(\lambda_0) \\ G_L(\lambda_0) \\ G_H(\lambda_0) \end{pmatrix}$

Table 8: Voting subgame G_{100} after one good answer

case ($G_T(\lambda_1) \leq G_T(\lambda_0)$, see figure 2) in which players of both types do not want to vote out the weakest player.

Lemma 1. *If* $\frac{3}{4} \leq \frac{G_T(\lambda_1)}{G_T(\lambda_0)} \leq 1$, *with* $T \in \{H, L\}$, *then* $(00,00)$ *and* $(11,11)$ *are both Nash equilibrium of the voting subgame* G_{100}.

The $(11,11)$ *equilibrium Pareto dominates the* $(00,00)$ *equilibrium.*

The $(00,00)$ *equilibrium risk dominates the* $(11,11)$ *equilibrium.*

Proof. It is easy to check that the strategies $(00,00)$ and $(11,11)$ form a Nash equilibrium of the game G_{100} under the condition $\frac{G_T(\lambda_1)}{G_T(\lambda_0)} \leq 1$. Moreover, $(11,11)$ Pareto dominates $(00,00)$ as $G_T(\lambda_0) \geq G_T(\lambda_1) > \frac{1}{2} G_T(\lambda_1)$.

To test for risk-domination, let us focus, following Harsanyi and Selten

(1988), on the reduced game where players can only choose between 00 and 11. If the column player plays 00 with probability $1-\varepsilon$ and 11 with probability ε, then the row player prefers 00 to 11 as long as

$$\varepsilon \leq \varepsilon_{00} = \frac{G_T\left(\lambda_1\right)}{2G_T\left(\lambda_0\right) - G_T\left(\lambda_1\right)} \ .$$

On the other hand, if the column player chooses 00 with probability ε and 11 with probability $1-\varepsilon$, then the row player prefers 11 to 00 as long as

$$\varepsilon \leq \varepsilon_{11} = 1 - \varepsilon_{00} \ .$$

Under the assumption $\frac{3}{4} \leq \frac{G_T(\lambda_1)}{G_T(\lambda_0)}$, it is always true that

$$\varepsilon_{00} > \frac{1}{2} > \varepsilon_{11},$$

which means that the Nash equilibrium $(00, 00)$ is always less risky than the $(11, 11)$ equilibrium. □

The second critical case is when only one player gave a wrong answer. Let G_{110} denote this voting subgame where it is assumed that the player with a bad answer votes randomly(1/2-1/2). Table 9 shows the reduced (where only the strategies 00 and 11 are given) payoff matrix for both players with good answers.

Lemma 2. *If* $\frac{3}{4} \leq \frac{G_T(\lambda_1)}{G_T(\lambda_0)} \leq 1$, *with* $T \in \{H, L\}$, *then* $(00, 00)$ *and* $(11, 11)$ *are both Nash equilibrium of the voting subgame* G_{110}.

The $(00, 00)$ *equilibrium Pareto dominates the* $(11, 11)$ *equilibrium.*

The $(11, 11)$ *equilibrium risk dominates the* $(00, 00)$ *equilibrium.*

Proof. It is readily confirmed that the strategies $(00, 00)$ and $(11, 11)$ form a Nash equilibrium of the game G_{110} under the condition $\frac{3}{4} \leq \frac{G_T(\lambda_1)}{G_T(\lambda_0)}$. Moreover, $(00, 00)$ Pareto dominates $(11, 11)$ as $G_T\left(\lambda_1\right) \geq \frac{3}{4}G_T\left(\lambda_0\right) > \frac{1}{2}G_T\left(\lambda_0\right)$.

	00	11
00	$\begin{pmatrix} G_L(\lambda_1) \\ G_H(\lambda_1) \\ G_L(\lambda_1) \\ G_H(\lambda_1) \end{pmatrix}$	$\begin{pmatrix} 1/4G_L(\lambda_0) \\ 1/4G_H(\lambda_0) \\ 3/4G_L(\lambda_0) \\ 3/4G_H(\lambda_0) \end{pmatrix}$
11	$\begin{pmatrix} 3/4G_L(\lambda_0) \\ 3/4G_H(\lambda_0) \\ 1/4G_L(\lambda_0) \\ 1/4G_H(\lambda_0) \end{pmatrix}$	$\begin{pmatrix} 1/2G_L(\lambda_0) \\ 1/2G_H(\lambda_0) \\ 1/2G_L(\lambda_0) \\ 1/2G_H(\lambda_0) \end{pmatrix}$

