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On the absorbability of the Guessing Game Theory. A Theoretical and Experimental Analysis

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A Theoretical and Experimental Analysis[*]

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Abstract

Theory absorption, a notion introduced by Morgenstern and Schwödiauer (1972) and further elaborated by Güth and Kliemt (2004), discusses the problem whether a theory can survive its own acceptance. Whereas this holds for strategic equilibria according to the assumptions on which they are based, the problem if theories are absorbable by at most boundedly rational decision makers is hardly discussed. Based on guessing game experiments we discuss the requirements of equilibrium theory absorption and test experimentally the effects of informing none, some or all players about how to derive equilibrium predictions.

JEL Classification: C72, C91

Key words: theory absorption, guessing game, p-beauty contest, individual behaviour, elimination of dominated strategies

1   Introduction

The concept of "theory absorption" points at the recursive effects economic theories may have on the system they aim at describing. Although potentially any economic theory can be absorbed for the resolution of a concrete problem (Dacey (1976)), the way a theory gets absorbed may differ from case to case, depending on its formulation, its accessibility, its understanding, and its acceptance by the individuals (Morgenstern (1972)). Adding to that, past experiences and learning may matter as well.

When theories of decision behaviour with and without strategic interaction become more widely accepted they will be used to predict others' behaviour. A theory is said to be absorbed by an individual if that individual refers to it for elaborating her own mental models and chooses to act according to its logical content. In interactive contexts, theory absorption will also be strongly related to the supposed behaviors of the others. Thus, it can be distinguished among unilaterally-, partially-, and fully-absorbable theories, depending on the number of individuals from one to all who follow its prescriptions and are satisfied with the result, so that, ceteris paribus, there would not be any reason for the individuals to modify the theory to adhere with, in other words the theory to absorb (Güth and Kliemt (2004)). Thus, a theory is fully absorbable if such prediction does not question the validity of the theory to predict.

Such absorbability holds for strategic equilibria (Cournot (1838), Nash (1951)) by definition. When expecting a given equilibrium, it is optimal to behave accordingly. For behavioural theories absorbability may not be granted. In bilateral negotiations such a theory could, for instance, predict an agreement at the mean of the initial demands what confirms with some intuition and empirical observations (Pruitt (1981), Sebenius (1992)). This, however, would inspire outrageous initial demands to which the theory, in all likelihood, would no longer apply. The problem of theory absorption has been pointed out by Morgenstern and Schwödiauer (1972) and further elaborated by Güth and Kliemt (2004). The latter especially focus on theories which can be absorbed by boundedly rational decision makers, distinguishing between partial (some but not all players are aware of the theory) and full theory absorption.

The guessing game (first introduced by Keynes (1936)) has several attractive characteristics for studying rationality and learning: it does not confound effects of rationality with

the effects of social preferences, such as inequality aversion, fairness, or reciprocity. Additionally, the guessing game is interactive, has a clear economic interpretation, and is very simple to explain. It therefore represents an excellent framework to tackle our research objective, namely, experimentally test theory absorption by boundedly rational decision makers. We will now discuss the equilibrium theory absorption for guessing games.

In a guessing game all $n(\geq 1)$ players $i = 1, ..., n$ have to choose a number $g_i \in [L, H]$ with $0 \leq L < H$. The player i who is closest to the target number $g^* = p \left(\sum_{i=1}^{n} \frac{g_i}{n} + d \right)$ with $p \in (0, 1)$ and $d \geq 0$, wins a previously fixed price (Nagel (1995), Duffy and Nagel (1997), Ho et al. (1998), Weber (2003)). Equilibria can be derived by commonly known iterated elimination of dominated strategies. Clearly, once all players know that all players know...that all players are aware of this principle and capable of deriving its implications, they are able to foresee its unique equilibrium prediction. For guessing games this illustrates full absorbability of strategic equilibria when the assumption of common knowledge of rationality holds. To illustrate partial theory absorption assume that just one of $n \geq 2$ players is aware of the principle of iterated elimination of dominated strategies and able to apply it. Obviously, such a player i will not use a dominated strategy and account for the effect of her own choice g_i on the target number g^*, but will she rely on her unique equilibrium strategy? Experience and experimental evidence (Nagel (1999))) suggest that this is not a best response to what others, more or less unaware of the theory, actually choose.

Unlike in other games (Roth (1995))) the experimental tests of guessing games (Camerer et al. (2001), Camerer (2003a), Friedman and Cassar (2004), Nagel (1995) or Nagel (1999)) all reveal convergence of behavior to equilibrium, with the debate basically concerning what induces faster convergence. Whether this relies on cognitively capturing of the principle of iteratively eliminating dominated strategies (further on referred to as PIEDS) or on noncognitive ideas of behavioral adaptation, such as the application of individual heuristics or e.g. mental representation (Camerer (2003b), Sbriglia (2006)), thus far remains unclear.

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." (Nagel (1995)) Iterative naïve best replies assume that, at each level, every player believes that she is exactly one level of reasoning deeper than all other players. A level-0 player chooses a 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 $p * 50$. Following this line of reasoning a level-2 player chooses $p^2 * 250$, a level-k player chooses $p^k * 50$, and so on. A player who takes infinite steps of reasoning and believes that all players take (infinite-1) steps chooses 0, reaching the equilibrium. This interpretation of the convergence pattern towards the equilibrium implies that different subjects are characterized by different cognitive levels.

Bosch-Doménech et al. (2002) analyzed 'newspaper and lab beauty-contest experiments' and categorized subjects according to their depth of reasoning. The authors recognized that subjects were actually clustered at level-1, level-2, level-3 and level-infinity as assumed by Rosemarie Nagel. All these results apply to the standard p-beauty contest game.

