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Guessing Games and People Behaviours: What Can we Learn?

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Guessing Games and People Behaviours: What Can we Learn?[♦]

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Abstract

In this paper we address the topic of guessing games. By developing a generalised theory of naïveté, we show how Güth et al.'s result (i.e. convergence toward interior equilibria is faster than convergence toward boundary equilibria) is compatible with Nagel's theory of boundedly rational behaviour. However, we also show how, under new model parameterisation, neither Güth et al.'s story of convergence towards interior equilibria, nor Nagel's theory of boundedly rational behaviour are verified. We conclude that the results of Nagel (1995) and Güth et al. (2002), however interesting, are severely affected by the *ad hoc* parameterisation chosen for the game.

JEL classification: C72, C91

Keywords: Guessing game, p-beauty contest, individual behaviour

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1. Introduction

In the last decade a growing effort has been devoted to explore the p-beauty contest game (Nagel, 1995; Duffy and Nagel, 1997; Canerer et al., 1998; Weber, 2003). The game itself is well known and extremely simple: players are asked to choose a number from a closed interval. The winning player will be the one that gets closer to a target number *G*. Such target is defined as the average of all guesses plus a constant, multiplied by a real number known to all players. Formally, we can write the target as: $G = p\left(\frac{1}{n}\sum_{i=1}^{n} g_i + d\right)$. In its simplest form the game parameterisation is set as follows: $0 \le p < 1$, *n* is the number of players in the contest, $g_i \in [0,100] \subset \mathbf{R}$ is subject *i*'s guess and *d* is a constant set equal to 0. Under such definition of *G* the game-theoretical solution is a unique Nash equilibrium where all players choose 0.[1] In fact, playing 0 is the only strategy that survives the procedure of *iterated elimination of dominated strategies* (IEDS). Let us assume that in the first iteration all players play the highest possible number (100 in our case); here we can immediately observe that the winning number will be $g = p100$. Now, a rational agent should know this and hence play $p100$. However, if all players are rational, the target will shift to $g = p(p100)$ or to $g = p^2 100$. Hence, rational players will now play $p^2 100$. This process goes on until the only possible equilibrium is reached, i.e. $g = p^{\infty} 100 = 0$. Of course, this solution requires that players constantly behave rationally (i.e. for all the infinite iterations of the game) and that everybody knows that everybody else also behaves always rationally. Note that the IEDS suggests what should not be played, and after an infinite number of iterations, the Nash equilibrium is reached.

Nagel, in her seminal paper, suggested "that the 'reference point' or starting point for the reasoning process is 50 and not 100. The process is driven by iterative, naïve best replies rather than by an elimination of dominated strategies" (1995: 1325). The *iterative naïve best replies* (INBR) strategy assumes that, at each level, every player believes that he/she is exactly one level of reasoning deeper than all other players.[2] A Level-0 player chooses a

[1] Note that "[f]or $p = 1$ and more than two players, the game is a coordination game, and there are infinitely many equilibrium points in which all players chose the same number". For $p > 1$ and $2p < n$ "all choosing 0 and all choosing 100 are the only equilibrium points. Note that for p > 1 there are no dominated strategies" (Nagel, 1995: 1314).

[2] Please note that in what follows we shall use Level, Step and Degree interchangeably.

number randomly in the given interval [0, 100], with the mean being 50. Therefore, a Level-1 player gives best reply to the belief that everybody else is Level-0 and thus chooses p50. Following this line of reasoning, a Level-2 player chooses $p^2$50, a Level-k player chooses p^k50, and so on. A player who takes infinite steps of reasoning, and believes that all players take (infinite-1) steps, chooses 0, the Nash equilibrium. This interpretation of the converging pattern towards the equilibrium implies that different subjects are characterised by different cognitive levels.

Bosch-Domènech et al. (2002) analysed ‘newspaper and lab beauty-contest experiments’ and categorised subjects according to their depth of reasoning. The authors recognised that subjects were actually clustered at Level-1, Level-2, Level-3 and Level-infinity as assumed by Rosemary Nagel.

