Trading Participation Rights to the “Red Hat Puzzle”. An Experiment

Choo, Lawrence C.Y

University of Exeter

6 May 2014

Trading Participation Rights to the "Red Hat Puzzle". An Experiment[*]

Lawrence C.Y Choo [†]

This Version: May 2014

Abstract

This paper investigates the conventional wisdom that markets should allocate the rights for performing decisional tasks to those players who might be best suited to perform the task. We embed the decisional tasks in a stylised setting of a game, motivated by Littlewood (1953) Red Hat Puzzle, where the optimal choices in the game require players to employ logical and epistemological reasoning. We present a treatment where players are permitted to trade their participation rights to the game. The payoffs are furthermore calibrated such that those players who know the optimal choices in the game should value the participation rights strictly more than those who do not. However, aggregated performances in this treatment were found to be significantly lower than the control treatments where players were not permitted to trade their participation rights, providing little support for the conventional wisdom. We show that this finding could be attributed to price "bubbles" in the markets for participations rights.

Keywords: *Game Theory, Trading Markets, Experimental Economics, Red Hat Puzzle*
JEL Classifications: *C92, C72, G02, G12*

Most societies integrate markets where economic players are able to buy and sell the "rights" for performing decisional tasks. An early example from the 17th to 19th centuries, is the British Army's purchase system, where commissioned ranks and responsibilities were sold at pre-determined prices (Bruce, 1980; Brereton, 1986). A more recent example, is the market for corporate governance, where managers compete for the rights to manage the corporate resources of a targeted firm (Jensen and Ruback, 1983). The *conventional wisdom* in the above examples is the idea that markets, when properly structured, should allocate the rights for performing decisional tasks, to those players who are best suited to perform the task. This paper presents an experimental design that puts the conventional wisdom to the test.

[*]We are grateful to Todd R. Kaplan, Miguel A. Fonseca, Shyam Sunder, Peter Bossaerts, Elena Asparouhova, the conference participants of Experimental Finance Tilburg 2013 and ESA World Meetings 2013, for their valuable suggestions and comments. We acknowledge the financial support from the University of Exeter Business School.

[†]Department of Economics, University of Exeter Business School, Rennes Drive, Exeter EX4 4PU, United Kingdom. *cylc201@exeter.ac.uk*

To do so, we embed the decisional tasks in the stylised setting of a game, motivated by Littlewood (1953) "Red Hat Puzzle", a well known logical reasoning problem.[1] In our TRADE treatment, markets are introduced by allowing players to trade their participation rights to the game. Here, players who sold their participation rights are compensated by the sales revenue for avoiding the decisional tasks in the game. Players who purchased additional rights will enter the game and their payoffs will depend on their behaviours in the game, multiplied by the number of rights owned. Thus by buying over another player's rights, one also buys over the other player's potential payoffs in the game.[2]

To the best of our knowledge, this is the first such paper that involves a design where players are permitted to trade their participation rights. We shall hence focus on some attractive features of the game that are ideal for purposes of our study. As the equilibrium analysis will show, the *optimal choices* in the game are (i) Pareto optimal for all players in the game (in expectations), (ii) Non-trivial nor obvious and requires players to employ logical and epistemological reasonings, and (iii) Independent of the number of participation rights owned or the ability to trade participation rights.

Point (ii) is central to the research question of this paper. Since the decisional tasks in the game requires players to employ logical and epistemological reasoning, therefore players' *sophistication* (e.g., strategic thinking abilities, cognitive reasoning abilities, problem solving skills) will be integral to them knowing the optimal choices. This naturally partitions the population of players into the *Sophisticated types* - those who have sufficient sophistication to know the optimal choices in the game - and the *Unsophisticated types* - those who have insufficient sophistication to ever know the optimal choices in the game. Point (i) suggests that the expected payoffs for participating in the game should be strictly higher for the Sophisticated types relative to the Unsophisticated types. When presented the opportunity to trade participation rights, it should therefore be incentive compatible for Sophisticated types to purchase rights and Unsophisticated types to sell their rights.[3] Aggregate performances in the TRADE treatment will therefore be a function of the number of players who had adhered to the optimal choices, weighted by the participation rights owned by those players. Finally, point (iii) suggest that aggregated performances in TRADE can be contrasted to the control treatments where players are not permitted to trade their participation rights to the game.

The conventional wisdom introduced at the start of this paper is for markets to allocate the rights for performing decisional tasks, to those players who are best suited to perform the task, in this case the Sophisticated types. We provided an environment in TRADE, where this should be

[1]The Red Hat Puzzle and its variations are commonly found in most graduate level game theory textbooks (e.g., Fudenberg and Tirole, 1993; Myerson, 1997; Osborne and Rubinstein, 1994; Maschler et al., 2013), discussions about common knowledge (Geanakoplos and Polemarchakis, 1982; Geanakoplos, 1994) and epistemological reasonings (Fagin et al., 1995).

[2]The TRADE treatment can be viewed as an asset trading market where the redemption value of the asset depends on the behaviours of the owner in a game.

[3]The difference in sophistications side-steps Milgrom and Stokey (1982) no-trade theorem, as both the Sophisticated and Unsophisticated types can have expected gains from trade.

possible. Therefore, if the conventional wisdoms holds, we should expect the aggregated performances in TRADE to be significantly higher than the control treatments.

The rest of this paper is organised as followed. Section I provides an overview of the related literature, Section II presents our experimental design and discusses the equilibrium analysis, Section III presents our test hypotheses, Section IV details our experimental procedures, Section details our experimental results and finally, Section VI concludes.

I. Related Literature

This paper draws from two distinct areas of research. The first pertains to previous experimental adaptions of the Red Hat Puzzle by Weber (2001) and Bayer and Chan (2007) and the second, developments in behavioural finance.

To describe the former area of research, we shall first present an illustration of the Red Hat Puzzle. Three girls, each wearing a coloured hat - red or black, were seated around a circle. Each girls sees all other hats but her own - all hats are black. An observer remarks that "there is at least one black hat" and asked the first girl if she knew the colour of her hat, to which she replied (publicly) with "No". The observer asked the second girl who also replied with "No". However, when the observer asked the third girl, she replied with "Black". How did the third girl know her hat colour?

To see how, first consider the case where only the first girl was wearing a black hat. Here, the first girl would immediately reply with "Black" since she does not see any other black hats. The second girl reasons that the first girl must have observed no other black hats, and replies with "Red". The same logic applies to the third girl. Now consider the case where the first and second girls were wearing black hats. The first girl remains uncertain and replies with "No". The second girl reasons that the first girl must have seen another black hat and replies with "Black". The third girl reasons that the second girl must have only seen one other black hat (the first girl's hat) and replies with "Red". Now returning to the initial illustration, the third girl observed that the second girl had replied with "No". She therefore reasons, that the second girl must have seen two black hats, and deduced her own hat to be black.

Each girl in the above illustration faces the decisional task of ascertaining her own hat colour, and she does so through a process of logical and epistemological reasoning. Geanakoplos and Polemarchakis (1982) described such a process as one of *indirect communication*, where each girl through their replies, communicate some information about their posteriors with regards to the true state of nature. Notice that the task for each girl becomes more complex and challenging as the number of black hats observed increases. For these reasons, players' sophistications are integral in them resolving their hats' colour.

Given these features, Weber (2001, experiment 2) and Bayer and Chan (2007) used the Red Hat Puzzle (neutral framing) to study level-k (Nagel, 1995; Stahl and Wilson, 1994, 1995; Costa-Gomes et al., 2001) reasoning behaviours. To do so, they converted the problem into a multi-period simultaneous choice game involving $n = 2, 3$ coloured hats. Players began the game observing $b \in \{0, 1, .., n-1\}$ black hats and could only choose from the actions "No" or "Black" at each period $t = 1, 2, .., n+1$. The game ends for all players at any period whereby a player chooses "Black". The optimal choices - we will detail this in the later sections - in the game are for players to choose "No" at all periods $t < b+1$ and "Black" at period $t = b+1$. Weber's research focused on the aggregated rate of adherence to the optimal choices.[4] In his $n = 3$ hat treatment, at instances where subjects where subjects observed $b = 0$ black hats, the adherence rate was unity. However, the adherence rates were observed to fall significantly as b increases.[5,6] Although subjects' behaviours in this paper may involve elements of level-k reasoning, we will omit such discussions as they divert attention from the main area of interest. Nevertheless, Weber's experiments point to heterogeneity in subjects' sophistications with respect to their behaviours in the Red Hat Puzzle. Assuming that the population of subjects can be partitioned into Sophisticated types and Unsophisticated types, the interest in this paper is whether markets would result in the participation rights being purchased by the Sophisticated types.

In a separate area of research, Kluger and Wyatts (2004) presented an innovative experimental design to study the behavioural arguments (De-Bondt and Thaler, 1985; Hirshleifer, 2001; Shleifer, 2000) that heterogeneity in traders' sophistications could explain market-wide anomalies. To do so, they embedded the Monty Hall problem into an asset market experiment.[7] Their design can be summarised with the following thought experiment. Assume that there exist an asset that allows you to switch doors in the Monty Hall problem for a winning prize of \$100 - after you had made your initial choice and the non-prize door is opened. A Unsophisticated type would wrongly judge the probability of winning the prize through switching doors at 1/2 and value the asset at \$50. A Sophisticated type would realise that the probability of winning the prize through switching doors is in fact 2/3 and value the asset at \$67. Focusing on mean prices, Kluger and Wyatts (2004) found that when all subjects in the market (6 subjects each market) were Unsophisticated - as judge by their behaviours in the Monty Hall problem, the mean price in the market was close to 50. However, when there were at least two Sophisticated subjects in the market, the mean price was close to 67.[8] The Monty Hall problem is of course slightly different to the decisional task proposed

[4]Given that in Weber (2001) experiments, the game ends at any period whereby a player chooses "Black", this presents an interesting problem in classifying behaviours at instances where the game had ended prematurely. To overcome this problem, Weber considered a player to have adhered to the optimal choices, if he had not deviated at the period which the game had ended.

[5]Weber (2001) results could be of independent interest as his subject pool included Caltech undergraduate and graduate students. Caltech students are often known for their skills in logical reasoning problems (Camerer, 2003).