Camerer et al. (2003) introduced a simple cognitive hierarchy model of games. The model predicts players are unlikely to play Nash strategies which are refined away by subgame or trembling-hand perfection. Instead, players assume certain members of their group to stop the iteration process with a proportion given by a Poisson distribution with the mean τ, indicating the average number of thinking steps. The main contribution of the paper is to show that the same model can explain limited equilibration in dominance-solvable games (like p-beauty contests).

Güth et al. (2002) proposed a game where d was initially set equal to zero and subsequently equal to 50. This allowed them to analyze the p-beauty contest from a different perspective, comparing, among other things, interior and boundary equilibria. They showed that "...interior equilibria trigger more equilibrium-like behavior than boundary equilibria". Thus, convergence towards the equilibrium is faster if the equilibrium is interior. Morone and Morone (2007) generalized the iterative naïve best replies strategy to the wider class of games with interior equilibria and analyze Güth et al's results concerning the properties of interior equilibria in a more general setting. The iterative naïve best replies strategy is compared to the iterative elimination of dominated strategies for the generalized p-beauty contest. They showed that Güth et al's result is compatible with Nagel's theory of bounded rational behavior.

Opposed to the previous experiments, we analyze just the first period choices of different guessing games, varying both parameters p and d. The contribution of this paper is to

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verify an immediate change in choice behavior, rather than convergence processes, when subjects are aware of PIEDS. We will illustrate that these subjects reflect on own and other subjects' behavior and, furthermore, adapt the theoretical choice predictions of PIEDS to the anticipated choices of boundedly rational interaction partners. Thus, we show that the notion of cognitive deliberation and adaptation are essential aspects of theory absorption, where the level of adaptation determines the level of absorbability.

In section 2 we discuss partial and full theory absorption for guessing games in more detail. Our experiment (section 3) distinguishes three treatments, differing in the number (none, some, all) of players in a group who are informed about PIEDS. Whereas these so-called absorption treatments are explored in a between-subject design, all player groups experience a variety of guessing games, with boundary $(g^* = L, g^* = H)$ and interior $(L < g^* < H)$ equilibria in a within-subject design. Section 4 presents the results which inform our conclusion (section 5).

2 (Iterated) Dominated Strategy Elimination in Guessing Games

Guessing games are usually presented in a normal form. We concentrate on symmetric games since this seems to be a natural first step when exploring theory absorption.

$$\Gamma = \left[N, \{G_i\}_{i \in N}, \{u_i\}_{i \in N} \right]$$

with n as the player number,

$$g_i \in G_i = G_i = [L, H] \, \forall i = 1..., n$$

as the set of strategies of players i satisfies $0 \leq L \leq H$,

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

as each player i's payoff function depending on the target number $g^* = p \left(\sum_{i=1}^{n} \frac{g_i}{n} + d \right)$, $p \in (0, 1)$, $d \geq 0$, $L < g^* < H$, C as a positive (monetary) endowment and $c(> 0)$ as a fine that subject i has to pay for deviating from the target number g^*.

Usually (Nagel (1995)), the payoff is positive only for player i whose guess g_i is closest to the target number g^*. Other studies (Güth et al. (2002), Morone and Morone (2007)) rely on payment schemes where all players can win but are punished according to their deviation from g^*.

To focus first on PIEDS, we discuss the trivial case of being punished for deviating from g^* if $n = 1$. All numbers $g_1 \in [L, H]$ of the only player 1 with $g_1 \neq g^*$ are given by

$$g_i^* = \max\left\{\min\left\{\frac{p*d}{1-p}, H\right\}, L\right\}.$$

With some analytic capability it is easy to compute g_1^* and to recognize it as the best choice one can make. Thus, informing the only player 1 about PIEDS should induce the choice of g_1^*, i.e., the solution principle should be fully absorbable even for boundedly rational decision makers.

For $n \geq 2$ the same principle is applicable and eliminates for all players $i = 1, ..., n$ all numbers g_i satisfying

$$g_i < \frac{p(n-1)L + nd}{n-p}$$

and

$$g_i > \frac{p(n-1)H + nd}{n-p}.$$

Such elimination requires no assumption about the others being aware of PIEDS. However, to derive the unique equilibrium strategies $g_i^* = g^*$ for all players $i = 1, ..., n$, namely

$$g^* = \max\left\{\min\left\{\frac{p*d}{1-p}, H\right\}, L\right\},$$

the following assumptions are required:

- (P.1) All players $i = 1, ..., n$ eliminate dominated strategies not just once but repeatedly.

- (P.2) All players $i = 1, ..., n$ are aware that all players $i = 1, ..., n$ know...that all players $i = 1, ..., n$ eliminate iteratively all dominated strategies.

This shows that guessing games qualify as good candidates for exploring partial and full absorbability of PIEDS implying the two solution principles $(P.1)$ and $(P.2)$. For example, when informing only one player of a group about PIEDS, the only thing this player can conclude is that the strategies g_i are dominated, leaving thereby her choice wide open. When informing all players about PIEDS and guaranteeing the applicability of $(P.1)$ and $(P.2)$, players should either immediately jump to play g^* or converge to g^* very quickly.

In Table 1 we report the nine parameterizations of the three treatments, where p and d specify the guessing games. It reports the convergence process for the randomly assigned parameters, starting at 0 or 100, similarly to Güth et al. (2002). The various rows of Table 1 refer to what can be eliminated at each iterative elimination step k, the bottom row refers to $k = \infty$ and specifies the equilibrium strategy for the respective game.