All these results apply to the standard p-beauty contest game. Under such a standard parameterisation of the game - i.e. $g_i \in [0,100]$, $p < 1$, and $d = 0$ - both the *iterative naïve best replies* and the *iterated elimination of dominated strategies* require the same number of iterations in order to solve the game. The picture changes if we set $d \neq 0$; in this case the game might well exhibit an interior equilibrium (i.e. different from 0 or 100) and, for specific values of p, the solution of the game obtained, using the two different strategies, involves different numbers of iterations needed to reach the equilibrium.

Güth et al. (2002) proposed a game where d was initially set equal to 0 and subsequently equal to 50. This allowed them to analyse the p-beauty contest from a different perspective, comparing, among other things, interior and boundary equilibria. They showed that the convergence toward the equilibrium is faster when the equilibrium is interior.

In this paper we aim at generalising the *iterative naïve best replies* strategy to the wider class of games with interior equilibria; analyse Güth et al.’s results concerning the properties of interior equilibria in a more general setting; and compare the *iterative naïve best replies* strategy with the *iterative elimination of dominated strategies* for the generalised p-beauty contest. We shall do this by means of a laboratory experiment.

2. A generalisation of the INBR strategy to a game with interior equilibria

Let n (> 2) be the number of subjects in the game. Each of them has to choose a number $g_i \in [L, H]$, where $L, H \in \mathbf{R}$. Their pay-off function is:

$$u(g_i) = C - c\left| g_i - p\left(\frac{1}{n}\sum_{j=1}^{n} g_j + d\right)\right|,$$

where C is a positive (monetary) endowment, c (> 0) is a fine subject i has to pay for every unit of deviation between his/her guess g_i and the target number G.[3] Then, for all $d \in \mathbf{R}$ and $p \in [0,1)$ there is a unique Nash equilibrium, which is given by:

$$\max\left(L, \lim_{n\to\infty} Lp^n + \sum_{i=1}^{n} dp^i\right) < g^* < \min\left(H, \lim_{n\to\infty} Hp^n + \sum_{i=1}^{n} dp^i\right).$$

If we want to solve this generalised p-beauty contest game with the *iterative naïve best replies* strategy we need to redefine it. Since the guessing interval is [L, H], the focal point[4] should be $\frac{H+L}{2}$. The equilibrium using the *iterative naïve best reply* strategy is given by:

$$\begin{cases} if \;\; p < 1 \quad g_i = \max\left(L, \lim_{n\to\infty} \dfrac{H+L}{2} p^n + \sum_{i=1}^{n} dp^i\right) \\ if \;\; p > 1 \quad g_i = \min\left(H, \lim_{n\to\infty} \dfrac{H+L}{2} p^n + \sum_{i=1}^{n} dp^i\right). \end{cases}$$

Now we have defined a generalised theory of naïveté which can be applied both to boundary solutions (as it was originally defined by Nagel, 1995) as well as to interior equilibria; this simple generalisation will help us comparing it with rationality theory.[5]

2.1 Rationality vs. naivety: posing our research questions

As already discussed, a p-beauty contest game exhibits a unique boundary Nash equilibrium if the target number is $G = p\left(\frac{1}{n}\sum_{j=1}^{n} g_j + d\right)$ and $d = 0$. Under the assumption of rationality, such converging dynamics takes, theoretically, infinite steps. The situation changes if we consider d values which are greater than 0. In this case the converging equilibrium could be boundary as well as interior.

[3] Note that this pay-off function was first used in Güth et al. (2002). We prefer it over the standard "winner takes it all" pay-off function as it prevents subjects' income polarisation.
[4] We are borrowing this term from Nagel (1995) where the focal point was *ad-hoc* set equal to 50.
[5] In what follows, when talking of 'theory of naïveté', we refer explicitly to Nagel's *iterative naïve best replies* strategy and to the *iterative elimination of dominated* when talking of 'rationality theory'.

Güth et al. (2002) carried out an experiment aiming at testing the diverse converging equilibria generated, assigning different values to the parameter *d*. The authors observed in the lab different converging speeds for different model parameterisations; specifically, they compared two treatments characterised by the following parameters: $p = ½$, $g \in [0, 100]$, $d = 0$ and $p = ½$, $g \in [0, 100]$, $d = 50$. Conducting a laboratory experiment, the authors observed that the latter treatment converged towards its Nash equilibrium faster than the former. This result counters the fact that the two treatments had the same degree of complexity. Such apparent contradiction was justified by the authors arguing that the observed difference in converging speeds was due to the fact that in the first case (i.e. $d = 0$) the steady state was a *boundary equilibrium* (i.e. 0), whereas in the second case (i.e. $d = 50$) the system converged towards an *interior equilibrium* (i.e. 50). Hence, they concluded that "interior equilibria trigger more equilibrium-like behaviour than boundary equilibria" (2002: 223).