Table 9: Reduced voting game G_{110} after one bad answer

To test for risk domination, assume that the column player chooses 00 with a probability $1-\eta$ and 11 with probability η. The row player still prefers to play 00 to 11 if and only if

$$\eta \leq \eta_{00} = \frac{G_T(\lambda_1) - 3/4G_T(\lambda_0)}{G_T(\lambda_1) - 1/2G_T(\lambda_0)}$$

On the other hand, if the column player chooses 00 with probability η and 11 with probability $1-\eta$, then the row player prefers 11 to 00 as long as

$$\eta \leq \eta_{11} = 1 - \eta_{00} \ .$$

Under the assumption $\frac{G_T(\lambda_1)}{G_T(\lambda_0)} \leq 1$, it is always true that

$$\eta_{00} < \frac{1}{2} < \eta_{11},$$

which means that the Nash equilibrium $(11, 11)$ is always less risky than the $(00, 00)$ equilibrium. □

The truthful equilibrium relies on the selection of the equilibrium of the subgame where both players with good answers vote the player with a wrong answer out in the subgame G_{110}, which is the Pareto dominant but risk dominated equilibrium. On the other hand, the truthful equilibrium also depends on the selection of the equilibrium of the subgame where both players with a bad answer vote one of them out in the subgame G_{100}, which is the Pareto dominated but risk dominant equilibrium. Is it logical to use a risk domination argument in one subgame while a Pareto domination argument in the other subgame?

When Pareto-domination and risk-domination run in opposite directions between two equilibria, it is unclear which equilibrium will actually be chosen. In particular it seems crucial to look at the degree of domination when Pareto and risk domination give different predictions. These degrees depend on the value of the ratio $\frac{G_T(\lambda_1)}{G_T(\lambda_0)}$. The study of both extreme cases ($\frac{G_T(\lambda_1)}{G_T(\lambda_0)} = 3/4$ and $\frac{G_T(\lambda_1)}{G_T(\lambda_0)} = 1$) provides intuitions on the selection process.

First, when $\frac{G_T(\lambda_1)}{G_T(\lambda_0)} = 3/4$*, the truthful equilibrium relies on non-intuitive selections.* Indeed, in the subgame G_{100}, $\varepsilon_{00} = 0.6$. Therefore the Pareto dominant equilibrium "voting out the player with a good answer", which should not be selected, is only slightly risky ($\varepsilon_{11} = 0.4$). At the same time, in the other subgame G_{110}, $\eta_{00} = 0$. Therefore the Pareto dominant equilibrium "voting out the player with a wrong answer", which should be selected, is infinitely risky as it involves playing a weakly dominated strategy.

Second, when $\frac{G_T(\lambda_1)}{G_T(\lambda_0)} = 1$*, the truthful equilibrium relies on intuitive selections.* In the subgame G_{100}, $\varepsilon_{00} = 1$. Therefore the Pareto dominant equilibrium "voting out the player with a good answer", which should not be selected, is indeed infinitely risky as it involves playing a weakly dominated strategy. At the same time, in the other subgame G_{110}, $\eta_{00} = 0.5$. Therefore the Pareto dominant equilibrium "voting out the player with a wrong answer", which should be selected, is not at all risky.

In addition, the equilibrium in both subgames, on which the truthful equilibrium relies, consist in voting a weak player out. Clearly, the "mise en scène" of the show makes it a focal point. Four elements are at play: the name of the game,[31] the stigmatization of people who make mistakes, the stigmatization of people who vote against a strong opponent,[32] and the way the host asks people to vote.[33]

To conclude, if $G_T(\lambda_1)$ *is close enough to* $G_T(\lambda_0)$*, there is strong theoretical points in favor of the selection in each subgame of the Nash equilibrium that sustains the truthful equilibrium.*

In order to explain more precisely observed behavior we, now, turn our attention to the estimation of the parameter values of the game thanks to the data of the real show.

6 Parameter values

Data analysis showed that contestants are heterogeneous, answer truthfully and vote out the weakest player. These results are consistent with the truthful equilibrium found in the theoretical analysis of a game with heterogeneity. Yet, such a truthful equilibrium does not exist for any parameter values. A key issue is then to determine if the parameter values estimated from our data are compatible or not with a truthful equilibrium. Unfortunately, the game played on TV is quite different from ours and the "estimations" given here must be taken as an illustration rather than a statistical test. In real life

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[31] For example, after each elimination the host says: "You are the weakest link, goodbye".