Table 1: Nine parameterizations of the guessing game

Number of elimination steps	eliminated strategies $p_i = 1/2$, d=0 $for\ i=1\dots8\ k_i s_i >$		$p_i = 1/2$, d=25 $for\ i=1\dots8\ k_i s_i >$		$p_i = 1/2$, d=50 $for\ i=1\dots8\ k_i s_i >$		$p_i = 1/3$, d=0 $for\ i=1\dots8\ k_i\ s_i >$		$p_i = 1/3$, d=25 $for\ i=1\dots8\ k_i\ s_i >$		$p_i = 1/3$, d=50 $for\ i=1\dots8\ k_i\ s_i >$		$p_i = 2/3$, d=0 $for\ i=1\dots8\ k_i\ s_i >$		$p_i = 2/3$, d=25 $for\ i=1\dots8\ k_i\ s_i >$		$p_i = 2/3$, d=50 $for\ i=1\dots8\ k_i\ s_i >$	
k_i in 0	0.00	100.00	0.00	100.00	0.00	100.00	0	100	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00
1.00	0.00	50.00	12.50	62.50	25.00	75.00	0.00	33.33	8.33	41.67	16.67	50.00	0.00	66.67	16.67	83.33	33.33	100.00
2.00	0.00	25.00	18.75	43.75	37.50	62.50	0.00	11.11	11.11	22.22	22.22	33.33	0.00	44.44	27.78	72.22	55.56	100.00
3.00	0.00	12.50	21.88	34.38	43.75	56.25	0.00	3.70	12.04	15.74	24.07	27.78	0.00	29.63	35.19	64.81	70.37	100.00
4.00	0.00	6.25	23.44	29.69	46.88	53.13	0.00	1.23	12.35	13.58	24.69	25.93	0.00	19.75	40.12	59.88	80.25	100.00
5.00	0.00	3.13	24.22	27.34	48.44	51.56	0.00	0.41	12.45	12.86	24.90	25.31	0.00	13.17	43.42	56.58	86.83	100.00
Infinity	0.00	0.00	25.00	25.00	50.00	50.00	0.00	0.00	12.50	12.50	25.00	25.00	0.00	0.00	50.00	50.00	100.00	100.00
Game order	7		1		4		5		9		3		2		6		8	

3   The Experimental Design

The experiment is performed in three treatments. Each contains nine successive guessing games with different parameters (See table 1 for the sequence of games). In each treatment, each participant faces all nine games in a within subject-design. The $n = 32$ subjects participating in a treatment are subdivided in groups of 8 what yields 4 independent observations. Subjects have to guess a number within $[L, H]$. The closer their guesses are to a target number, the more money they earn, as defined above by $u(g_i)$ where C is a positive (monetary) endowment, and c (> 0) is a fine that subject i has to pay for every unit of deviation between her guess g_i and the target number g^*.

In the first treatment (UU), all subjects received instructions with rules on how to play a guessing game but no information concerning PIEDS. The UU treatment therefore, served as a control treatment. In the second treatment (UI -partial theory absorption), all subjects

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were provided with the guessing game instructions, and half of them received theoretical information about how to derive the equilibrium solution. More precisely, "informed" subjects received detailed information about PIEDS and an illustration of its application[1]. Both "informed" and "uninformed" subjects were equally frequent in the groups and knew how many group members were informed about PIEDS and how many not, thus, inducing the conditions of partial theory absorption. In the third treatment (II), all subjects were informed about PIEDS and knew that all subjects had been informed about this principle. At the beginning subjects were told that they had been matched randomly and that their group composition would remain the same for the whole experiment. After reading the instructions a questionnaire ensured the understanding of the basic rules but not of PIEDS.

We only provided feedback about the average of the guessed numbers in each group (where $n = 8$) and the personal payoff per round to limit the risk of participants' reputation seeking (Camerer et al. (2001)). The changing parameters (Ho et al. (1998)) reduce the possibility to condition on previous choices.

The experiment was run in April 2006 at the experimental laboratory of the Max Planck Institute of Economics in Jena. We used the z-Tree to run the computerized experiments (Fischbacher (1998)). Ninety-six undergraduate students from Jena University, 32 in each of the 3 sessions, were recruited to participate in the experiment using the ORSEE software (Greiner (2004)).[2] The average earnings, including a show-up fee of 4 Euros, amounted to 8.41 Euros. A session lasted about 45 minutes.

4   Experiment Results

The experiment aims to test whether PIEDS can be captured cognitively or is adapted non cognitively, using different guessing games. For boundedly rational subjects, absorbing the

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[1]Example: "Any number, chosen by all of the group members won't exceed 100. This means, the average won't exceed 100. The average + d ($d = 50$) times q (here $q = 1/3$) is 50. Therefore, the number you should choose, should not exceed 50. If all members of your group will realize this, everybody else will choose 50 and therefore the average will be 50. Your number should again not exceed the average + d times $q = 1/3$, which is 33.33 in order to earn as much points as possible." And so on, essentially explaining table 1.

[2]All of the 57 female and 39 male students participated at least twice in previous experiments.

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equilibrium prediction is unlikely. We, therefore, compare theoretically perfect strategic interaction with guesses of boundedly rational subjects in the three treatments.

Analyzing nine different guessing games, individual choice behavior is unlikely to be consistent within all games. Therefore, we restrict ourselves to the use of the absolute deviations from equilibria instead of using the concept of thinking depths in order to infer the level of application of PIEDS. This fits the spirit of the experiment: designing a suitable setting for testing theory absorption to prevent and discourage qualitative learning [3] in order to disentangle the possible effects of revealing how to derive the equilibrium.

4.1 General effects of theory absorption

Result 1 *Providing subjects with theoretical information about PIEDS leads to smaller deviations from equilibria, a longer processing time to choose a number and higher profits in the first period as well as in all periods.*

The deviations from equilibrium serve as a measure of theory absorption in terms of acceptability of the theory and the tendency to act according to its equilibrium prediction. For convenience, we compare the 0.25, 0.5 and the 0.75 quantile aggregates of the nine period choices per subject instead of the mean. This provides a more robust picture of actual behavior. To check for general effects we start by comparing UU and II subjects. Differences to the UI treatment are examined in more detail in section 4.3.3.