Although it seems appealing, this explanation might be misleading. In fact, dropping the assumption of perfect rationality and applying the theory of naïveté generalised in the section above, we can theoretically calculate the converging dynamics and the equilibria obtainable, using Güth et al. (2002) parameterisation and then compare these results to those obtained applying rationality.

We report these results in table 1 below. Under the assumption of rationality (i.e. *repeated elimination of strictly dominated strategies*), an infinite number of iterations is required independently from the value assigned to *d*, hence suggesting that the problems have an identical degree of complexity. The picture changes under bounded rationality assumption (i.e. *INBR*): in this case an infinity-order belief is required to reach the Nash equilibrium when $d = 0$, and only a zero-order belief when $d = 50$. In fact, when $d = 50$, subjects immediately play the Nash equilibrium (which in this case is 50) irrespectively to their sophistication level.[6]

This finding suggest that, if we buy Nagel's idea of bounded rationality and apply the generalised theory of naïveté previously derived, Güth et al. (2002) experimental results could be explained by the fact that the two treatments have a different degree of complexity

[6] This can be easily proved numerically. Note that in this very specific case the Nash equilibrium coincides with the "expected choice of a player who chooses randomly from a symmetric distribution" as well as to "a salient number à la Shelling" (Nagel, 1995: 1315).

rather then by the intrinsic capacity of triggering equilibrium-like behaviours of interior equilibria.

Step	p=1/2, d=0, L=0, H=100		p=1/2, d=50, L=0, H=100	
	IEDS	INBR	IEDS	INBR
1	0<g<50	g=25	25<g<75	g=50
2	0<g<25	g=12.5	37.5<g<62.5	g=50
3	0<g<12.5	g=6.25	43.74<g<56.25	g=50
4	0<g<6.25	g=3.13	46.87<g<53.12	g=50
…				
infinity	g=0	g=0	g=50	g=50

Table 1: Güth et al. (2002) treatments - *IEDS* vs. *INBR*

In short, we are posing here the problem of understanding what the true reason behind the observed difference in converging dynamics is. In what follows we shall attempt to test the robustness of Güth et al. (2002) results by replicating the p-beauty experiment using different parameterisations. Subsequently, we shall focus our attention on Nagel's theory of naïveté, attempting to understand if it holds also for games which display interior equilibria.

3. Aim and setting of the experiment

As discussed above, a preliminary target of our experiment is testing the robustness of the hypothesis according to which "[a]n interior equilibrium […] is supposed to yield smaller deviations of the guesses from the game-theoretic equilibrium than a boundary equilibrium, since participants often try to avoid extreme choices …" (Güth et al., 2002: 221-22). In order to test for the validity of such hypothesis we will consider a new set of problems' characterisation defined by different parameterisations of the game. Specifically, we shall compare the original parameterisation adopted by Güth et al. with a similar setting where we vary the value of *p* (set equal to 2/3) and the value of *d* (set equal to 25 and 50). It is worth noting that, like in the original experimental setting, this new parameterisation produces an interior game-theoretical equilibrium and a boundary one (when the value of *d* is respectively 25 and 50). If Güth et al.'s result is robust to different model parameterisations, we would expect to observe a faster convergence in the game with interior equilibrium; otherwise, we shall confute the validity of their results for problems' parameterisations different from those originally selected by the authors.

Once addressed this point, we will move on to consider Nagel's theory of naïveté in the case of games with interior equilibria. In doing so, we will study the first-period choices in two games characterised as above (i.e. p = 2/3 and d = 25 or 50) and in a new game parameterisation where we will vary the interval $[L, H]$, assigning different values to the upper and lower bound. This will allow us to verify the occurrence of Nagel's naïveté also in games with interior equilibria.