[6]Bayer and Chan (2007) results are slightly more difficult to interpret as they reported on "rationalizable behaviours". Such behaviours might also include those that are inconsistent with the optimal choices.

[7]The Monty Hall problem is from the TV gameshow "Let's Make A Deal" where the Host, Monty Hall, hides a winning prize behind three closed doors. A contestant is invited to choose one of the doors to open, but before doing so, Monty is committed to opening a non-prize door. Thereafter Monty presents the contestant the opportunity to switch their choice to the other unopened door. The dominant strategy here is for the contestant to always switch since the probability of winning the prize by doing so is 2/3.

[8]Kluger and Wyatts (2004) suggest that their findings were due to Bertrand competition between two Sophisticated subjects. This explanation is challenge by Asparouhova et al. (2012) who questioned why Unsophisticated subjects do not participate in the Bertrand competition, and if they do so, why wouldn't prices converge to the *incorrect*

in this paper, since it does not involve strategic interactions. Their research also did not focus on the allocation of assets but suggest that players' sophistications could be determinants of their pricing behaviours.

II. Experimental Design & Equilibrium Analysis

Three treatments are considered in this paper, BASE1, BASE2 and TRADE. However, only in TRADE were players allowed to trade their participation rights to the game. To motivate the experimental design, we will first present a generalised framework that is applicable to all treatments. Thereafter, we will show how the treatments vary and finally, the equilibrium analysis of each treatment.[9]

A. *The Generalised Framework*

In the generalised framework, *tokens* will represent players' participation rights to the game. There are two distinct stages, the pre-game stage, where players trade tokens, followed by the game stage, where players perform the decisional tasks in the game. Let $1_G \in \{0, 1\}$ be an exogenous parameter that determines if players are permitted to enter the pre-game stage. The generalised framework will begin with following parameters.

There are $N = \{1, 2, ..., n\}$ set hats with $M = \{1, 2, ..., m\}$ set members under each hat. Let player i_j refer to the $j \in M$ member of hat $i \in N$. Nature chooses the true state $s \in S \equiv \times_{i \in N} H_i \setminus \{R_1, R_2, ..., R_n\}$, where $H_i \in \{B_i, R_i\}$ denotes hat i's colour - Black(B) and Red(R). There exist a common prior over S where each state $s' \in S$ is equally likely. For any state $s \in S$, denote $Y(s) = \{1, 2, .., y\} \subseteq N$ as the set of B hats.

Each player observes all other hats' colour but his own. Denote $b_{i_j}(s) \in \{0, 1, 2, ..., n-1\}$ as the total number of B hats that player i_j observes for any $s \in S$ - this refers to player i_j's private information.[10] In addition, players are also publicly informed that the true state consist of *"at least one B hat"*. Since players under the same hat must make the same observations, $b_{i_j}(s) = b_{i_{j'}}(s) = b_i(s)$ for any $j, j' \in M$, $i \in N$ and $s \in S$. Finally, each player is endowed with one *token* and a working capital of $\bar{L} \gg 0$, issued as an interest-free loan.

A.1. The Pre-Game Stage

Players only enter the pre-game stage if $1_G = 1$. Here, players are allowed to trade tokens but only with those other players under the same hat. This results in n markets in simultaneous

equilibrium.

[9]Due to the treatments considered in this paper, the experimental design involves features that are different from those previous experiments by Weber (2001) and Bayer and Chan (2007). Thus direct comparisons to their results will not be prudent.

[10]Alternatively, one could employ Aumann (1999) *sematic* approach where each player's knowledge of the true state is represented by the information partition $\mathcal{P}_{i_j}$ over S. Such an approach might be more precise but it makes the discussion more taxing with no obvious benefits. Nevertheless, the analysis will be identical.

Table I. Generic Token Redemption Rate (β_{i_j}) for Each Player i_j

	$H_i = B_i$	$H_i = R_i$
$e_{i_j} = a_b$	$\mu - \delta(t_{i_j} - 1)$	$\mu - \delta(t_{i_j} - 1) - \alpha$
$e_{i_j} = a_r$	$\mu - \delta(t_{i_j} - 1) - \alpha$	$\mu - \delta(t_{i_j} - 1)$

operations. In the absence of short-sales, let $p_i \geq 0$ denote the token transaction price in market $i \in N$, $x_{i_j} \in \{0, 1, 2, ..., m\}$ denote player i_j's after transaction inventory of tokens and $L_{i_j} \geq 0$ denote player i_j's after transaction holding of capital. Assume that token inventories are public information and $\bar{L}$ is sufficiently large to never be binding. If $x_{ij} = 0$, players' payoffs are immediately computed - to be discussed later.

A.2. The Game Stage

Only players with *at least one token* ($x_{ij} > 0$) may enter the game stage, where they each face the decisional task of resolving their hats' colour. There are $t = 1, 2, .., n+1$ discrete periods, where at each period $t < n + 1$, players are simultaneously presented with the question *"Do you know your hat colour?"*, to which they must independently and simultaneously reply with the following actions: "My Hat is R" (a_r), "My Hat is B" (a_b) or "No, I don't Yet Know" (a_n). The rules are such that each player (and that player only) ends the game stage at the period t_{i_j} whereby the action $e_{i_j} \in \{a_r, a_b\}$ was chosen. This implies that players only proceed to the next period if he had chosen a_n in the previous period. To ensure that all players must eventually end the game stage, players can only choose from the actions a_b and a_r if they make it to the $n+1$ period. Finally, any action chosen in period t will be public information in period $t + 1$.

A.3. Payoffs

Players' payoffs (Π_{i_j}) are computed when they have either ended the pre-game stage with $x_{i_j} = 0$ tokens or ended the game stage with choosing $e_{i_j} \in \{a_r, a_b\}$. Here, the true state of nature is revealed, the players' loans ($\bar{L}$) are repaid and their tokens are each redeemed at the heterogenous rate $\beta(\mu, \delta, \alpha, H_i, t_{i_j}, e_{i_j}) \geq 0$ - in a slight abuse of notation I will write $\beta(\mu, \delta, \alpha, H_i, t_{i_j}, e_{i_j})$ as β_{i_j}. Table I depicts the generic tokens redemption rate for each player i_j, where $\mu > (1/2)\alpha > (n+1)\delta > 0$. The redemption rate can be summarised as followed. Each token has an initial value of μ that decreases by δ each time the player chooses a_n. In addition, the token's value decreases by α if he had incorrectly guessed his hat colour - choosing a_b (a_r) if $H_i = R_i$ ($H_i = B_i$). The payoffs are therefore determined as[11,12]

$$\Pi_{i_j} = \begin{cases} (L_{i_j} - \bar{L}) + \beta_{i_j} x_{i_j} = \beta_{i_j} & \text{if } 1_G = 0 \text{ \& } x_{i_j} = 1 \\ (L_{i_j} - \bar{L}) + \beta_{i_j} x_{i_j} = p_i + (\beta_{i_j} - p_i) x_{i_j} & \text{if } 1_G = 1 \text{ \& } x_{i_j} > 0 \\ (L_{i_j} - \bar{L}) = p_i & \text{if } 1_G = 1 \text{ \& } x_{i_j} = 0 \end{cases} \tag{1}$$

This completes the description of the generalised framework.

B. How the Treatments Vary

When $1_G = 1$ and $m \geq 1$, players enter a market (pre-game stage) where they trade their participation rights (tokens) for performing the decisional tasks in the game stage. Since the markets in the pre-game stage will only consist of those players under the same hat, they must have the same information ($b_i(s)$) and are hence "competing" for the same decisional task. Players who sold their tokens are compensated by the sales revenue (p_i) for avoiding the game stage. And since players' tokens are redeemed at the end of the treatment, purchasing another players' tokens not only buys over his participation rights, but also his potential payoffs in the game.

For any fixed $n \geq 2$, variations in the generalised framework can be achieved by specifying the number of members under each hat ($m \geq 1$) and whether players are permitted to enter the pre-game stage (1_G). The three treatments are differentiated as followed:

BASE1: $n = 3$, $m = 1$ and $1_G = 0$.
BASE2: $n = 3$, $m = 6$ and $1_G = 0$.
TRADE: $n = 3$, $m = 6$ and $1_G = 1$.

Players in BASE1 and BASE2 hence always enter the game stage with exactly one token. BASE1 refers to the primitive description of the Red Hat Puzzle. TRADE is the central interest of this paper, where players are permitted to trade their participation rights to performing the decisional tasks in the game stage. Since TRADE and BASE1 differ on both m and 1_G, BASE2 was introduced to control for any potential difference that might be driven by changes in m.[13]

C. Equilibrium Analysis

The following assumptions are made in the equilibrium analysis (a) All players are risk-neutral, (b) There is common knowledge of *Rationality* and (c) There is common knowledge of *Sophistication.* Adapting Myerson (1997, p.2) description of players, we refer to rational players as those who seek to maximise their own payoffs, and sophisticated players as those who knows everything

[11]When $1_G = 0$, we must have it that $\bar{L} = L_{i_j}$ and $x_{i_j} = 1$ since players are not permitted to enter the pre-game stage.

[12]Since players are each endowed with one token, their net transactions in the pre-game stage can be denoted as $v_{i_j} = x_{i_j} - 1$, where the market clearing conditions require that $\sum_j v_{i_j} = 0$ for all $i \in N$. As such, we can rewrite players' holding of capital as $L_{i_j} = \bar{L} - p_i v_{i_j}$.

[13]Physical limitations in the laboratory restrict the BASE2 and TRADE treatments to six players under each hat.

there is to know about the game and makes the same logically conclusions as a designer of the game would make. Given these assumptions, players may start the treatment uncertain of their hats' colour, but they would always know the process of ascertaining their hats' colour in the game stage. We will first detail the equilibrium analysis of BASE1 and thereafter extend the discussions to BASE2 and TRADE. Finally, the equilibrium payoffs will be derived for all treatments.