[32] After the vote, the host mocks the players who could not respond to easy questions. Moreover, if the weakest-link is not voted out, the compère almost systematically asks some players to explain there votes and after their answers the host points out that the eliminated player is not the weakest-link and reminds the players that by not eliminating the weakest-link they will not earn a lot of money.

[33] "Who is not up to the standard of the rest of you? Who has lost the plot? Who is least likely to cope with the pressure? Who has stopped you from reaching a decent target? Who is not up to the standard of the team?"

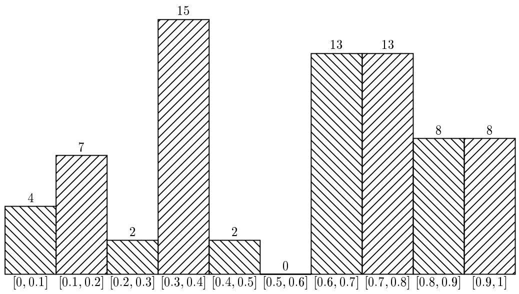

Figure 3: Distribution of θ in round 8

people ability, θ, to answer right to a random question on "general culture" is distributed between 0 and 1, while in our model we assumed that θ can only take two values θ_L or θ_H. Therefore the main difficulty is to determine two classes of players. In particular, there is no obvious way to do it and we have to make subjective choices. In round 8 it is possible to distinguish two groups of players as shown by the histogram of figure 3. We used this information to create a group of (30) weak players who answered less than one question over two and a complementary group of 42 strong contestants. Next, we used data from the first seven rounds to estimate θ_L and θ_H as what matters (in the bayesian revision) is the information revealed by a good answer before round 8. The expected gains G_{HH} and G_{LL} and the probability K are easy to compute.

Therefore, as shown in table 10, $\rho = 30/72 \simeq 0.42$, $\theta_L = 0.65$ and $\theta_H = 0.77$. From which it follows that $\lambda_0 \simeq 0.52$ and $\lambda_1 \simeq 0.38$. Next, we computed the values[34] of m (the accumulated normalized gain from round 1 to 7), G_{LL} and G_{HH} as well as the value of K (the probability with which a L type wins vs a H type). It appears that with these parameter values, the probability K is relatively small while the amount m is rather large which means that any type of player prefers to play the endgame vs a type L (case Weak-Weak of

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[34] These values are normalized by G_{LH}.

Table 10: Parameter values based on rounds 1 to 7

	ρ	θ_L	θ_H	λ_0	λ_1	K	G_{HH}	G_{LL}	m	Truth
$\widetilde{\theta} = 0.55$	0.42	0.65	0.77	0.52	0.38	0.14	2.38	0.55	8.45	Yes

figure 2). Still, **a truthful equilibrium can exist** because the value of λ_0 and λ_1 are sufficiently close (condition 1 of corollary 1) to one another. The observation of a good answer does not provide enough information about the type of one's opponent.

Tables 11 and 12 present the reduced voting subgames using the parameter values of table 10 (multiplying the payoffs by 100 and giving round numbers). It appears that $G_T(\lambda_1)$ is close to $G_T(\lambda_0)$ and therefore the selection of the appropriate subgame equilibria is in line with theoretical intuition. In table 11, the Pareto dominant equilibrium is very risky and coordination on the Pareto dominated equilibrium is the most natural outcome. Indeed, with the values of table 11, $\varepsilon_{00} \approx 0.98$ for a type L and 0.99 for a type H. On the other hand, in table 12 the Pareto dominant equilibrium is only slightly more risky than the alternative equilibrium and coordination on the Pareto dominant equilibrium is expected. Indeed, with the values of table 12 $\eta_{00} \approx 0.47$ for a type L and 0.49 for a H type.

This section shows that we cannot reject that people (despite their myopia) play the truthful (and entertaining) equilibrium which is coherent with theory.