3.1 The design of the experiment

In each treatment of the experiment there are n = 32 subjects divided into 8 groups, each of 4 subjects. In each group subjects have to guess a number in the real interval [L, H]. The closer their guess is to the target the higher is the pay-off. As discussed above, the general form of the pay-off function is: $u(g_i) = C - c\left|g_i - p\left(\frac{1}{n}\sum_{j=1}^{n} g_j + d\right)\right|$.

The experiments were run in October 2005 at the Max Planck Institute of Jena. The software of the computerised experiment was developed in z-Tree (Fischbacher, 1998). Jena University students who participated at the experiment were recruited using the ORSEE software (Greiner, 2004). The age of players ranged from 21 to 31 years, and the average pay-off paid to players amounted to 11.95 Euro (sd = 1.76), the duration of each treatment was 40 minutes. Groups were formed randomly at the beginning of the experiment and were kept invariant over the whole experiment (i.e. 40 periods).

4. Results and interpretation

4.1 Studying converging dynamics

In this section we will analyse the results obtained in our experiments. However, before moving to our new findings we shall recall results obtained by Güth et al. (2002) which will serve as a reference point to our study. Schematically we summarise Güth et al. results in the following table:

	Parameterisation	Game-theoretical equilibrium	Speed of convergence
Güth et al. Treatment 1	p=1/2, d=0, L=0, H=100	Convergence toward a boundary equilibrium (g=0)	slower
Güth et al. Treatment 2	p=1/2, d=50, L=0, H=100	Convergence toward an interior equilibrium (g=50)	faster

Table 2: Güth et al. (2002) summary of results

As we can see, the authors presented two comparable cases and showed how the treatment where the game-theoretical equilibrium is interior, displayed a higher speed of convergence. We shall now present our results and compare them to those obtained by Güth et al.

In figures 1 and 2 we report the average guesses in each group for our first and second treatments. These results appear to confute the findings of Güth et al. (2002), as guesses converge steadily towards the equilibrium, but the interior equilibria treatment converges slower.

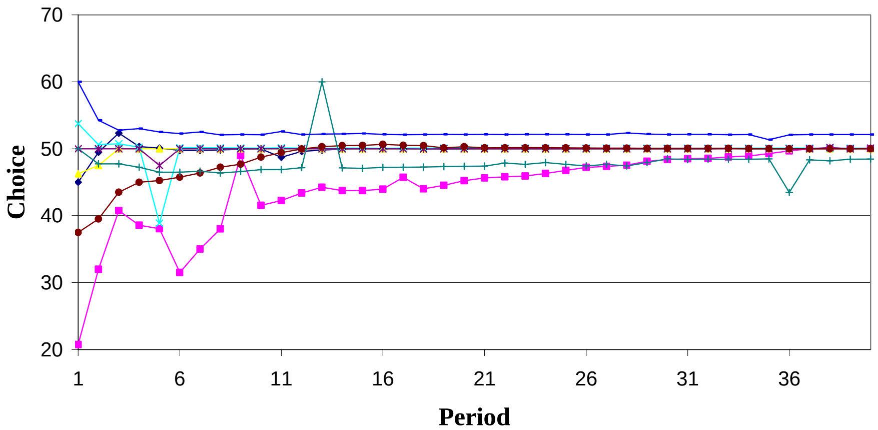


Figure 1: Treatment 1 - group averages (p = 2/3; d = 25)

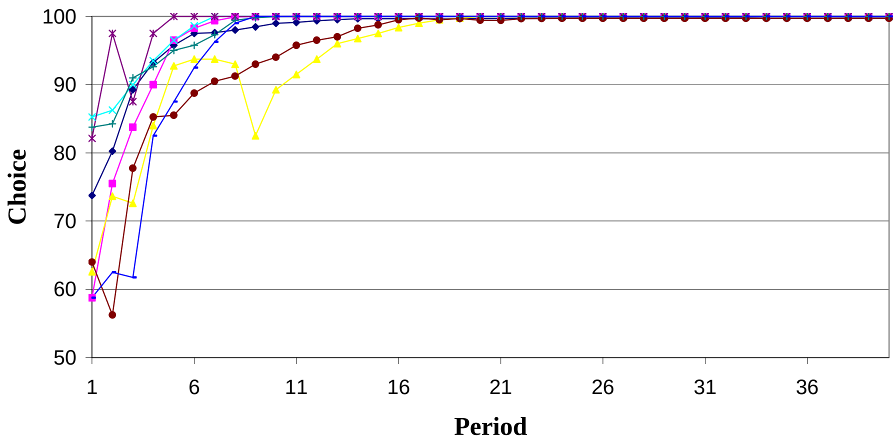


Figure 2: Treatment 2 - group averages (p = 2/3; d = 50)