C.1. Equilibrium Analysis of BASE1

Players enter the game stage with exactly one token and seek to maximise their token redemption rate since $\Pi_{i_j} = \beta_{ij}$. To show the optimal choices, it is useful to first identify the dominant action at each period t for players who are certain and uncertain of their hats' colour. In the former case, the dominant action is obvious, choose a_b or a_r if they know their hats to be B or R respectively - choosing a_n incurs an additional "cost" of δ with no obvious benefits. The dominant action in the latter case is less obvious. By Bayes rule, uncertain players must hold equal posterior to being under either hat colours - this will be clearer in the later discussions. Here, players at period t face an inter-period tradeoff between (OptionA) Ending the game stage with $e_{i_j} \in \{a_b, a_r\}$ and (OptionB) Choosing a_n and ascertaining their hats' colour at some later period $t' = t+1, t+2, .., n+1$. The expected token redemption rate with OptionA and OptionB are $\mu - \delta(t-1) - (1/2)\alpha$ and $\mu - \delta(t'-1)$ respectively. Given that $(1/2)\alpha > (n+1)\delta$, OptionA will always be dominated by OptionB for any $t' = t+1, t+2, .., n+1$. Therefore uncertain players should always choose a_n.

We are now in the position to describe the *indirect communication* (Geanakoplos and Polemarchakis, 1982) process by which players ascertain their hats' colour. For this we return to the illustration introduced in Section I where $n = 3$ and $s = \{B_1, B_2, B_3\}$. Each player begins period 1 of the game stage observing $b_i(s) = 2$ and remains uncertain. Since each state in S is equally likely, players applying Bayes rule must assign equal posterior to being under either hat colours. Given the public announcement, it can only be common knowledge that there is *at least one B hat*.[14] However, each player privately knows there to be at least two B hats. Uncertain players in period 1 thus choose a_n. At period 2, having observed the public information - the previous period's actions, each player reasons that if there was only one B hat, then some player must have observed no B hats, ascertained his hat's colour to be B and choose a_b in period 1. Since no one had done so, there cannot be only one B hat in the true state. Of course each player already knew this and there should be no revisions to their posteriors. Again uncertain players choose a_n. Finally at period 3, given the public information, each player reasons that if there were only two B hats, then some players must have observed one other B hats, ascertained their hats' colour to be B, and choose a_b in period 2. Since no player had done done so, there cannot be only two B hat in the true state and given that $b_i(s) = 2$, each player ascertains their own hat to be B. Players thus choose a_b in period 3 and their tokens are each redeemed at the rate $\mu - 2\delta$.

The above discussions can be extended to any $n \geq 2$ coloured hats and the equilibrium prediction

[14] Alternatively, Aumann (1976) agreement theorem, show that the only event in S which can be commonly knowledge must include the entire states of nature S.

is for players to ascertain their own hat colour at period $b_i(s)+1$. The *optimal choices* in the game stage are for players to choose a_n at all periods $t < b_i(s)+1$, and at period $b_i(s)+1$, choose a_b if $i \in Y(s)$ and a_r if $i \notin Y(s)$. Adherence to the optimal choices will result in players' token being redeemed at the Pareto optimal equilibrium rate $\beta^*_{i_j} = \mu - b_i(s)\delta$.

Notice role that the common knowledge assumptions play in the equilibrium discussions. If they are not met, players cannot exclude the possibility that an action chosen by some other player is due to unsophisticated or irrational behaviours. However, given that adherence to the optimal choices is Pareto optimal, each player should strictly prefer the common knowledge assumptions to be met.

C.2. Equilibrium Analysis of BASE2

BASE2 only differs from BASE1 in the number of players under each hat. However, players under each hat have the same private information ($b_i(s)$), face the same decisional task and choose their actions both independently and simultaneously. This implies that the optimal choices for each player must be identical at all periods, for players under the same hat: Choose a_n at all periods $t < b_i(s)+1$, and at period $b_i(s)+1$, choose a_b if $i \in Y(s)$ and a_r if $i \notin Y(s)$. Thus, increasing the number of players under each hat, has no implications on the optimal choices in the game stage and adherence will result in tokens being redeemed at the Pareto optimal rate $\beta^*_{i_j} = \mu - b_i(s)\delta$.

C.3. Equilibrium Analysis of TRADE

TRADE only differs from BASE2 on the availability of the pre-game stage. Hence, the equilibrium predictions in TRADE will pertain to the equilibrium prices in markets $i \in N$ of the pre-game stage and the optimal choices in the game stage. To show the equilibrium predictions in TRADE, we will first begin with the game stage and thereafter work backwards to the pre-game stage.

Players in TRADE enter the game stage with $x_{ij} \geq 1$ tokens. The equilibrium discussions in BASE2, suggest that the number of players under each hat has no influence on the optimal choices. How about the token ownerships? The answer as it turns out is no. This is because if adherence to the optimal choices is Pareto optimal for players with one token (as in BASE1 and BASE2), it must also be Pareto optimal for players with more than one token.

By backward deduction, players in the markets of the pre-game stage observing $b_i(s)$ should expect to ascertain their hats' colour in period $b_i(s)+1$ of the game stage. Given the token redemption structure, whatever colour it may be, players should hence expect their tokens to be redeemed at $\beta^*_{i_j} = \mu - b_i(s)\delta$ and by this logic, should only purchase additional tokens at prices $p_i \leq \mu - b_i(s)\delta$ or sell tokens at $p_i > \mu - b_i(s)\delta$. Since players only trade tokens with the other players under the same hat, this establishes the equilibrium price $p^*_i = \beta^*_{i_j} = \mu - b_i(s)\delta$ in each market $i \in N$, where players are indifferent between buying or selling tokens.

C.4. Equilibrium Payoffs

Given the equilibrium discussion, the equilibrium payoff can be derived for players in each treatment by substituting p_i^* and $\beta_{i_j}^*$ where relevant

$$\Pi_{i_j}^* = \begin{cases} \beta_{i_j}^* = \mu - b_i(s)\delta & \text{if } 1_G = 0 \ \& \ x_{i_j} = 1 \\ p_i^* + (\beta_{i_j}^* - p_i^*)x_{i_j} = \mu - b_i(s)\delta & \text{if } 1_G = 1 \ \& \ x_{i_j} > 0 \\ p_i^* = \mu - b_i(s)\delta & \text{if } 1_G = 1 \ \& \ x_{i_j} = 0 \end{cases} \tag{2}$$

Notice that the equilibrium payoff ($\Pi_{i_j}^*$) only depends on $b_i(s)$ and is independent of the treatment variations. For any fixed n, the treatments are therefore payoff equivalent for any player observing $b_i(s)$.

III. Test Hypotheses

This paper seeks to investigate the conventional wisdom that markets should allocate the rights for performing decisional task to those players who are best suited to perform the task, in this case, those who know the optimal choices in the game stage. The equilibrium analysis suggest that behaviours of players in the game stage are independent of the treatment variations. How therefore would the experimental design test the conventional wisdom?

For this we return to the main features of the game stage. (i) *Adherence to the optimal choices are Pareto optimal for all players in the game Stage* and (ii) *Adherence to the optimal choices when* $b_i(s) > 0$ *requires players to employ logical and epistemological reasonings* - when players observe $b_i(s) = 0$ the decisional task is trivial and obvious. As such, if players are heterogeneous in their sophistications as suggested by previous experimental adaption of the Red Hat Puzzle (Weber, 2001; Bayer and Chan, 2007), then markets in the pre-game stage of TRADE should allocate the participation rights (tokens) to those players who know the optimal choices.

To see why this might be so, assume that the population of players consist of both Sophisticated and Unsophisticated types. When $b_i(s) > 0$, the Unsophisticated types, limited by their abilities to know the optimal choices, do not expect to ever ascertain their true hat colour in the game stage. The dominant behaviour for such types would be to randomise between a_b and a_r in the very first period of the game stage with the expected token redemption rate of $\mu - (1/2)\alpha$.[15] If presented the opportunity to enter the pre-game stage, such types should only purchase additional tokens at prices $p_i \leq \mu - (1/2)\alpha$ and sell their token at prices $p_i > \mu - (1/2)\alpha$. Assume for now that the Sophisticated types alway expect to ascertain their true hat colour in the game stage. They should thus only purchase tokens at prices $p_i \leq \beta_{i_j}^* = \mu - b_i(s)\delta$ and sell their token at $p_i > \beta_{i_j}^* = \mu - b_i(s)\delta$. Since $(1/2)\alpha > (n+1)\delta$, at prices $p_i \in (\mu - (1/2)\alpha, \mu - b_i(s)\delta]$, it is therefore incentive compatible for Sophisticated types to purchase tokens and Unsophisticated types to sell tokens. Furthermore,

[15]Choosing a_n is dominated as they incur a cost of δ with no expected revisions to their posterior in the later periods.

Sophisticated types should know that given the availability of pre-game stage, the only players who will eventually enter the game stage must also be Sophisticated types. Thus markets in the pre-game stage should result in the allocation of the rights for performing the decisional task in the game stage to those who know the optimal choices.

To make comparison treatments, the following two terms are introduced

Adherence Rate: The ratio of players in the game stage who had adhered to the optimal choices.
Efficiency Rate: The ratio of tokens redeemed at the Pareto optimal equilibrium rate $\mu - b_i(s)\delta$.[16]

Both terms focus on the behaviours of players in the game stage and whether they had adhered to the optimal choices. However, they differ on the weights assigned to the players' behaviours in respective treatments. The adherence rate assigns uniform weights to the behaviours of all players in the game stage, whilst the efficiency rate assigns greater weights to the behaviours of players with more tokens. These differences are irrelevant for BASE1 and BASE2, since players always enter the game stage with exactly one token - the adherence and efficiency rates must be identical. However, this will not necessarily be true for players in TRADE, as they first enter the pre-game stage. Since comparisons between treatments should account for the activities in the pre-game stage, thus the efficiency rate would be a more suitable measure of aggregated performances in the respective treatments. This brings us to the following test hypotheses

H1: The efficiency rate in BASE1 is similar to that of BASE2.

H2: The efficiency rate in TRADE is higher than those in BASE1 and BASE2.

H3: The likelihood of adherence for subjects in TRADE is increasing with token ownership, at instances where $b_i(s) = 1, 2$.

H4: The likelihood of adherence for subjects in TRADE is strictly higher for subjects who had purchased tokens at prices $p_i \in (\mu - (1/2)\alpha, \mu - b_i(s)\delta]$ relative to subjects who had purchased tokens at $p_i \notin (\mu - (1/2)\alpha, \mu - b_i(s)\delta]$ or had not purchased tokens, at instances where $b_i(s) = 1, 2$.