7 Conclusion

The Weakest Link game show is not a trivial quiz show. It raises interesting questions both from a theoretical and an empirical point of view. Most importantly, it allows a confrontation between theoretical prediction and real

	00	11
00	$\begin{pmatrix}203\\276\\203\\276\end{pmatrix}$	$\begin{pmatrix}405\\551\\0\\0\end{pmatrix}$
11	$\begin{pmatrix}0\\0\\405\\551\end{pmatrix}$	$\begin{pmatrix}415\\555\\415\\555\end{pmatrix}$

Table 11: Reduced voting game after one good answer

	00	11
00	$\begin{pmatrix}405\\551\\405\\551\end{pmatrix}$	$\begin{pmatrix}104\\139\\312\\417\end{pmatrix}$
11	$\begin{pmatrix}312\\417\\104\\139\end{pmatrix}$	$\begin{pmatrix}208\\278\\208\\278\end{pmatrix}$

Table 12: Reduced voting game after one bad answer

life behavior. For the parameter values estimated on our data, both a mute and a truthful equilibrium exist. The complex Weakest Link game, however, reduces to a coordination issue in the voting subgames which involves a tradeoff between Pareto domination and risk domination. Empirically, it appears that the players coordinate on the appropriate equilibria in the voting subgames (they vote out the weakest-link) and therefore the truthful equilibrium is selected. In the voting subgames, the players choose the Pareto dominant equilibrium if this one is not too risky but prefer the Pareto dominated equilibrium if the Pareto dominant equilibrium is very risky. These empirical results are compatible with the conclusions drawn by experimental studies (Cooper, DeJong, Forsythe, and Ross (1990), Huyck, Battalio, and Beil (1990), Cooper, DeJong, Forsythe, and Ross (1992), Clark, Kay, and Sefton (2000)). Furthermore it seems that the environment in which the game is played is indeed favorable to such a coordination.

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Appendix

A Statistical test for the strategic lie

Let t denote the number of a given round ($t = 1$ to 7) and i the number of a player ($i = 1$ to N). It is assumed that player i is characterized in round t by a parameter $0 \leq \theta_i^t \leq 1$ which is the probability with which player i knows the answer to any given question. Let $\theta^t = E\left(\theta_i^t\right)$ be the average rate of good answers in round t in the population of contestants.

The test: "Do contestants answer in the same way in rounds t and $t+1$?" can be written as:

$$\mathrm{H}_0 : \quad \theta^t - \theta^{t+1} = 0$$

Let n_i^t denote the number of questions asked in round t to player i and let r_i^t be the number of correct answers given in round t by player i. An estimator of $\theta^t - \theta^{t+1}$ is given by

$$\frac{1}{N}\sum_{i=1}^{N}\left(\frac{r_i^t}{n_i^t} - \frac{r_i^{t+1}}{n_i^{t+1}}\right)$$

The variance of this estimator is:

$$\frac{1}{N^2}\sum_{i=1}^{N}\frac{\theta_i^t\left(1-\theta_i^t\right)}{n_i^t} + \frac{1}{N^2}\sum_{i=1}^{N}\frac{\theta_i^{t+1}\left(1-\theta_i^{t+1}\right)}{n_i^{t+1}}$$

which can be rewritten under H_0 as:

$$\frac{1}{N^2}\sum_{i=1}^{N}\left[\theta_i^t\left(1-\theta_i^t\right)\right]\left[\frac{1}{n_i^t} + \frac{1}{n_i^{t+1}}\right]$$

Using

$$\widehat{\theta}_i^t = \frac{r_i^t + r_i^{t+1}}{n_i^t + n_i^{t+1}}$$

as an estimator of θ_i^t, the statistical test is $|T_{t,t+1}| \leq 1.96$ where $T_{t,t+1}$ is given by

$$T_{t,t+1} = \frac{\frac{1}{\sqrt{N}} \sum_{i=1}^{N} \left(\frac{r_i^t}{n_i^t} - \frac{r_i^{t+1}}{n_i^{t+1}} \right)}{\sqrt{\frac{1}{N} \sum_{i=1}^{N} \left[\widehat{\theta}_i \left(1 - \widehat{\theta}_i \right) \right] \left[\frac{1}{n_i^t} + \frac{1}{n_i^{t+1}} \right]}}$$

Table 13 shows the different values of the test for $t = 1$ to 7. First for both players who reached the endgame. Next, only for the winner and finally only for the loser.