In fact, in treatment 2 the system reaches a steady boundary equilibrium in less than 25 iterations. This result is consistent for each of the eight groups considered in our experiment, a fact which gives a certain degree of robustness to it. On the contrary, not all groups considered in treatment 1 reach a steady equilibrium within the time frame considered (i.e. 40 periods). Moreover, the converging dynamic towards the interior equilibrium is on average statistically significantly slower; more precisely we tested the hypothesis that the two distributions have the same variance. We used the Freund-Ansari-Bradley test. In periods 1, 4, and 6 we rejected the null hypothesis at a significance level of 10 percent and in periods 2 and 3 we rejected the null hypothesis at a significance level of 5 percent, in favour of the alternative hypothesis that the variance in treatment 2 is smaller. Hence we can infer that convergence towards equilibrium is faster in treatment 2.

Note that this finding confutes also the generalised version of Nagel's theory of naïveté as also in this case an infinity-order belief is required to reach the equilibrium when d = 50, and only a zero-order belief is required when d = 25. As is shown in table 3, following the generalised naïveté theory when d = 25, subjects should immediately play the Nash equilibrium irrespectively to their sophistication level. However, this does not happen in the lab.

Step	Treatment 1 p=2/3, d=25, L=0, H=100		Treatment 2 p=2/3, d=50, L=0, H=100	
	IEDS	INBR	IEDS	INBR
1	16.67<g<83.33	g=50	33.33<g<100	g=66.67
2	27.78<g<72.22	g=50	55.56<g<100	g=77.78
3	35.18<g<64.81	g=50	70.37<g<100	g=85.19
4	43.41<g<56.58	g=50	80.24<g<100	g=90.12
…				
infinity	g=50	g=50	g=100	g=100

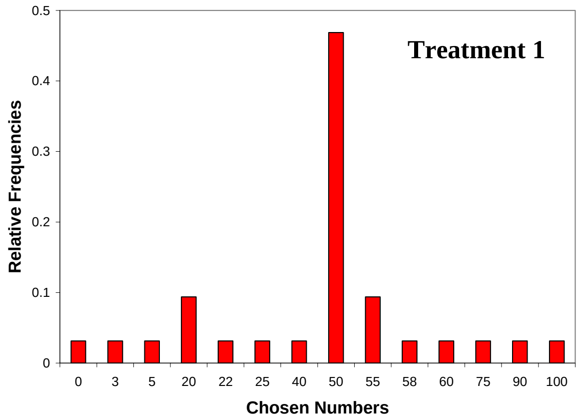
Table 3: Treatments 1 and 2 - *IEDS* vs. *INBR*

All in all, this first set of results would suggest a rejection of both Güth et al. (2002) account of convergence (i.e. that interior equilibria trigger more equilibrium-like behaviour than boundary equilibria) as well as our generalisation of Nagel (1995) theory of naïveté, as they proved to be not robust to our new model parameterisation.

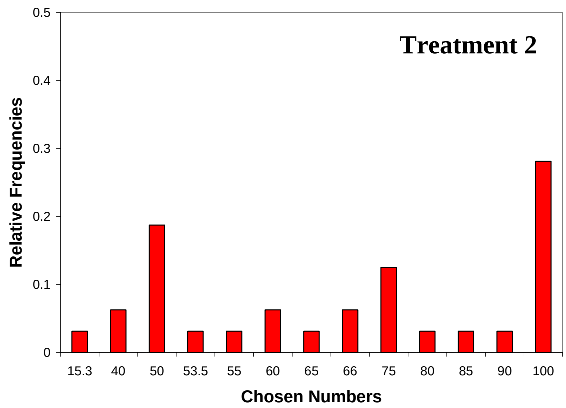
This could also imply that Nagel's game-theoretical result cannot be generalised to interior equilibria as it holds solely for boundary equilibria. In what follows, we shall concentrate our attention on first-period choices in order to investigate whether this last hypothesis is actually confirmed by different model parameterisations.