Table 2: First period results of subjects in UU, UI and II, where $*$, $'$ and $+$ mark significant differences ($p < 0.05$) respective to UU ($*$) or UI-U ($'$) or UI-I ($^{+}$)subjects

Treatment	Individual choice deviation from the equilibria			Groups' average choice deviation from the equilibria			Time per subject to choose a guess			Individual profit		
	0.25	0.5	0.75	0.25	0.5	0.75	0.25	0.5	0.75	0.25	0.5	0.75
UU $*$	9.50	16.50	25.00	16.46	18.25	20.48	21.25	32.50	43.50	0.57	21.05	32.85
UI-U$'$	13.25	17.50	25.00	9.84	12.53*	12.60	21.50	27.50	47.00	2.34	15.70	28.85
UI-I^{+}	4.50	12.25	19.75	9.84	12.53	12.60	40.75	57.50$'$	71.25	3.55	34.1	40.04
II	0.00	3.50*$^{+}$	15.00	3.66	5.53*$^{+}$	8.06	23.75	45.00*	63.00	15.27	39.69*$^{+}$	44.53

[3]Rosemarie Nagel gives clear evidence for behavioral adjustment toward equilibrium and ascribes it to qualitative learning, sensitive to changes in the parameters (Nagel (1995)).

First round choices reflect choice behavior undisguised by learning effects and conditioning. Providing PIEDS has a clear impact as shown by table 2. Subjects of the UU treatment deviated significantly more from the equilibrium than II subjects $(p < 0.01)$[4] Providing the groups with PIEDS influenced all group members and thus, the group averages of UU subjects deviate significantly more from the first equilibrium than II groups' averages $(p < 0.01)$. As revealed by the time usage UU subjects typed in their guesses in significantly less time than II subjects $(p < 0.01)$. Subjects of the UU treatment earned significantly less than II subjects $(p < 0.02)$. This is not obvious since the payment depends on individual choice distance to the average of a group. In period one UU subjects hold a significantly larger variance of the discrepancy of individual choices to the groups averages $(p < 0.02)$.[5] Hence, providing PIEDS has a significant impact on subjects' choice behavior already in the first round. We relate this to the acceptance, application and the trust into others accepting and applying the guessing game theory.

Effects remained significant if all periods are taken into account (see table 4). Subjects of the UU treatment revealed a higher choice deviation from the equilibria than II subjects $(p < 0.01)$. The groups' average choices in the UU treatment deviated more from the equilibria than II groups' average choices $(p < 0.01)$. Furthermore, uninformed subjects (UU) chose their guesses in less time than II subjects $(p < 0.01)$. The disadvantage of earning less than II subjects prevailed. The informed subjects earned more than UU subjects during all nine periods $(p < 0.01)$.

Providing subjects with PIEDS induced immediate changes in choice behavior. Thus, subjects projected the own choice onto the choice of similarly informed group members. PIEDS and $P.1$ and $P.2$ increased trust into the correct diagnose of others' choice behavior (Dawes (1988)). The advantage of informed as opposed to uninformed subjects emanate from the regular application and the trust into others to applicate PIEDS. Since informed subjects expected more choices to be close to equilibrium the variance of choices in groups decreased, leading to higher payoffs.

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[4] All tests are performed with an asymptotic Wilcoxon signed rank test, exceptions are made explicit.

[5] UU subjects hold an absolute variance of 286.74 while II subjects deviate significantly less from the group average (85.84)

4.2 Equilibrium behavior

Result 2 *Providing PIEDS induces a greater number of equilibrium choices.*

To disentangle possible learning effects from immediate theory absorption we analyze how often subjects use the equilibrium strategy. In the first period, II subjects chose the equilibrium significantly more often than UI and UU subjects ($p < 0.01$, resp. $p < 0.01$). The number of first period equilibrium hits in the UI treatment did not differ significantly from the number of UU treatment hits. We relate the high rates of first period equilibrium choices to the large number of students of economy and natural sciences. However, all informed subjects performed significantly ($p = 0.011$) better than uninformed subjects. Claiming PIEDS to be fully absorbable would require subjects to follow advice (i.e., eliminate strategies until further elimination will not grant higher payoffs) and not to deviate from it, thus, to stick to the theory, being satisfied with its predicted outcome. At least when knowing that all players have been informed about PIEDS (II), one ought to see an immediate jump to the equilibrium in the first and in all periods. This did not prove to be the case.[6]

Still, the significant differences in subjects' behavior among treatments indicate that actors actually perceive the reflexive character of the game theoretic propositions i.e., they can relate such propositions to the context they are facing. The knowledge of PIEDS induces them to modify their behavior. The way behavior is modified depends on the anticipation of other subjects' limited absorption capabilities and on mistrust whether participants appreciate the advice given. These modifications (the choice deviation from equilibrium) increased with the decrease of disseminated knowledge.[7]

Analyzing subjects' choice behavior over all periods suggests similar conclusions: in the II treatment, subjects hit the equilibrium significantly more often than UI ($p < 0.001$) and UU ($p = 0.003$) treatment subjects. Informing all UI subjects that half of them received just basic information, while the other half was informed about PIEDS, significantly reduced the overall equilibrium hits when compared to the number of hits in the UU treatment

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[6] In the first as well in all periods a binomial test revealed no constant equilibrium choice behavior of any subjects ($p < 0.001$).

[7] Average first period choice deviation from equilibrium of II: 5.53, UI: 9.97 and UU: 18.7

Table 3: Equilibrium choice behavior, where $*$ and $'$ mark significant differences ($p < 0.05$) to either UU ($*$) or UI ($'$) subjects

period	1	2	3	4	5	6	7	8	9	total
UU^*	15.63%	6.25%	6.25%	34.38%	3.13%	21.88%	12.50%	0.00%	0.00%	**11.11%**
UI'	12.50%	3.13%	28.13%	9.38%	6.25%	9.38%	6.25%	6.25%	3.13%	**9.38%**
II	43.75%*'	6.25%	59.38%	40.63%	6.25%	28.13%	9.38%	21.88%	12.50%	**25.35%*'**

($p < 0.001$). However, within the UI treatment the frequency of equilibrium choices was significantly higher among informed (21 equilibrium hits), as opposed to uniformed (6 equilibrium hits), subjects ($p < 0.001$).