Table 13: Test

T	$T_{1,2}$	$T_{2,3}$	$T_{3,4}$	$T_{4,5}$	$T_{5,6}$	$T_{6,7}$	$T_{7,8}$
Winner + Loser, $N = 72$	0.96	-0.49	0.72	-0.62	1.38	0.36	3.65
Winner only, $N = 36$	0.17	-0.25	0.34	-0.08	0.75	0.94	1.30
Loser only, $N = 36$	1.21	-0.43	0.64	-0.90	1.19	-0.42	3.80

B Statistical test for the heterogeneity

We restrict ourselves to the winners of the 36 games. The test developed in appendix A allows us to model the rate of good answers in the following way:

$$r_{it} = \theta_i + \varepsilon_{it}$$

where θ_i is the probability with which player i knows the answer, and ε_{it} is the error term with mean zero and variance σ_ε^2. All error terms are independent. To test H_0:

$$\theta_1 = \theta_2 = \ldots = \theta_{36}$$

we follow the methodology presented in the chapter 2 of Cheng Hsiao. The test is equivalent to the ordinary hypothesis test based on sums of squares residuals from linear regression outputs. We note S_1 the unrestricted residual sum of squares in the unrestricted model:

$$S_1 = \sum_{i=1}^{36} \sum_{t=1}^{8} \left(r_{it} - \overline{r_i}\right)^2$$

where $\overline{r_i} = \frac{1}{8}\sum_{t=1}^{8} r_{it}$. Similarly let S_2 denote the restricted residual sum of squares under the homogeneity constrains:

$$S_2 = \sum_{i=1}^{36} \sum_{t=1}^{8} \left(r_{it} - \overline{r}\right)^2$$

where $\overline{r} = \frac{1}{8\times 36}\sum_{i=1}^{36}\sum_{t=1}^{8} r_{it}$.

The statistic

$$F = \frac{\left(S_2 - S_1\right) / \left(36 - 1\right)}{S_1 / \left(36 \times 8 - 36\right)}$$

is Fisher distributed with 35 and 252 degrees of freedom.

Table 14 shows that the hypothesis of homogeneity is rejected by the data.

Table 14: Test

F	$F_{95\%}\left(35, 252\right)$	H_0
4.66	1.47	rejected

C Proof of corollary 1

★ The condition

$$G_L\left(\lambda_1\right) \geq \frac{3}{4} G_L\left(\lambda_0\right),$$

can be rewritten

$$2K\left(1+m\right)\left(\frac{1}{4} + \frac{3}{4}\lambda_0 - \lambda_1\right) \geq \left(\frac{3}{4}\lambda_0 - \lambda_1\right)\left(G_{LL} + m\right).$$

First if

$$\frac{3}{4}\lambda_0 \leq \lambda_1, \text{ then the condition is always true.}$$

Next, if

$$\frac{3}{4}\lambda_0 > \lambda_1, \text{ then the condition can be rewritten as}$$

$$G_{LL} \leq (1+m)\,\overline{G_{LL}} - m,$$

where $\overline{G_{LL}} = 2K\frac{1+3\lambda_0-4\lambda_1}{3\lambda_0-4\lambda_1}$. Moreover, as G_{LL} is lower than 1 by definition, we must compare $\overline{G_{LL}}$ with 1. Indeed, it comes that

$$(1+m)\,\overline{G_{LL}} - m \leq 1 \Leftrightarrow \overline{G_{LL}} \leq 1, \text{ and}$$
$$\overline{G_{LL}} \geq 1 \text{ if and only if } \lambda_0 \leq \frac{4}{3}\lambda_1 + \frac{2}{3}\frac{K}{1-2K}.$$

★ The condition

$$G_H(\lambda_1) \geq \frac{3}{4}G_H(\lambda_0),$$

can be rewritten

$$\left(\frac{1}{4} + \frac{3}{4}\lambda_0 - \lambda_1\right)(G_{HH}+m) \geq 2(1-K)(1+m)\left(\frac{3}{4}\lambda_0 - \lambda_1\right)$$

which is obviously true if $\frac{3}{4}\lambda_0 \leq \lambda_1$. If $\frac{3}{4}\lambda_0 > \lambda_1$, using the fact that $\frac{1}{4} + \frac{3}{4}\lambda_0 - \lambda_1 > 0$, it comes that

$$\text{the condition is true if } G_{HH} \geq (1+m)\,\underline{G_{HH}} - m,$$

where $\underline{G_{HH}} = 2(1-K)\frac{3\lambda_0-4\lambda_1}{1+3\lambda_0-4\lambda_1}$. Moreover, as by definition G_{HH} is larger than 1, we must compare $\underline{G_{HH}}$ with 1. Indeed, it comes that

$$(1+m)\,\underline{G_{HH}} - m \geq 1 \Leftrightarrow \underline{G_{HH}} \geq 1.$$

It follows that

$$\underline{G_{HH}} \leq 1 \text{ if and only if } \lambda_0 \leq \frac{4}{3}\lambda_1 + \frac{1}{3}\frac{1}{2(1-K)-1}.$$

Finally, it is readily confirmed that

$$\frac{1}{3}\frac{1}{2(1-K)-1} \geq \frac{2}{3}\frac{K}{1-2K}$$

which ends the proof.