4.2 Studying first-period choices

Figure 3 displays first choices frequencies for both treatment 1 and treatment 2 described in the section above. As we can immediately observe, in figure 3a almost half of the subjects immediately played the (interior) Nash equilibrium. This might lead us to maintain that agents are behaving rationally, as they are instantly able to solve the game applying the *iterated elimination of dominated strategies*. However, we should note that in this very specific case the Nash equilibrium coincides with the salient number calculated following Nagel's definition of a player strategic of degree 0. Moreover, as showed in table 3, it coincides also with the choice of a person strategic of degree $n \in \mathbf{N}$ (i.e. invariantly of the sophistication level, a person playing the *iterative naïve best replies* always chooses 50).



3a: (p = 2/3; d = 25; [0, 100])



3b: (p = 2/3; d = 50; [0, 100])

Figure 3: Choices in the first period - Treatments 1 and 2

This implies that, by simply looking at this data, we cannot distinguish among subjects playing 50 as they could be rationally applying the IEDS strategy or they could be as well behaving naively and following an INBR strategy.

We now turn to look at the second treatment. In this case the Nash equilibrium was boundary and equal to 100 and was played in the first period by almost 30 percent of the players. Note that the a person playing strategic of degree 1 would play 66.67; a person strategic of degree 2 would play 77.78, and so on (as reported in the last column of table 3 above). Not many subjects played strategic of degree 1, 2, 3, …, as can be easily detected in figure 3b. However, almost 30 percent of them might have played strategic of degree infinite or, alternatively, might have rationally applied the IEDS strategy. Interestingly, almost 20 percent of the subjects (i.e. 6 out of 32) played 50, which in this case was not a focal point in the sense of being the expected choice of a player who chooses randomly from a symmetric distribution, but was probably perceived as a salient number being the mean of the interval [0, 100]. This fact leads us to believe that when the focal point à la Nagel coincides with a salient number (like the mean of the interval) we might observe players guessing that number for reasons other than playing strategic of degree 0, as suggested by Nagel (1995).

In other words, we shall maintain that Nagel's results might be affected by the specific parameterisation of the model. In order to test this hypothesis we ran two new treatments where the interval boundaries were shifted to the right and were selected as odd integers.

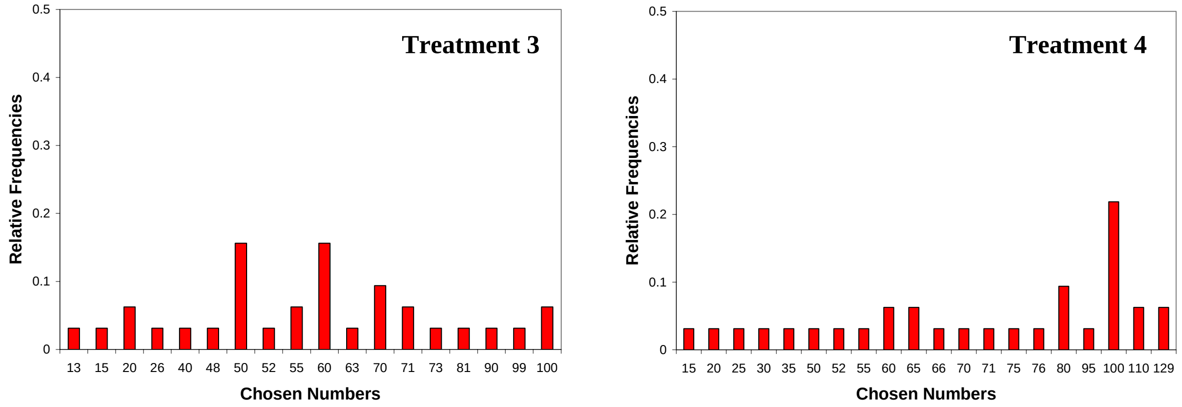
Specifically we selected the following interval: [13, 129]. All other parameters were left unaltered. The Nash equilibrium and its converging dynamic are reported in table 4 for both strategies.