H1 serves as an empirical warm up where we examine the marginal influences of increasing m on the aggregated performances in the game stage. Building on this finding, we can thus proceed to H2, where we examine the main research question of this paper. If the conventional wisdom is to hold, we should expect the aggregated performances in TRADE to be significantly higher than those in BASE1 and BASE2. This is simply due to the fact that markets should result in the allocation of tokens to those players who know the optimal choices.

H3 and H4 seeks to provide support for any potential findings from H2. If markets did result in the allocation of tokens to those players who know the optimal choices, we should expect the likelihood of adherence to the optimal choices to be increasing with token ownership for subjects

[16]If a player with three tokens was had adhered to the optimal choices, then three tokens would have been redeemed at the equilibrium rate.

Table II. Demographics of Subjects by Schools Enrolled

School	BASE1	BASE2	TRADE
Business School	16	13	23
Engineering, Mathematics & Physical Science	3	1	5
Humanities	9	6	0
Life & Environmental Science	4	3	2
Social Sciences & International Studies	1	10	6
Others	3	3	0
Total	36	36	36

in TRADE. In addition, since the allocation of tokens with markets is due to the difference in valuations amongst subjects, we should therefore expect subjects' token pricing behaviours to be related to their behaviours in the game stage. As the optimal choices are trivial when players observe $b_i(s) = 0$, the potential effects of markets in the pre-game stage should only be evidential when subjects observe $b_i(s) = 1, 2$.

IV. Experimental Procedures

Two experimental sessions, were conducted for each treatment. Each session had involved 18 inexperienced subjects, recruited on a first come basis from the undergraduate cohort at the University of Exeter, through the ORSEE (Greiner, 2004) software. Table II reports on the subjects' demography in each treatment, by the schools they were enrolled into - Economic students study at the Business School. Although subjects had no formal training in game theory, those with stronger background in economics, engineering, mathematic or physics may potentially have some advantage with abstract reasoning problems due to their background training. This will be controlled for in the econometric analysis.

The experiments were conducted with the Z-Tree (Fischbacher, 2007) software and employed non-neutral framing of the pre-game and game stages. Each session had consisted of one practice round and ten paying rounds, where subjects' payoffs were denoted in the fictitious currency, ECU. The following payoff parameters were employed: $\mu = 950$, $\delta = 50$, $\alpha = 700$ and $\bar{L} = 6000$. Subjects' overall payoffs were determined as the average over all ten rounds and converted into cash at the exchange rate of 67ECU/£1 in the BASE1 and BASE2 treatments, and 100ECU/£1 in the TRADE treatments.[17] The average duration of the BASE1 and BASE2 sessions were 95 minutes, whilst the TRADE sessions were 130 minutes. In addition to their experimental earnings, subjects also received a show-up fee of £5 in the BASE1 and BASE2 sessions, and £8 in the TRADE sessions. Including the show-up fees, the average cash earnings were £16.64, £16.91 and £16.12 in the BASE1, BASE2 and TRADE treatments, respectively. Before collecting their cash

[17] The difference in exchange rates was introduced to control for any potential income effect due to a higher show-up fee being paid in the TRADE sessions.

payments, subjects were required to complete the Cognitive Reflective Test (Frederick, 2005) and self-declare any prior familiarity with the Red Hat Puzzle or similar problems.[18]

For efficient comparisons between treatments, two sequences of states ($s \in S$) were randomly generated prior to the experimental proper. This was introduced to ensure that at each round of the respective treatments, there were the same number of subjects who observed zero, one or two black hats.

Prior to experiment proper, we conducted a pilot test on the software and the instructions. The pilot test had raised some interesting challenges with the experimental design, which prompted us to make minor modifications to the design of BASE1 and BASE2. In the following, we will first detail the modification made and thereafter the experimental procedures in the respective treatments.

A. Minor Modifications to BASE1 and BASE2

The pilot session was based on the BASE2 treatment design. Here subjects were sometimes observed to be adhering to the optimal choices despite the fact that they were following some randomisation process - through their feedbacks.

To overcome the likelihood that observed adherences were purely coincidental, we included an "outside option" for subjects to discretely end the game stage in a manner that does not affect the equilibrium analysis of the game. In addition to the actions a_b, a_r and a_n, subjects could also choose the outside option with the action "Toss a Coin, I will never know (a_c)". If the subjects chooses a_c, he ends the game stage with a fixed cost of 250 ECU, in addition to any other deductions incurred when choosing a_n. In doing so, he assigns the computer to choose the action a_b or a_r on his behalf - with equal probability. The computer's choice will have no consequence on his payoffs. For example if subject A choose a_n in the first period and a_c in the second period - the computer had chosen a_b on his behalf, his token will be redeemed at the rate of 950-50-250=650 ECU. All other subjects would have observed that A had chosen a_b in the second period. However, only the experimenter would know that subject A had chosen a_c.

The action a_c will always be dominated in the equilibrium analysis and does not influence the optimal choices. The expected token redemption rate with adhering to the optimal choices is $950 - 50(b_i(s))$, with choosing a_c at any period t is $700 - 50(t-1)$, and randomising with either a_b or a_r for uncertain players is $600 - 50(t-1)$. Thus for subjects who do not expect to ever ascertain their hats' colour, the action a_c dominates all other actions. The outside option was omitted from TRADE, since an equivalent outside option already exist, the ability to sell your token and avoid the game stage altogether.

[18]The Cognitive Reflective Test involves three question that triggers the wrong "instinctive" answer. (Q1) A bat and a ball cost \$1.10 in total. The bat costs \$1.00 more than the ball. How much does the ball cost? (Q2) If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets? (Q3) In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?

B. BASE1

Upon entering the experiment, subjects were allowed 40 minutes to read through the instructions (see Appendix A) and complete a questionnaire, testing their understanding of the experimental design. Thereafter, subjects were randomly paired with two other subjects into a *group* and remained within the same group for the duration of the experiment - total of 12 group. At the start each round, subjects were randomly assigned to one of three hats and were presented with the other hats' colours. Subjects were also informed that *there is at least one black hat* and proceed directly into the game stage. To avoid confusion, the notion of tokens were omitted from the subjects' instructions. The game stage proceed as discussed and each period had lasted a maximum of 240 seconds. At each period $t > 1$, subjects were presented on their computer screens the period $t - 1$ actions of all other subjects within their group. A limitation of the software design was such that subjects had to proceed through the periods together. This meant that subjects who had chosen the actions a_b, a_r or a_c were facing a blank screen as they waited for other subjects to proceed through the periods. However, subjects were observed to have taken the opportunity to "sketch" their behaviours in the game.

C. BASE2

The sessions differ from the BASE1 sessions in the following: Each group consisted of 18 subjects, with 6 subjects under each hat (see Appendix B for the instructions) - total of 2 groups. However, subjects were again randomly assign to one of three hats in each round. At each period $t > 1$, subjects were presented on their computer screens a table that depicted the aggregated period $t - 1$ actions, by all subjects in the respective hats. For example, subjects under hat 1, will observe the relative frequencies of the actions a_b, a_r and a_n, chosen by all subjects under hat 2 and 3.

D. TRADE

Each group again consisted of 18 subjects with 6 subjects under each hat (see Appendix C for the instructions) - total of 2 groups. When the round begins, subjects first observed the other hats' colours. Thereafter, subjects enter the pre-game stage, where trade was facilitated through a continuous double auction mechanism that lasted for 120 seconds - the market only consisted of the other subjects under the same hat. Here, a price ceiling of 1200 ECU was imposed on the bid and ask prices, to restrict subjects from intentionally making losses. This also ensures that each subject was not capital constrained from purchasing all other tokens within his market.

After the pre-game stage had ended, only subjects with at least one token entered the game stage - subjects without any tokens were able observe the proceedings of the game stage on their computer screens but prevented from participating. The game stage proceeded as described in the BASE1, with the exception that the action a_c was not available and the public information available to subjects at each period $t > 1$. Here, their computerised screens depicted the aggregated period $t-1$ actions, by all subjects under the respective hats ranked by their token ownership. For example, subjects under hat 1, will observe the relative frequencies of the actions a_b, a_r and a_n chosen by those subjects under hat 2 and 3 with one, two, three,..., six tokens.

Since the loan of 6000 ECU had to be repaid at the end of the round, some subjects may incur negative payoffs - 20 observed bankruptcy out of the 360 instances. A lower bound of 0 ECU was introduced to restrict subjects from making negative payoffs in any round.

V. Results

In the following discussions, we will omit the suffix i and j, and make references to those instance where experimental subjects observed $b = 0, 1, 2$ black hats. It is worth to remember that the experimental procedures ensured that there will be the same number of subjects starting each round in the respective treatments, observing b black hats. However, the ability to trade tokens meant that only a subset of subjects in TRADE would have eventually entered the game stage. Nevertheless, there will still be the same number of tokens due for redemption at the equilibrium rate $\beta^* = 950-50b$. For these reasons, comparisons of aggregated performances between treatments will focus on the efficiency rates.

In the following sub-sections, we will first present the aggregated performances in all treatments to examine H1 and H2. Thereafter, we will focus on the prices and token ownerships in TRADE to give an overview to H3 and H4. Finally, we will revisit H2 in the econometric analysis, where H3 and H4 will be jointly evaluated.

A. Aggregated Performances

Table III reports on the efficiency rates in BASE1, BASE2 and TRADE. Each cell depicts the total number of tokens redeemed at the equilibrium rate β^*, with the ratio in parenthesis. The final column of each panel depicts the pooled efficiency rate for that round and the final row, over all rounds.

Interpretation of BASE1's and BASE2's data should be straightforward. For example in round 1 of BASE1, there were 24 subjects who began the game stage observing $b = 1$. However, only 16 of those subjects were found to have adhered to the optimal choices, and thus only 16 tokens were redeemed at $\beta^* = 900 - 50(1) = 900$ ECU. The efficiency rate was thus computed as $16/24 \approx 0.67$. Interpretation of TRADE's data is less straightforward. In the round 1 of TRADE, there were again 24 subjects who began the round observing $b = 1$. However, after trading tokens in the pre-game stage, only 19 subjects had eventually entered the game stage. Out of these 19 subjects, 11 subjects were found to have adhered to the optimal choices but 12 tokens were redeemed at the equilibrium rate - this implies that one of the 11 subjects must be owning two tokens. The efficiency rate was computed to be $12/24 = 0.5$.