Of the 432 choices made by the 48 uninformed subjects a total of 38 choices matched the equilibrium (8.79%). As much as 47.92% of these uninformed subjects failed to achieve a single equilibrium hit. Of the 48 informed subjects choosing a number in the 9 periods, there were in total 94 equilibrium hits (21.76%) and only 33.33% of the subjects failed to choose the equilibrium.

In relation to its frequency in the experiment, interior equilibria had been chosen significantly more often than border equilibria ($p < 0.001$). This indicates that interior solutions are easier to calculate and is consistent with former findings (Ho et al. (1998), Güth et al. (2002)). Differences in the frequencies of equilibrium choices among treatments can be seen in Figure 1.

By comparing uninformed and informed subjects' choices over all treatments, we conclude that providing PIEDS induces significantly more equilibrium choices ($p < 0.001$). Rejecting the hypothesis of equivalent equilibrium choice behavior between the II and the UU treatment in period one (over all periods) on the 1% (5%) level, suggests the cognitive capturing of PIEDS as a source of instant changes in choice behavior.

4.2.1 Partial theory absorption

Result 3 *Definite knowledge about the heterogeneous information structure of the group induces (un)informed UI subject to hold (lower) higher choice deviations from equilibrium, a (higher) similar time usage and (similar) lower profits than (UU) II subjects.*

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Figure 1: frequency of equilibrium hits

Relative frequency of equilibrium hits

□ border ■ interior
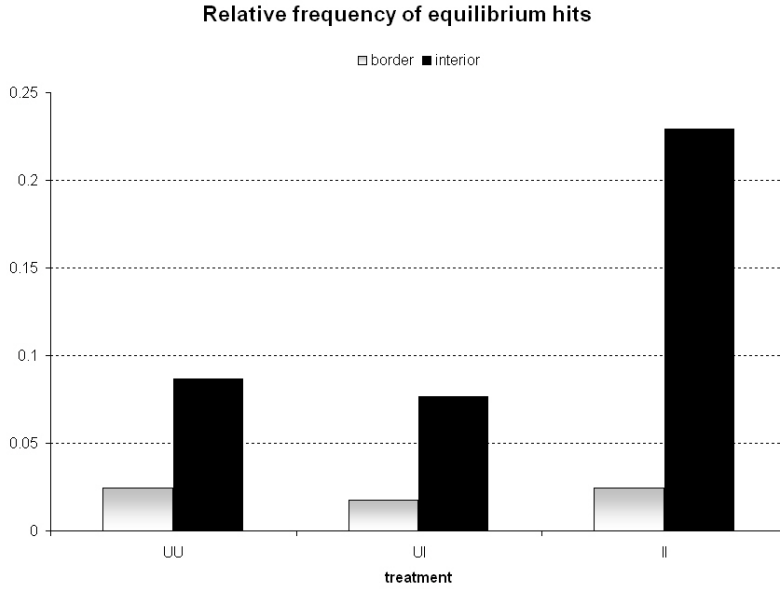
Having shown the influence of PIEDS by comparing the homogeneously (un)informed subjects we now analyze the deviation from these benchmark findings in the presence of heterogeneously informed subjects.

Analyzing period one (see table 2), informed UI subjects deviated significantly more from the equilibrium than II subjects ($p < 0.01$). On the other hand, first period choices of uninformed UI subjects differed not significantly from UU subjects' choices. Within the UI treatment both, informed and uninformed subjects, acted similarly. Again, aware of the presence of uninformed subjects informed UI subjects seemed to have anticipated large equilibrium deviations of their uninformed group mates and adapted their choices in the hope to sustain profits. Opposed to this cognitive adaptation, uninformed UI subjects acted similar to UU subjects. They required the same time to choose a guess. Considering PIEDS, their informed counterparts needed significantly more time to enter their choices ($p < 0.023$). Since the informed subjects entered slightly (but not significantly) lower numbers the deviations of UI groups' averages from equilibrium were significantly smaller than those of UU groups. As a matter of consequence profits of informed UI subjects were significantly smaller than the profits of II subject ($p < 0.03$). We did not observe any significant differences between uninformed UI and UU subjects nor between the UI subjects. Hence, when acting in heterogeneously informed groups subjects in possession

Table 4: All period results of subjects in UU, UI and II, where *, ′ and $^+$ mark significant differences ($p < 0.05$) respectively to UU (*), UI-U (′) or UI-I ($^+$)subjects

Treatment	Individual choice deviation from the equilibria			Groups' average choice deviation from the equilibria			Time per subject to choose a guess			Individual profit		
	0.25	0.5	0.75	0.25	0.5	0.75	0.25	0.5	0.75	0.25	0.5	0.75
UU*	8.38	19.9	33.00	11.94	18.50	26.91	16.75	24.00	36.00	0.00	24.57	38.20
UI-U′	8.00	17.00*	27.00	10.12	14.58 *	20.91	20.00	32.00 *	52.25	4.83	29.02*	39.33
UI-I$^+$	5.00	14.75 ′	25.00	10.12	14.58	20.91	26.00	43.50 ′	60.00	9.06	26.86	38.82
II	0.00	10.00*$^+$	25.00	7.42	10.96*$^+$	18.20	25.00	43.00*$^+$	64.00	9.17	30.84*$^+$	42.71

of PIEDS anticipated the mental limitations of uninformed group members, changed their choice behavior but still suffered profit losses compared to II subjects.