Step	Treatment 3 p=2/3, d=25, L=13, H=129		Treatment 4 p=2/3, d=50, L=13, H=129	
	IEDS	INBR	IEDS	INBR
1	25.33<g<102.67	g=64.00	42<g<119.33	g=80.67
2	33.56<g<85.11	g=59.33	61.33<g<112.89	g=87.11
3	39.03<g<73.41	g=56.22	74.22<g<108.60	g=91.41
4	42.69<g<65.60	g=54.15	82.81<g<105.73	g=94.27
…				
infinity	g=50	g=50	g=100	g=100

Table 4: Treatments 3 and 4 - *IEDS* vs. *INBR*

Note that treatments 1 and 3 and treatments 2 and 4 share the same parameters (*p* and *d*) and converge to the same Nash equilibrium (in treatment 4, though, the Nash equilibrium is interior whereas in treatment 2 it is boundary). We tested the hypothesis that (T1 - T3) and (T2 - T4) come from the same distribution using the Wilcoxon Signed Ranks Test; we can reject the null hypothesis respectively at the 0.0001 and at the 0.001 level. This result suggests that many players do not choose numbers at random but instead are influenced by the value of the boundaries L and H of the game.

In treatments 3 and 4 the game-theoretical Nash equilibrium is always interior and requires an infinity-order belief to be reached independently of the strategy adopted. Looking at figures 4a and 4b we can easily observe that guesses are much less clustered if compared to treatments 1 and 2; further, the number of subjects playing immediately the Nash equilibrium is lower than that observed in figures 1 and 2. Specifically, in treatment 3 only 15 percent of subjects played immediately Nash, and in treatment 4 this share raised slightly to nearly 22 percent.



4a: (p = 2/3; d = 25; [13, 129])

4b: (p = 2/3; d = 50; [13, 129])

Figure 4: Choices in the first period - Treatments 3 and 4

As in both treatments there is a very low level of clustering around any focal point, it is hard to believe that agents have been following an *iterative naïve best replies* strategy.[7] However, we shall try to verify if data actually clusters around those iteration levels. In order to test this hypothesis we follow the methodology proposed by Nagel (1995); specifically, we define *neighbourhood*[8] of Step *i*, where $i \in [0, 1, 2, 3, 4]$.

Intervals between two neighbourhood intervals of Step *i* and Step *i* + 1 are called *interim intervals*. In figure 5 we show the relative frequency of each of these *neighbourhood* and *interim intervals* for the respective treatment. Note that we cannot define *neighbourhoods* for treatment 1 as the *iterative naïve best replies* strategy leads to the Nash equilibrium at each and every iteration step. Hence, all neighbourhoods would overlap around the game-theoretical equilibrium.

Looking at figure 5 we can easily observe that there is not much clustering around iteration levels. The relative frequency is never higher than 15.6 percent, being on average lower than 6 percent. Not surprisingly, most of the frequencies are clustered in the upper and lower interim interval. This is certainly due to the fact that these are broader intervals; however, confronting these charts with those reported in figures 3 and 4, we can maintain

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[7] That is, taking (H + L)/2 +d as an initial reference point and considering several iteration steps from this point (Step 0 → p [(H + L)/2 + d]; Step 1 → p (Step 0 +d); …;Step i → p(Step i-1 +d)).

[8] In general the neighbourhood interval of Step i has the boundaries (Step i)p^h and (Step i)p^{-h}, where h is the smallest integer such that two neighbourhood intervals do not overlap. Following Nagel (1995), we rounded intervals upper and lower boundaries to the nearest integers, since mostly integers were observed.

that people tend to cluster initially around round numbers which they perceive as *salient* (like 100, 50 or even 60 and 70 when the guessing space was set as [13, 129]). These findings confirm our assumption that subjects tend to play the focal point when it coincides with other salient numbers of the distribution.