Pairwise comparisons between treatments will be made for the pooled efficiency rates at each b instances and the aggregated efficiency rate over all b instances. We will employ both Chi-Square and Fisher's Exact one-tail tests, where the p-values are reported as ρ and $\hat{\rho}$ respectively.

First consider the observations in BASE1 and BASE2. At instances where subjects observed $b = 0$, the pooled efficiency rates in both treatments were unity. This should not be surprising, since given the public information that "*there is at least one black hat*", each subject should have immediately ascertained their hats to be black and choose a_b in the first period. When subjects observed $b = 1$, the optimal choices become less trivial and required them to employ logical and epistemological reasoning. However, at most instances, the majority of subjects had understood the optimal choices. Here, the pooled efficiency rates were found to be 0.70 and 0.68 in BASE1 and BASE2 respectively - the difference was not found to be significant ($\rho = 0.741$, $\hat{\rho} = 0.413$). At the most complex task of the game stage, where subjects observed $b = 2$, the pooled efficiency rates were now found to be 0.14 and 0.15 in BASE1 and BASE2 respectively - the difference was again not found to be significant ($\rho = 0.859$, $\hat{\rho} = 0.500$). The fall in efficiency rates from $b = 1$ to $b = 2$ is fairly obvious. This suggest that the decisional task at instances where $b = 2$ might have been too complicated for most subjects. This is evidential in their behaviours, where 50% and 40% of the observations in BASE1 and BASE2 respectively, had resulted in subjects deviating at the very first period of the game stage. Finally, the aggregated efficiency rates over all rounds and b instances were found to be 0.54 and 0.53 in BASE1 and BASE2 respectively. This was again not found to be significantly different ($\rho = 0.881$, $\hat{\rho} = 0.470$).

Result 1: *Consistent with H1, the aggregated efficiency rates over all observations in BASE1 and BASE2 were not found to be significantly different. Furthermore, the pooled efficiency rates at instances in BASE1 and BASE2 where subjects observed $b = 0$, $b = 1$ and $b = 2$ black hats, were not found to be significantly different.*

To some extend, Result 1 is convenient since it suggest that increasing the number of subjects under each hat has little or no obvious influences on their behaviours in the game stage. Therefore, if the efficiency rates in TRADE were significantly different to those of BASE1 and BASE2, this could likely be attributed to the market allocation in the pre-game stage of TRADE.

Now consider the observations in TRADE. At instances where subjects observed $b = 0$, the efficiency rate was unity. However, at instances where subjects observed $b = 1$, the pooled efficiency rate was now found to be 0.49, significantly lower and different to those reported in BASE1 and BASE2 ($\rho < 0.001$ and $\hat{\rho} < 0.001$ in all comparisons). At instances where subjects observed $b = 2$, the efficiency rate was found to be 0.18. This might seem higher than those reported in BASE1 and BASE2, but the differences were not found to be significant ($\rho > 0.393$ and $\hat{\rho} > 0.495$ in all comparisons). Finally, the aggregated efficiency rate over all rounds and b instances in TRADE was found to be 0.44, significant lower than those reported in BASE1 and BASE2 ($\rho < 0.018$ and $\hat{\rho} < 0.012$ in all comparisons).

Result 2: *Contrary to H2, the aggregated efficiency rate over all observations in TRADE was found to be significantly lower than those in BASE1 and BASE2. The differences were primarily*

Table III. Efficiency Rates (BASE1, BASE2 and TRADE)

	BASE1				BASE2				TRADE			
Round	$b=0$	$b=1$	$b=2$	Agg.	$b=0$	$b=1$	$b=2$	Agg.	$b=0$	$b=1$	$b=2$	Agg.
I	12(1.0)	16(.67)	-	**28(.78)**	12(1.0)	16(.67)	-	**28(.78)**	12(1.0)	12(.50)	-	**24(.67)**
II	12(1.0)	21(.88)	-	**33(.92)**	12(1.0)	18(.75)	-	**30(.83)**	12(1.0)	12(.50)	-	**24(.67)**
III	-	17(.71)	1(.08)	**18(.50)**	-	17(.71)	1(.08)	**18(.50)**	-	8(.33)	5(.42)	**13(.36)**
IV	-	7(.58)	4(.17)	**11(.31)**	-	8(.67)	3(.13)	**11(.31)**	-	4(.33)	2(.08)	**6(.17)**
V	-	7(.58)	2(.08)	**9(.25)**	-	7(.58)	5(.21)	**12(.33)**	-	8(.67)	5(.21)	**13(.36)**
VI	-	7(.58)	5(.21)	**12(.33)**	-	6(.50)	3(.13)	**9(.25)**	-	6(.50)	8(.33)	**14(.39)**
VII	6(1.0)	15(.63)	3(.50)	**24(.67)**	6(1.0)	15(.63)	1(.17)	**22(.61)**	6(1.0)	11(.46)	0(.00)	**17(.47)**
VIII	-	18(.75)	1(.08)	**19(.53)**	-	18(.75)	2(.17)	**20(.56)**	-	14(.58)	1(.08)	**15(.42)**
IX	12(1.0)	20(.83)	-	**32(.89)**	12(1.0)	18(.75)	-	**30(.83)**	12(1.0)	10(.42)	-	**22(.61)**
X	-	6(.50)	2(.08)	**8(.22)**	-	8(.67)	4(.17)	**12(.33)**	-	10(.83)	2(0.08)	**12(.33)**
Agg.	42(1.0)	134(.70)	18(.14)	**194(.54)**	42(1.0)	131(.68)	19(.15)	**192(.53)**	42(1.0)	95(.49)	23(.18)	**160(.44)**

Table IV. Adherence Rates by Token Ownership (TRADE)

Tokens	$b = 0$	$b = 1$	$b = 2$	Agg.
1	10(1.0)	47(.67)	12(.32)	69(.59)
2	9(1.0)	16(.47)	1(.05)	26(.41)
3	3(1.0)	4(.33)	3(.33)	10(.42)
4	-	1(.50)	0(.00)	1(.17)
5	1(1.0)	0(.00)	-	1(.33)
6	-	-	0(.00)	0(.00)
Agg.	23(1.0)	68(.57)	16(0.23)	107(.50)

driven by the lower pooled efficiency rates at instances where subjects in TRADE observed $b = 1$*. At other instances where subjects observed* $b = 0$ *or* $b = 2$*, the pooled efficiency rates were not found to be significantly different from those of BASE1 or BASE2.*

Taken together, Results 1 and 2 suggest that allowing subjects to trade their participation rights to the game stage had actually worsen aggregated performances, relative to the control treatments. Furthermore, comparisons between treatments suggest that such differences were primarily attributed to instances in TRADE where subjects observed $b = 1$ black hats. How might we reconcile such discrepancies? Perhaps this finding is symptomatic of the complexity in the decisional task. When $b = 0$, the task was too trivial, and we do not observe any differences between the treatments. When $b = 2$, the task was too complex for most subjects, thus any marginal influence from the ability to trade tokens was minimal. As such, the "tipping point" lies at instances where subjects observed $b = 1$. This raises the question as to why the aggregated performances in TRADE might be lower than those in BASE1 and BASE2.

With repeated games, the reader might be concerned with potential learning over rounds. We find little evidence of learning. The aggregated efficiency rates over rounds I-V were found to be 0.55, 0.55 and 0.44 in BASE1, BASE2 and TRADE respectively. The same rates over rounds VI-X were found to be 0.53, 0.52 and 0.44 respectively.

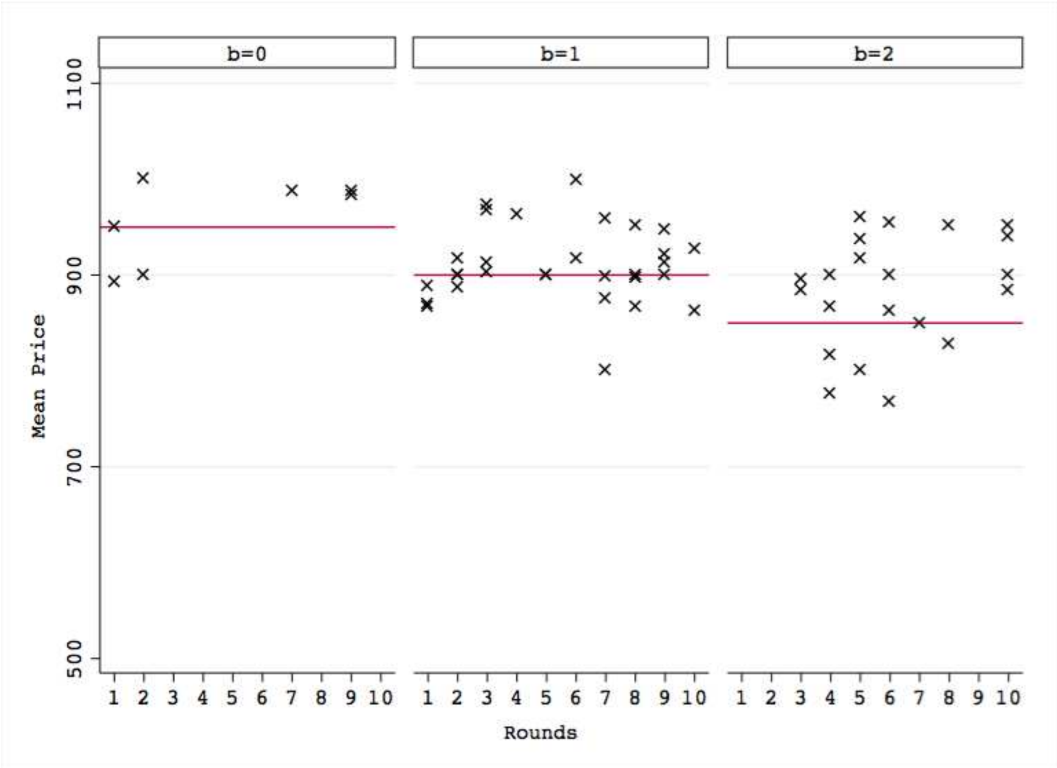
B. Behaviours and Token Ownership (TRADE)

A plausible explanation to Result 2 is that markets in the pre-game stage of TRADE had often resulted in the allocation of participation rights (tokens) to those subjects who did not know the optimal choices (Unsophisticated types). To investigate this explanation, we report on Table IV, the adherence rates by token ownership.