Table 4 takes all periods into account. We found that uninformed UI subjects - aware of the presence of informed subjects - deviated from the equilibrium significantly less than if they would in a homogeneously uninformed group ($p < 0.02$). With no theory to capture, this shall be a consequence of non-cognitive idea adaptation. Since we found evidence for this effect only by analyzing nine periods the non-cognitive adaptation seems to be based on an improvement of the individual heuristics or changes in the mental representation of outcomes. On the contrary, informed UI subjects were aware that a cognitive capturing of PIEDS by uninformed UI subjects was unlikely. Thus, partial theory absorption increased the likelihood of choice deviations from equilibrium, endangering profits. Therefore, an additional cognitive adaptation of PIEDS' advises arose, reflected by chosen numbers deviating significantly more from the equilibrium than II subjects' chosen numbers ($p < 0.05$). In addition, uninformed UI subjects performed worse than informed UI subjects, in terms of choice deviations from the equilibrium ($p < 0.05$). We, therefore, suggest uninformed UI subjects being the driving force behind higher group average deviations from equilibria of UI subjects compared to II subjects ($p < 0.012$). Still, the average deviations from equilibria were less intense than those of the UU groups ($p < 0.01$). Interestingly uninformed UI subjects needed more time typing in their choices than UU subjects ($p < 0.01$).This indicates that knowledge about partial theory distribution had an impact on the deliberation time of uninformed subjects, prompting them to think more intensively. Whilst informed UI subjects needed more time than their uninformed counterparts ($p < 0.01$) their time consumptions was lower than IIs' ($p < 0.05$). While we found similar profits within the UI treatment, uninformed UI subjects still earned more

than UU subjects ($p < 0.05$). However, we observed clear differences between informed UI and II subjects ($p < 0.05$).

While uninformed subjects adapted their choice behavior in mixed groups, without suffering losses (compared to the homogeneous uninformed group), informed subjects carried the burden of profit losses (compared to II subjects' profits). The payoff loss of informed subjects within a mixed informed group can be seen as a consequence of the uncertainty of uninformed subjects' choice behavior. Since uninformed UI subjects did not know PIEDS, we claim the excess time consumption and the smaller choice deviation from equilibrium compared to UU subjects to be an essentially non-cognitive adaption of behavior.

5   Conclusions

A theory can be considered fully absorbable if all decision makers follow a theory's advice, believe all other involved decision makers will do so, not violating assumptions of satisficing as made by the theory, and will not revise the recommended advise. It is considered as unilaterally absorbable if just one decision maker is in possession of the theory and the same assumptions are fulfilled. We used PIEDS as a unilateral absorbable theory to solve the guessing game and tested its application, informing a group not at all (UU), partially (UI) and fully (II) about it.

Solely providing the basic rules of the guessing game (UU) and mainly neglecting learning effects a more or less random choice behavior was revealed. Subjects chose numbers significantly closer to the equilibrium in II groups where PIEDS was explained to all in detail. Thus, suggesting that boundedly rational II subjects captured the principle and reflected its advises. This capturing and reflecting on PIEDS was observed at the very first period and at all periods. However, where we noticed a significant impact in terms of frequency of equilibrium hits, longer processing times, lower group average deviations from equilibrium and higher profits of II compared to UU subjects, the hypothesis of full theory absorption (i.e. all subjects stick to the theory, not revise the advise and immediately jump to the equilibrium) had to be rejected.

To satisfy their profit aspirations II subjects adapted their choices to the expected limitations of bounded rational group members. Thus, we link this to both: a cognitive capturing of PIEDS and the following cognitive adaptation of the theory's predictions.

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The knowledge about partial theory absorption decreased trust into UI group members' mental capabilities. Claiming informed UI subjects being able to capture PIEDS similarly to II subjects, they cognitively adapted its predictions even more in the presence of uninformed UI subjects in order to sustain profits. On the contrary, uninformed UI subjects could not reflect PIEDS but the presence of informed subjects in an essentially non-cognitive way. Consequently, they changed significantly their choice behavior. Compared to UU subjects, uninformed UI subjects required more time to deliberate and chose numbers closer to the equilibria if tracked over all periods. Therefore, the UI group averages deviated less from equilibria than UU group averages.

Hence, we link the partial absorption of PIEDS to a combination of non-cognitive ideas adaptation by uninformed subjects and cognitive alternations of the captured principle by informed subjects. The degree to which the theory's predictions are alternated depends on the level of known information dissemination. Clearly, in ex-ante partially informed groups, trust into the capabilities of cognitive capturing PIEDS is smaller than in fully informed groups. In those the slightest mistrust in the capturing capabilities - as it is natural in a bounded rational world - leads to revisions of PIEDS' predictions, thus to a violation of the assumptions of full theory absorption.

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6 Appendix

6.1 Instructions for the II treatment

Welcome to this experiment and thank you for your participation.

You are a member of a group consisting of eight persons. All group members have the same instructions like you. Each person of your group has to choose a number between 0 and 100 where 0 and 100 are possible as well. You can choose each number you like. Please note, that numbers with more than 2 decimals are excluded. The chosen numbers of your group members will remain unknown to you.

You can earn points in each round. Your payoff depends on how close your number is to a modification of the groups' average (target number). The closer your number is to a target number the higher is your payoff in points.

You can calculate you payoff in points this way:

$$\textbf{points per round = 50 - 2,5*} \left| your\ chosen\ number - \overbrace{q*(average + d)}^{target number} \right|$$
$$\underbrace{\hphantom{your\ chosen\ number - q*(average + d)}}_{distance}$$

At the begin of each round all group members choose a number simultaneously . The target number (modification of the average) is q times the average of your group members choices.

example:

- x_1 = your chosen number

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- $x_2 =$ the number chosen by the 2nd group member

- $x_3 =$ the number chosen by the 3rd group member

- $x_4 =$ the number chosen by the 4th group member
  $\vdots$

- $x_8 =$ the number chosen by the 8th group member

> The *average* is determined by: $\frac{x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8}{8}$
> The *target number* is defined as: $q*(average+d)$

where q and d may vary during the experiment. Both variables are presented to you on the screen before each round.