D Round by round statistics

Table 15: Summary statistics for round 1 which lasts 2 min. 30 sec.

V	Gender		Age		r_1		t_1	Gain
status	out	in	out	in	out	in		
$\overline{V}$	0.44	0.53	42	39	0.34	0.76	2.25	5 075
σ	0.5	0.5	14	15	0.29	0.3	0.45	3 483
min	0	0	23	18	0	0	1	0
max	1	1	74	79	1	1	3	15 000
N	36	288	36	288	36	288	324	36

Table 16: Summary statistics for round 2 which lasts 2 min. 20 sec.

V	Gender		Age		r_2		t_2	Gain
status	out	in	out	in	out	in		
$\overline{V}$	0.55	0.53	40	39	0.42	0.71	2.35	4 300
σ	0.5	0.5	16	14	0.29	0.3	0.48	2 890
min	0	0	18	18	0	0	1	300
max	1	1	73	79	1	1	3	12 750
N	36	252	36	252	36	252	288	36

Table 17: Summary statistics for round 3 which lasts 2 min. 10 sec.

V	Gender		Age		r_3		t_3	Gain
status	out	in	out	in	out	in		
$\overline{V}$	0.55	0.53	40	39	0.39	0.73	2.48	3 800
σ	0.5	0.5	15	14	0.29	0.3	0.51	2 370
min	0	0	18	18	0	0	2	300
max	1	1	72	79	1	1	4	9 000
N	36	216	36	216	36	216	252	36

Table 18: Summary statistics for round 4 which lasts 2 min.

V	Gender		Age		r_4		t_4	Gain
status	out	in	out	in	out	in		
$\overline{V}$	0.42	0.55	40	38	0.44	0.72	2.65	3 250
σ	0.5	0.5	17	14	0.3	0.27	0.48	1 670
min	0	0	21	18	0	0	2	300
max	1	1	76	79	1	1	3	7 800
N	36	180	36	180	36	180	216	36

Table 19: Summary statistics for round 5 which lasts 1 min. 50 sec.

V	Gender		Age		r_5		t_5	Gain
status	out	in	out	in	out	in		
$\overline{V}$	0.69	0.51	41	38	0.50	0.74	2.90	3 775
σ	0.47	0.5	17	13	0.25	0.28	0.38	2 670
min	0	0	18	18	0	0	2	300
max	1	1	79	76	1	1	4	12 000
N	36	144	36	144	36	144	180	36

Table 20: Summary statistics for round 6 which lasts 1 min. 40 sec.

V	Gender		Age		r_6		t_6	Gain
status	out	in	out	in	out	in		
$\overline{V}$	0.42	0.55	39	37	0.44	0.71	3.30	2 300
σ	0.5	0.5	14	12	0.25	0.25	0.46	1 450
min	0	0	19	18	0	0	3	0
max	1	1	76	69	1	1	4	7 500
N	36	108	36	108	36	108	144	36

Table 21: Summary statistics for round 7 which lasts 1 min. 30 sec.

V	Gender		Age		r_7		t_7	Gain
status	out	in	out	in	out	in		
$\overline{V}$	0.52	0.55	38	37	0.50	0.68	3.86	2 400
σ	0.5	0.5	13	12	0.30	0.27	0.48	1 940
min	0	0	19	18	0	0	3	0
max	1	1	68	69	1	1	5	7 500
N	36	72	36	72	36	72	108	36

Table 22: Summary statistics for round 8 which lasts 1 min. 20 sec.

V	Gender		Age		r_8		t_8	Gain
status	out	in	out	in	out	in		
$\overline{V}$	0.55	0.55	38	36	0.47	0.62	5.06	4 250
σ	0.5	0.5	14	10	0.28	0.23	0.56	3 410
min	0	0	18	21	0	0	3	0
max	1	1	69	58	1	1	6	14 400
N	36	36	36	36	36	36	72	36