For example, there were 70 instances where subjects in TRADE observing $b = 1$ had entered the game stage with exactly one token, out of which subjects were found to have adhered to the optimal choices in 47 instances - the adherence rate was therefore $47/70 \approx 0.67$.

At instances where $b = 0$, the ownership of tokens had no influence on the adherence rates. However, at instances where $b = 1$ or $b = 2$, the adherence rates were found to decrease with token

Figure 1. Mean Prices in Pre-game Stage of TRADE



ownership. This observations are clearly contradictory to H3. However, they lend some support to the explanation that markets had resulted in the allocation of tokens to those subjects who did not know the optimal choices.

C. Prices and Behaviours in Game Stage (TRADE)

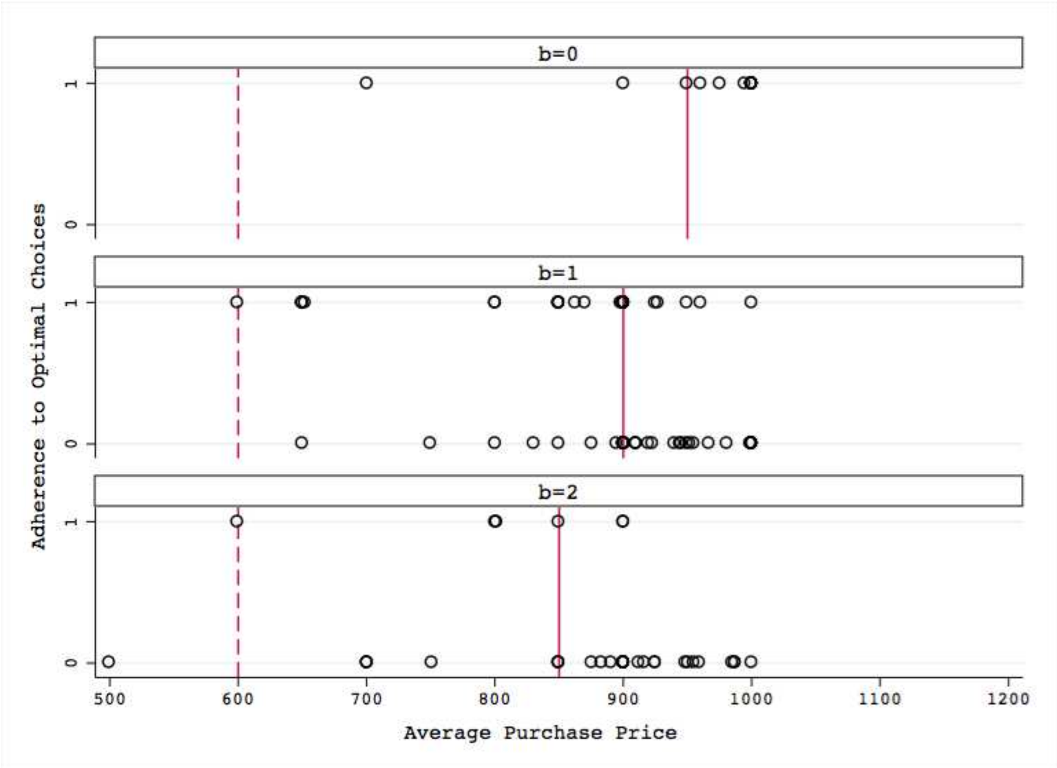
How might we explain the observations in Table IV? For some insights, we studied the prices of tokens in markets of the pre-game stage. Figure 1 present the mean transaction prices in markets where subjects had observed $b = 0, 1, 2$ black hats. The horizontal line in each panel indicates the equilibrium price $p^* = 950 - 50b$. The weighted volume of trade were found to be 1.11, 0.80 and 0.82 (total number of trades as a ratio of the the total number of tokens available for trade) in markets where subjects observed $b = 0, 1, 2$ respectively. Given that each market only consisted of six subjects, there seems to be a robust number of transactions.

Mean prices were frequently found to be above the equilibrium price - 57%, 46% and 71% of observations in markets where subjects observed $b = 0, 1, 2$ respectively - which are indicative of price "bubbles" in the markets. Such price bubbles could have severe implications on the allocative outcomes of markets, since at prices $p > 950 - 50b$, sophisticated types should strictly prefer to sell their tokens and avoid the game stage altogether.[19]

However, if price bubbles had led to tokens being frequently purchased by subjects who might

[19]This raises the question as to the types of subjects who might be purchasing tokens at such elevated prices.

Figure 2. Average Purchase Price ($\ddot{p}$) and Adherence to Optimal Choices (TRADE)



otherwise not known the optimal choices, then we should expect to find some relationship between subjects' pricing behaviours in the market and their eventual behaviours in the game stage. If such a relationship does not exist, then price bubbles could be an independent phenomenon that is inconsequential to the behaviours of subjects in the game stage. We hence derived for each subject in TRADE, his average purchase price ($\ddot{p}$), which was computed as the sum of all his purchasing expenditure in the market divided by the total number of tokens purchased.[20]

Figure 2 presents the plot of $\ddot{p}$ and behaviours in the game stage. Each observation indicates the $\ddot{p}$ for an individual subject and whether he was found to have adhered to the optimal choices in the game stage (the numeral 1 indicates that the subject had adhered). This of course excludes all observation where subjects were *inactive* - did not purchase tokens in the market - or had sold all their tokens.

It is difficult to see any linear relationship between adherence and $\ddot{p}$, and there is no theoretical justification for one. However, the economic intuition in TRADE is for Sophisticated types to be purchasing tokens at prices $p \in (600, 950 - 50(b)]$ at instances where $b > 0$. We hence partition the observations into two clusters, those with $\ddot{p} \in (600, 950 - 50(b)]$ - the area between the horizontal lines on each panel mark out this region - and $\ddot{p} \notin (600, 950 - 50(b)]$. In doing so, we notice some

[20]As trade was facilitated through a continuous double auction mechanism, subjects could purchase and sell token simultaneously within the trading period. Thus the average purchase price seeks to normalise his overall purchasing activities within the trading period. One could alternatively consider the average sale price, however we prefer to work with the purchasing activities since it may better describe a subject's expected token redemption rate.

Table V. Adherence Rates by Average Purchase Price (TRADE)

	$b = 1$	$b = 2$
$\ddot{p} \in (600, 950 - 50(b)]$	27(0.67)	3(0.30)
$\ddot{p} \notin (600, 950 - 50(b)]$	6(0.22)	3(0.11)

relationship between $\ddot{p}$ and behaviours of subjects. To see this more clearly, we report on Table V, the adherence rates at instances where $\ddot{p} \in (600, 950 - 50(b)]$ and $\ddot{p} \notin (600, 950 - 50(b)]$. One immediately observes the rates to be higher in the former relative to the latter condition when $b = 1$ - 0.67 and 0.22 respectively - and when $b = 2$ - 0.30 and 0.11 respectively.

Take together these observations provide some support for H4 and suggest that subjects' pricing behaviours in TRADE may be related to their behaviours in the game stage. More significantly, it lends weight to the explanation, that the price bubbles in the markets of TRADE had often resulted in the allocation of tokens to those subjects who might not have known the optimal choices. These observations will be formally tested in our econometric analysis.

D. Econometric Analysis

This section employs econometric methods to re-examine the Result 2, and jointly investigate H3 and H4, whilst controlling for subject specific characteristics. Given that subjects remained within the same group for the duration of the experiment, we should hence expect the residual estimates to be highly correlated amongst subjects of the same group but independent from those of other groups. As such, the approach taken in this paper follows that of Bayer and Chan (2007), with the three-level hierarchical Generalised Linear Latent and Mixed Model (Rabe-Hesketh et al., 2005).

The first level refers to observations at round r, the second level refers to subjects indexed by l and the third level refers to groups indexed by g. To ensure variations in the data, all observations where subjects observed $b = 0$ or when subjects did not participate in the game stage were excluded. This resulted in 827 level-1 variables, 105 level-2 variables and 16 level-3 variables.[21] The regression model adopts a *logistic* link function

$$\text{Logit}[\text{Prob}(y_{rlg} = 1)|\mathbf{x}_{rlg}, \zeta_{lg}^{(2)}, \zeta_g^{(3)}] = \mathbf{x}'_{rlg}\beta + \zeta_{lg}^{(2)} + \zeta_g^{(3)} \quad (3)$$

where the dependent variable denotes the adherence to the optimal choice in round r, by subject l belonging to group g. The model assumes that $\zeta_{lg}^{(2)}|\mathbf{x}_{rlg}, \zeta_g^{(3)} \sim \mathcal{N}(0, \psi^{(2)})$, where $\psi^{(2)}$ denotes the between-subject, within-group variances. Furthermore, it assumes that $\zeta_g^{(3)}|\mathbf{x}_{rlg} \sim \mathcal{N}(0, \psi^{(3)})$, where $\psi^{(3)}$ denotes the between-group variance. The observations from BASE1 and BASE2 were pooled together to form the BASE observations. Thereafter interactive dummies were introduced

[21] Although there were a total of 108 subjects in all treatments, there were three subjects in the TRADE treatment who had always sold their tokens when they observed $b = 1$ or $b = 2$. There were hence only 105 level-2 variables in the regression.

to distinguish TRADE observations from those of BASE at instances where subjects observed $b = 1$ and $b = 2$. Five regression models were considered, where the estimation process employs the adaptive quadrature numerical methods to maximise the marginal log-likelihoods.[22] The regression results are reported on Table VI, where the p-values are presented in parenthesis. The likelihood-ratio test prefers regression 4 to all other regressions (at the 1% significance level) but the discussions will make references to regression 5, since it introduces some subject specific coefficients. The estimates in the respective regression were also found to be consistent with the random-effects logistic regression results - not reported here.

The discussion henceforth will make references to the average subject, a hypothetical subject where the coefficient estimates are set to their averages. The log-likelihood of adherence decreases by 1.38 at instances where $b = 1$, and increases by 0.69 at instances where $b = 2$, for an average subject in TRADE relative to an average subject in BASE. However, only the former was found to be mildly significant (p-value=0.085).