The difference between your chosen number and the target number might be bigger or smaller than zero. All what matters is the distance, that's why we take the absolute value of this difference.

Therefore, the *distance* is alway positive and determined by $|your\ chosen\ number\ -\ target\ number|$

Your payoff per round is: $50\ points - 2,5 * distance$

All explanations are summarized in the following formula:

$$\textbf{payoff per round = 50 - 2,5*}\ \underbrace{\left|your\ chosen\ number - \overbrace{q*average}^{target\ number}\right|}_{distance}$$

If the distance time 2.5 is bigger than 50 you will still receive 0 points. You might not earn additional points but you will never loose points.

At the end of each round you will receive information about your chosen number, the target number and your earnings.

After 9 periods the experiment ends and you'll receive recapitulating information about your payoffs. Payoffs are accumulated over all rounds and paid privately in cash. The transaction course is $1\,point = 2\,Cent$

additional tips:

1. To earn as many points as possible, you've got to guess which number is equal to $q * average + d$ of all chosen numbers. Choose this number.

2. Any number, chosen by all of the group members won't exceed 100. This means, the average won't exceed 100. The average+d (here $d = 50$) times q (here $q = 1/3$) is 50. Therefore, the number you should choose, should not exceed 50.

3. If all members of your group will realize this, everybody else will choose 50 and therefore, the average will be 50. Your number should again not exceed the average + d (100) times $q = 1/3$, which is 33.33 in order to earn as much points as possible.

4. If, again, all members of your group will realize this, everybody else will choose 33.33, therefore the average will be 33.33. Your number should again not exceed the average + d (83.33) times $q = 1/3$, which is 27.77 in order to earn as much points as possible. etc., etc.

5. If you and every group member will think this way, everybody will realize that the optimal number to be chosen is 25. This number will ensure the maximum payoff of 0.5 Ă per round.

Remember, all group members received these additional tips. All know as well, that all received these tips.

Please answer some controll questions before starting the experiment. This ensures the understanding of the rules of this experiment. Please remain seated during all the time.

If you have questions, please raise your hand. Your question will be answered privately .
Please wait for further instructions at the end of the experiment!

controll questionnaire

Assume, you chose 24, the other group members chose 21, 66, 100, 91, 73 and 23.

1. Calculate the average.

2. What is the target number if $q = 2/3$ and $d = 0$?

3. How big is the distance to your number?

Assume, you chose 54, the average of what the other group members chose is 78.

1. Calculate the average including your number.

2. What is the target number if $q = 2/3$ and $d = 0$?

3. How much would you earn if $q = 2/3$ and $d = 25$?

In the previous round the parameter had been $d = 0$ and $q = 1/3$. Now, $d = 50$ and $q = 1/3$. What phrase you consider to be true?

1. The groups' average plus d increases.

2. The target number decreases.

3. No statement possible.

6.2   Instructions for the UU treatment

Welcome to this experiment and thank you for your participation.

You are a member of a group consisting of eight persons. All group members have the same instructions like you. Each person of your group has to choose a number between 0 and 100 where 0 and 100 are possible as well. You can choose each number you like. Please note, that numbers with more than 2 decimals are excluded. The chosen numbers of your group members will remain unknown to you.

You can earn points in each round. Your payoff depends on how close your number is to a modification of the groups' average (target number). The closer your number is to a target number the higher is your payoff in points.

You can calculate you payoff in points this way:

$$\textbf{points per round} = \textbf{50 - 2,5*} \left| your\ chosen\ number - \overbrace{q * (average + d)}^{targetnumber} \right|$$

$$\underbrace{}_{distance}$$

At the begin of each round all group members choose a number simultaneously . The target number (modification of the average) is q times the average of your group members choices.

example:

- x_1 = your chosen number

- x_2 = the number chosen by the 2nd group member

- x_3 = the number chosen by the 3rd group member

- x_4 = the number chosen by the 4th group member
  $\vdots$

- x_8 = the number chosen by the 8th group member

> The *average* is determined by: $\frac{x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8}{8}$
> The *target number* is defined as: $q^*(average+d)$

where q and d may vary during the experiment. Both variables are presented to you on the screen before each round.

The difference between your chosen number and the target number might be bigger or smaller than zero. All what matters is the distance, that's why we take the absolute value of this difference.

Therefore, the *distance* is alway positive and determined by $|your\ chosen\ number\ -\ target\ number|$

Your payoff per round is: $50\ points - 2,5*distance$

All explanations are summarized in the following formula:

$$\textbf{payoff per round} = \textbf{50 - 2,5*} \underbrace{\left| your\ chosen\ number - \overbrace{q*average}^{target\ number} \right|}_{distance}$$

If the distance time 2.5 is bigger than 50 you will still receive 0 points. You might not earn additional points but you will never loose points.

At the end of each round you will receive information about your chosen number, the target number and your earnings.

After 9 periods the experiment ends and you'll receive recapitulating information about your payoffs. Payoffs are accumulated over all rounds and paid privately in cash. The transaction course is $1\,point = 2\,Cent$

Remember,all of your group members have the same information like you. All know as well, that all received the same information.

Please answer some controll questions before starting the experiment. This ensures the understanding of the rules of this experiment. Please remain seated during all the time. If you have questions, please raise your hand. Your question will be answered privately . Please wait for further instructions at the end of the experiment!

6.3   Instructions for the UI treatment / informed subjects

Welcome to this experiment and thank you for your participation.

You are a member of a group consisting of eight persons. All group members have the same instructions like you. Each person of your group has to choose a number between 0 and 100 where 0 and 100 are possible as well. You can choose each number you like. Please note, that numbers with more than 2 decimals are excluded. The chosen numbers of your group members will remain unknown to you.

You can earn points in each round. Your payoff depends on how close your number is to a modification of the groups' average (target number). The closer your number is to a target number the higher is your payoff in points.