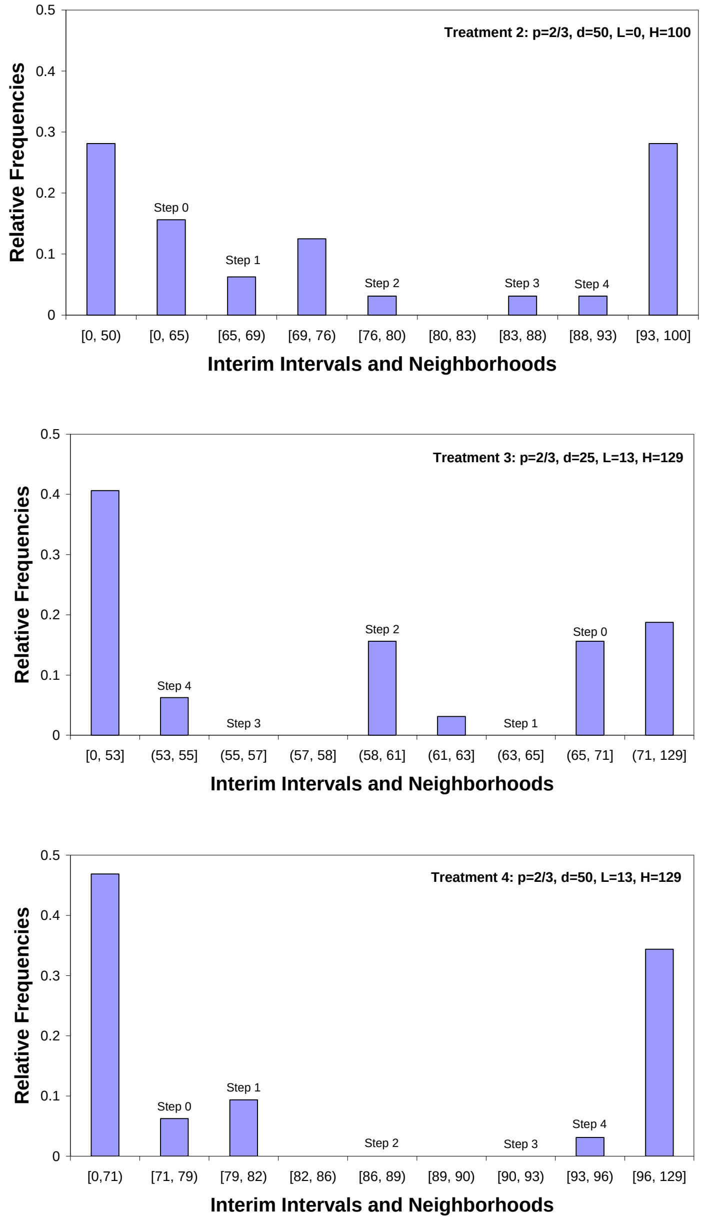

Figure 5: Relative frequencies of choices in the first period according to the interval classification with reference point *(H + L)/2 +d*

5. Conclusions

In this paper we have addressed the topic of guessing games with the aim of understanding if people play in a rational or naïve way. Two pieces of results of the relevant literature triggered our interest. First, Nagel showed how in the first period players deviate strongly from game-theoretic solution. Hence, she proposed a "theory of boundedly rational behaviour in which the 'depth of reasoning' are of importance" (1995: 1325). The author showed that starting from a reference point X (where X was set equal to 50) iteration steps 1 and 2 play a significant role, that is, most of the observations are in the corresponding neighbourhoods. Second, Güth et al. (2002) studied people's behaviour in four different types of experimental beauty-contests. Under the assumption of rational behaviour they found faster convergence to the equilibrium when the equilibrium was interior.

By developing a generalised theory of naïveté (which accounted for interior equilibria) we showed how Güth et al.'s result was compatible with Nagel's theory of boundedly rational behaviour. However, we also wanted to test the sensitivity of both results to different model parameterisations. By conducting a new series of experiments we countered both results showing how, under new parameters, neither the convergence towards interior equilibria was always faster, nor the starting from a reference point X (which in our case was different from 50), iteration steps 1 and 2 played any significant role.

We conclude that the results of Nagel (1995) and Güth et al. (2002), however interesting, are severely affected by the *ad hoc* parameterisation chosen for the game. Far from providing conclusive evidence on the issue of guessing games and people behaviours, this paper aims at raising questions: what are the true driving forces behind subjects decision in a p-beauty contest game? Further, do subject in the lab behave rationally or do they follow naïve strategies? Can we really define a unifying theory of behaviour applicable to all subjects?

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