Result 2': *Consistent with Result 2, the likelihood of adherence for an average subject in TRADE was significantly lower at instances where $b = 1$, relative to an average subject in BASE. At instances where $b = 2$, no significant effect was observed.*

For the average subject in TRADE, the log-likelihood of adherence decrease by 1.13 when $b = 1$ and by 0.20 when $b = 2$, for each additional token owned. Again, only the former coefficient was found to be significant (p-value=0.007). This is consistent with the findings on Table IV, where adherence rates in TRADE were observed to have decrease with token ownership. However, the surprise here is such that the coefficients were only significant at instances where subjects observed $b = 1$.

Finally, for the average subject in TRADE, the log-likelihood of adherence increases by 2.015 and by 0.029 at instances where $b = 1$ and $b = 2$ respectively, when $\ddot{p} \in (600, 950 - 50(b)]$, relative to other instances where subjects were found to be inactive or $\ddot{p} \notin (600, 950 - 50(b)]$. Once again, only the former was found to be significant (p-value=0.002). To confirm this finding, we also considered an alternative regression where the interactive dummy variables were specified for subjects in TRADE for $\ddot{p} \notin (600, 950 - 50(b)]$. Here the likelihood of adherence was found to be significantly lower for subjects with $\ddot{p} \notin (600, 950 - 50(b)]$ at instances where $b = 1$ but not significantly different at instances where $b = 2$.

This econometric results suggest that after controlling for purchases prices and token ownership, the likelihood of adherence of an average subject in TRADE is mildly different to an average subject in BASE at instances where $b = 1$ and not significantly different when $b = 2$. The regression results also suggest that price bubbles had lead to the tokens being purchased by subjects who might not have understood the optimal choices in the game stage. This brings us to the following results

Result 3: *Contrary to H3, the likelihood of adherence to the optimal choices was decreasing with*

[22]The adaptive quadrature method was employ to increase computation efficiency and estimation precision (Rabe-Hesketh et al., 2002).

Table VI. Econometric Regression Results

Dependent Variable: Adherence to the Optimal Choices					
Regression	(1)	(2)	(3)	(4)	(5)
Coefficient	Est.	Est.	Est.	Est.	Est.
$(b=2)$	-3.911^{***} (0.000)	-4.327^{***} (0.000)	-3.936^{***} (0.000)	-4.810^{***} (0.000)	-4.831^{***} (0.000)
$(b=1)\times$TRADE	-0.936^{*} (0.065)	-0.567 (0.291)	-1.413^{**} (0.010)	-1.010^{*} (0.081)	-1.381^{*} (0.085)
$(b=2)\times$TRADE	0.999^{*} (0.096)	1.089^{*} (0.093)	0.943 (0.140)	1.080 (0.106)	0.695 (0.313)
$(b=1)\times$Token	-	-0.610^{*} (0.062)	-	-1.111^{***} (0.004)	-1.131^{***} (0.007)
$(b=2)\times$Token	-	-0.169 (0.723)	-	-0.206 (0.676)	-0.201 (0.681)
$(b=1)\times$TRADE$\times\ddot{p}\in(600,950-50(b)]$	-	-	1.399^{**} (0.012)	2.016^{***} (0.002)	2.015^{***} (0.002)
$(b=2)\times$TRADE$\times\ddot{p}\in(600,950-50(b)]$	-	-	0.162 (0.860)	0.018 (0.984)	0.029 (0.976)
Sequence	-	-	-	-	0.252 (0.570)
Familiarity	-	-	-	-	-0.622 (0.314)
Gender	-	-	-	-	0.676 (0.147)
CRT Score	-	-	-	-	0.054^{*} (0.09)
Business School	-	-	-	-	1.029 (0.285)
Eng, Math & Phy Science	-	-	-	-	1.852 (0.128)
Humanities	-	-	-	-	0.841 (0.431)
Life & Environmental Science	-	-	-	-	1.111 (0.343)
Social Science & Int'l Studies	-	-	-	-	0.922 (0.375)
Constant	1.194^{***} (0.000)	1.798^{***} (0.000)	1.201^{***} (0.000)	2.303^{***} (0.000)	1.054 (0.293)
$\psi^{(2)}$	3.68^{***}	3.54^{***}	3.82^{***}	3.64^{***}	3.26^{***}
$\psi^{(3)}$	$\frac{1.7}{10^{11}}$	$\frac{2.8}{10^{10}}$	$\frac{2.4}{10^{11}}$	$\frac{4.8}{10^{11}}$	$\frac{1.2}{10^{12}}$
Negative Log-Likelihood	395.01	393.12	391.62	387.51	384.20

***:p-value<0.01; **:p-value<0.05 and *:p-value<0.10

Level-1 Observations $n=827$; Level-2 Observations $n=105$ and Level-3 Observations $n=16$.

token ownership for subjects in TRADE at instances where $b = 1$. At instances where $b = 2$, no significant effect was observed.

Result 4: *Consistent with H4, the likelihood of adherence to the optimal choices was found to higher for those whose $\ddot{p} \in (600, 950 - 50(b)]$ relative to those who were inactive or whose $\ddot{p} \notin (600, 950 - 50(b)]$, at instances where subjects in TRADE observed $b = 1$. At instance where $b = 2$, no such relationships were found to be significant.*

The regressions did not find any significant effects due to differences in gender, sequence administered, schools or prior familiarity. The latter point is interesting since the decisional task for subjects in the game stage might be trivial if they had prior familiarity with the problem. However, this finding highlights a central feature of the Red Hat Puzzle, such that prior familiarity might only helpful if it was common knowledge. There is some mild evidence that the likelihood of adherence is increasing with the subjects' scores in the Cognitive Reflective Test (CRT). The CRT test involved three questions which required subjects to employ some effort in thought and reasoning before providing the answers. Given that the adherence to the optimal choices in the game stage also requires logical reasoning, perhaps the CRT test score is capturing some of these abilities. Despite the subject characteristics controls, there still seem to be significant between-subject variances ($\psi^{(2)}$) although the between group variances ($\psi^{(3)}$) were not found to be significant.

Once again the results raises the question as to why any differences between the BASE and TRADE treatments or within the TRADE treatment, were only found to be significant at instances where $b = 1$. Our prior on this matter is that the decisional task where $b = 2$ was too complicated or complex for most subjects to comprehend. This is evidential in the above regressions, where the log-likelihood of adherence was found to decrease by at least 4.831 (p-value=0.0001) in all treatments when an average subject observes $b = 2$ relative to observing $b = 1$. By this extension, subjects may have perceived the optimal choices at instances where $b = 1$ to be similar to those where $b = 2$. If such misperception were indeed reflected in the purchase prices of tokens in TRADE, one should expect the average purchase prices at instances where $b = 1$ to not be significantly different from those where $b = 2$. We hence conducted a linear regression on the average purchase price ($\ddot{p}$) with the situation dummies b_0 and b_2 which refer to these instances where subjects observed $b = 0$ and $b = 2$, with $b = 1$ as the reference. The p-values are again reported in parenthesis.

$$\ddot{p} = \underset{(0.001)}{80.76} b_0 - \underset{(0.276)}{21.38} b_2; \quad N = 121,\ R^2 = 0.10 \tag{4}$$

The regression result found $\ddot{p}$ to be significantly higher at instances where $b = 0$ relative to instances where $b = 1$. However, at instances where $b = 2$, $\ddot{p}$ was not found to be significantly different from those at $b = 1$. This lends some weight to the possibility that subjects may have misperceived the optimal choices at instances where $b = 2$ to be similar to those where $b = 1$.

VI. Conclusions

This paper was motivated by the question as to whether markets, as suggested by the conventional wisdom, were able to allocate the rights for performing decisional tasks to those players who are best suited to perform the tasks. To do so we embedded the decisional tasks in a game motivated by Littlewood (1953) Red Hat Puzzle, and introduced markets where players were able to trade their participation rights (in the form of tokens) to the game. Three treatments were considered and we provided an economic intuition, consistent with the conventional wisdom, that aggregated performances in TRADE should be higher than those in BASE1 and BASE2.

Aggregated performances in TRADE were found to be significantly lower than BASE1 and BASE2. We show that this was primarily driven by instances in TRADE where subjects had observed $b = 1$ black hat. To seek some explanations to this result, we studied the mean prices in the markets of the pre-game stage in TRADE. Here, price bubbles were often observed in markets where subjects observed $b = 0, 1, 2$ black hats. We conjectured that price bubbles could have important consequences on the allocative outcomes of markets, as they might result in the tokens being purchased by subjects who might otherwise have not known the optimal choices. Our econometric regression provided some support for this conjecture at instance where subjects in TRADE observed $b = 1$.

The results also shed some light on Kluger and Wyatts (2004) experiment findings with the Monty Hall problem, that when there are at least two Sophisticated subjects in the market, prices will converge to the equilibrium price. Clearly this is not the case in this paper, even when the data suggest there to be more than two Sophisticated subjects. Their results might have been due to the nature of the Monty Hall problem, where the "instinctive" price (Unsophisticated price) is naturally lower than the equilibrium price. When the instinctive price is less obvious, such as in this paper, their results may no longer hold.

The question therefore is why might subjects in TRADE be willing to purchase tokens at prices $p > 950 - 50b$, especially at instances where $b = 1$. A possible explanation is simply that such subjects may not be aware of their own limitations and hence mis-priced the tokens. This phenomenon is sometimes known in the behaviour finance literature as the "overconfidence effect" (Odean, 1998; Shleifer, 2000).

To some extend, the results might also shed some light to the empirical literature in corporate governance. In an extensive survey of the corporate takeover literature by Martynova and Renneboog (2008), the authors found little evidence that operating performances of the acquired firms had improved ex-post takeovers. Surveys on behavioural finance also suggest that bidding firms often overpay in corporate takeovers, a phenomenon usually known as the "Winner's Curse" (Kagel and Levin, 1986; Thaler, 1988; Barberis and Thaler, 2003). This paper capture some of the discussions with respect to the Winner's Curse as most subjects in TRADE who had purchased additional tokens, had done so at elevated prices and were found to have performed worse in the decisional task.