You can calculate you payoff in points this way:

$$\textbf{points per round = 50 - 2,5*} \; \underbrace{\left| your\ chosen\ number - \overbrace{q*(average+d)}^{targetnumber} \right|}_{distance}$$

At the begin of each round all group members choose a number simultaneously . The target number (modification of the average) is q times the average of your group members choices.

example:

- $x_1 = $ your chosen number

- $x_2 = $ the number chosen by the 2nd group member

- $x_3 = $ the number chosen by the 3rd group member

- $x_4 = $ the number chosen by the 4th group member
  $\vdots$

- $x_8 = $ the number chosen by the 8th group member

> The *average* is determined by: $\frac{x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8}{8}$
>
> The *target number* is defined as: $q*(average+d)$

where q and d may vary during the experiment. Both variables are presented to you on the screen before each round.

The difference between your chosen number and the target number might be bigger or smaller than zero. All what matters is the distance, that's why we take the absolute value of this difference.

Therefore, the *distance* is alway positive and determined by $|your\ chosen\ number - target\ number|$

Your payoff per round is: $50\ points - 2,5 * distance$

All explanations are summarized in the following formula:

$$\textbf{payoff per round = 50 - 2,5*} \left| your\ chosen\ number - \overbrace{q * average}^{target\ number} \right|$$

$$\underbrace{}_{distance}$$

If the distance time 2.5 is bigger than 50 you will still receive 0 points. You might not earn additional points but you will never loose points.

At the end of each round you will receive information about your chosen number, the target number and your earnings.

After 9 periods the experiment ends and you'll receive recapitulating information about your payoffs. Payoffs are accumulated over all rounds and paid privately in cash. The transaction course is $1\ point = 2\ Cent$

additional tips:

1. To earn as many points as possible, you'tve got to guess which number is equal to $q * average$ of all chosen numbers. Choose this number.

2. Any number, chosen by all of the group members won'tt exceed 100. This means, the average won'tt exceed 100. The average times q is $66,67$ if $q = 2/3$. Therefore the number you should choose, should not exceed $66,67$.

3. If all members of your group will realize this, everybody else will choose $66,67$ and therefore the average will be $66,67$. Your number should again not exceed the average times $q = 2/3$, which is $44,45$ in order to earn as much points as possible.

4. If again all members of your group will realize this, everybody else will choose $44,45$, therefore the average will be $44,45$. Your number should again not exceed the average times $q = 2/3$, which is 29.63 in order to earn as much points as possible. etc., etc.

5. If you and every group member will think this way, everybody will realize that the optimal number to be chosen is 0. This number will ensure the maximum payoff of 0.5 Ă per round.

Out of you group 4 subjects (including you) received the instructions and these additional tips. The four remaining group members know just the instructions but not the additional tips. All persons of your group know as well, that there are four members holding additional information and four knowing just the basic instructions.

Please answer some controll questions before starting the experiment. This ensures the understanding of the rules of this experiment. Please remain seated during all the time. If you have questions, please raise your hand. Your question will be answered privately . Please wait for further instructions at the end of the experiment!

6.4   Instructions for the UI treatment / uninformed subjects

Welcome to this experiment and thank you for your participation.

You are a member of a group consisting of eight persons. All group members have the same instructions like you. Each person of your group has to choose a number between 0 and 100 where 0 and 100 are possible as well. You can choose each number you like. Please note, that numbers with more than 2 decimals are excluded. The chosen numbers of your group members will remain unknown to you.

You can earn points in each round. Your payoff depends on how close your number is to a modification of the groups' average (target number). The closer your number is to a target number the higher is your payoff in points.

You can calculate you payoff in points this way:

$$\textbf{points per round} = \textbf{50 - 2,5*} \left| \textit{your chosen number} - \overbrace{q * (\textit{average} + d)}^{\textit{targetnumber}} \right|$$

$$\underbrace{\qquad\qquad\qquad\qquad\qquad\qquad\qquad}_{\textit{distance}}$$

At the begin of each round all group members choose a number simultaneously . The target number (modification of the average) is q times the average of your group members choices.

example:

- x_1 = your chosen number

- x_2 = the number chosen by the 2nd group member

- x_3 = the number chosen by the 3rd group member

- x_4 = the number chosen by the 4th group member
  $\vdots$

- x_8 = the number chosen by the 8th group member

The *average* is determined by: $\frac{x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8}{8}$

The *target number* is defined as: $q*(average+d)$

where q and d may vary during the experiment. Both variables are presented to you on the screen before each round.

The difference between your chosen number and the target number might be bigger or smaller than zero. All what matters is the distance, that's why we take the absolute value of this difference.

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Therefore, the *distance* is alway positive and determined by $|your\ chosen\ number\ -\ target\ number|$

Your payoff per round is: $50\ points - 2,5 * distance$

All explanations are summarized in the following formula:

$$\textbf{payoff per round} = \textbf{50 - 2,5*}\ \underbrace{\left| your\ chosen\ number - \overbrace{q * average}^{target\ number} \right|}_{distance}$$

If the distance time 2.5 is bigger than 50 you will still receive 0 points. You might not earn additional points but you will never loose points.

At the end of each round you will receive information about your chosen number, the target number and your earnings.

After 9 periods the experiment ends and you'll receive recapitulating information about your payoffs. Payoffs are accumulated over all rounds and paid privately in cash. The transaction course is $1\ point = 2\ Cent$

Out of your group all eight members (including you) received these basic instructions. But four group members (not you) received additional information concerning the course of the game (tips). All subjects know as well, that there are four members holding additional information and four knowing just the basic instructions.

Please answer some controll questions before starting the experiment. This ensures the understanding of the rules of this experiment. Please remain seated during all the time. If you have questions, please raise your hand. Your question will be answered privately . At the end of the experiment please wait for further instructions!