To conclude, this paper provides evidence that introducing a market where rights for performing tasks can be traded, do not naturally lead to the allocation of such rights to those players who might be best suited to perform the task. This is contradictory to the conventional wisdom and has important implications for any economic designer considering the best mechanism to allocate decisional tasks. Again it is important to emphasis that the task in this paper pertains to those requiring players to employ logical and epistemological reasoning. The conventional wisdom may hold in other circumstances, when the performances in the decisional tasks depend on other factors such as effort, information, knowledge or expertise. Nevertheless, we see potential for such a market design in other more straightforward games, e.g., Guessing Game (Nagel, 1995) , Centipede Game. This will be an ambition for further research.

REFERENCES

Asparouhova, Elena, Peter Bossaerts, Jon Eguia, and Bill Zame, 2012, Asset pricing and asymmetric reasoning, Working Paper.

Aumann, Robert J., 1976, Agreeing to disagree, *The Annals of Statistics* 4, 1236–1239.

Aumann, Robert J., 1999, Interactive epistemology I: Knowledge, *International Journal of Game Theory* 28, 263–300.

Barberis, Nicholas, and Richard Thaler, 2003, Chapter 18 a survey of behavioral finance, in M. Harris G.M. Constantinides, and R.M. Stulz, eds., *Financial Markets and Asset Pricing*, volume 1, Part B of *Handbook of the Economics of Finance*, 1053 – 1128 (Elsevier).

Bayer, Ralph C., and Mickey Chan, 2007, The dirty faces game revisited, School of Economics Working Papers 2007-01, University of Adelaide, School of Economics.

Brereton, J.M, 1986, *The British Soldier: A Social History from 1661 to the Present Day* (The Bodley Head Limited: London).

Bruce, Anthony P.C., 1980, *The Purchase System in the British Army, 1660-1871* (Royal Historical Society: London).

Camerer, Colin F., 2003, *Behavioral Game Theory: Experiments in Strategic Interaction* (Princeton University Press).

Costa-Gomes, Miguel A., Vincent P. Crawford, and Bruno Broseta, 2001, Cognition and behavior in normal-form games: An experimental study, *Econometrica* 69, 1193–1235.

De-Bondt, Werner F.M, and Richard Thaler, 1985, Does the stock market overreact?, *Journal of Finance* 40, 793–805.

Fagin, Ronald, Joseph Y. Halpern, Yoram Moses, and Moshe Vardi, 1995, *Reasoning About Knowledge* (Cambridge: MIT Press).

Fischbacher, Urs, 2007, z-tree: Zurich toolbox for ready-made economic experiments, *Experimental Economics* 10, 171–178.

Frederick, Shane, 2005, Cognitive reflection and decision making, *Journal of Economic Perspectives* 19, 25–42.

Fudenberg, Drew, and Jean Tirole, 1993, *Game Theory* (MIT Press, Cambridge).

Geanakoplos, John D., 1994, Common knowledge, in Robert Aumann, and Sergiu Hart, eds., *Handbook of Game Theory with Economic Applications*, volume 2, chapter 40, 1437–1496 (Elsevier).

Geanakoplos, John D., and Heraklis M. Polemarchakis, 1982, We can't disagree forever, *Journal of Economic Theory* 28, 192–200.

Greiner, Ben, 2004, The online recruitment system orsee 2.0 - a guide for the organization of experiments in economics, Working Paper Series in Economics 10, University of Cologne, Department of Economics.

Hirshleifer, David, 2001, Investor psychology and asset pricing, *Journal of Finance* 56, 1533–1597.

Jensen, Michael C., and Richard S. Ruback, 1983, The market for corporate control, *Journal of Financial Economics* 11, 5–50.

Kagel, John H., and Dan Levin, 1986, The winner's curse and public information in common value auctions, *American Economic Review* 76, 894–920.

Kluger, Brian D., and Steve B. Wyatts, 2004, Are judgement errors reflected in market prices and allocations? experimental evidence based on the monty hall problem, *Journal of Finance* 59, 969–997.

Littlewood, John E., 1953, *A Mathematician's Miscellany* (Meuthen and Co Ltd).

Martynova, Marina, and Luc Renneboog, 2008, A century of corporate takeovers: What have we learned and where do we stand?, *Journal of Banking and Finance* 32, 2148–2177.

Maschler, Michael, Eilon Solan, and Shmuel Zamir, 2013, *Game Theory* (Cambridge University Press).

Milgrom, Paul, and Nancy Stokey, 1982, Information, trade and common knowledge, *Journal of Economic Theory* 26, 17–27.

Myerson, Roger B., 1997, *Game Theory: Analysis of Conflict* (Harvard University Press).

Nagel, Rosemarie, 1995, Unraveling in guessing games: An experimental study, *American Economic Review* 85, 1313–1326.

Odean, Terrance, 1998, Volume, volatility, price and profit when all traders are above average, *Journal of Finance* 53, 1887–1934.

Osborne, Martin J., and Ariel Rubinstein, 1994, *A Course in Game Theory* (MIT Press, Cambridge).

Rabe-Hesketh, Sophia, Anders Skrondal, and Andrew Pickles, 2002, Reliable estimation of generalized linear mixed models using adaptive quadrature, *The Stata Journal* 2, 1–21.

Rabe-Hesketh, Sophia, Anders Skrondal, and Andrew Pickles, 2005, Maximum likelihood estimation of limited and discrete dependent variable models with nested random effects, *Journal of Econometrics* 128, 301 – 323.

Shleifer, Andrei, 2000, *Inefficient Markets* (Oxford University Press, Oxford).

Stahl, Dale O., and Paul W. Wilson, 1994, Experimental evidence on players' models of other experimental evidence on players' model of other players, *Journal of Economic Behavior and Organization* 25, 309–327.

Stahl, Dale O., and Paul W. Wilson, 1995, Models of other players: Theory and experimental evidence, *Games and Economic Behavior* 10, 218–254.

Thaler, Richard H., 1988, Anomalies: The winner's curse, *Journal of Economic Perspectives* 2, 191–202.

Weber, Roberto A., 2001, Behavior and learning in the "Dirty Faces" game, *Experimental Economics* 4, 229–242.

Appendix A. Instructions BASE1

There will be 10 experiment rounds, where you receive a payoff (denoted in ECU) at the end of each round. Upon completion of all 10 rounds, your earnings for the experiment will be computed as the average over ten rounds and converted to cash at the exchange rate of 67 ECU to £1. In addition, you will also receive a £5 show up fee. We shall now describe each experimental round.

Each round will involve three coloured hats - A, B and C. Each hat can be either Red or Black, and there is exactly one player under each hat.

1. You will not be able to see your own hat colour.

2. You will see on your computer screens the other two hat colours.

3. There will always be one black hat.

To determine the hat colours, the computer randomly picks from 1 of the 7 possible outcomes (see Table A1). For example, in outcome 2, Hat A is red, Hat B is black and Hat C is black. The player under Hat A will see that: Hat B is Black and Hat C is Black. The player under Hat B will see that: Hat A is Red and Hat C is Black. Finally, the player under Hat C will see that: Hat A is Red and Hat B is Black. There is an equal chance for any one of these outcomes. Notice that at each outcome, there will always be at least one black hat. See Figure A1 for an example of what you might observe. Here you are under Hat A and you see that both Hat B and C are black.

Your task in each round is to determine the colour of your hat. You will do this in the decision stage that will consist of 4 period. At each period the computer will present you with the following question, to which you must choose from 4 possible actions (a), (b), (c) or (d).

Computer's question: *"Do You Know your hat colour?"*

Your actions (a) My Hat is RED, (b) My Hat is BLACK, (c) No! I will decide in a later period and (d)Toss a Coin, I would never know.

Here are some rules:

RULE 1: *At each period, you have a maximum of 4 minutes to choose an action*

RULE 2: *You will immediately end the decision stage if the actions (a), (b) or (d) were chosen*

RULE 3: *You will only go to the next period if you had chosen (c) in the previous period*

RULE 4: *If you arrive at period 4, you can only chose from the actions (a), (b) or (d)*

RULE 5: *If you had chosen (d) the computer will simulate a coin toss and choose on your BEHALF either option (a) or (b) with equal chances*

RULE 6: *Any action chosen will be known to all other players in the subsequent period. Note: If you had chosen (d) and the computer chooses (b) on your behalf, the other players will only see that you had chosen (b).*

You are said to have "determined you hat colour" when you choose (a), (b) or (d). This is why you will only go to the next period if you have chosen (c). For example, if you had chosen (a) in period 1, the decision stage immediately ends for you. In period 2, all other players will observe that you had chosen (a) in period 1. However, if you had chosen (c) in period 1, you go on to period 2, when you must again choose your action. All players will also observe that you had chosen (c) in period 1. Here, are some screenshots to help you understand the decision stage design (Figure A2 and Figure A3).

Figure A2 presents an illustration of the first period in the decision stage. You are under Hat B and you see the other hat colours. In addition the computer presents you with the question "Do you know you hat colour" to which you must reply with one of the 4 possible actions.

Figure A3 presents an illustration of the second period in the decision stage. You are under Hat B and you see the other hat colours. The computer again presents you with the question "Do you know you hat colour" to which you must reply with one of the 4 possible actions. In addition, you also see on your screen the actions chosen by the other players in the previous period (period 1). You see that the player under Hat A had chosen (b) in period 1. You also see that the player under Hat C had chosen (b) in period 1. Finally, in this illustration you had chosen (c) in period 1.

After all players had ended the decision stage, your hat colour with be made known and your payoffs for the round will be determined. Your Payoffs depends on whether you had correctly determined you hat colour and the period which you had "determined your hat colour". If you had chosen (a) or (b), then your payoffs will depend on whether you are correct and the period which you had chosen them (see Table A2). If You had chosen (d), then your payoffs will only depend on the period which you had chosen (d) (see Table A3).

The payoffs can be easily summarised as followed. You start the round with 950 ECU. You get 50 ECU deducted for each time you had chosen (c). In addition, you get 700 ECU deducted if you had chosen (a) or (b) and was found to be incorrect, or no deduction if found to be correct. If you had chosen (d), you'll get a fixed deduction of 250 ECU. Here are some examples to help you understand the payoff

1. You hat is black. In period 1 you choose (c), in period 2 you choose (c) and in period 3 you choose (b). You have correctly determined your hat colour and your payoffs are therefore 850 ECU.
2. You hat is black. In period 1 you choose (c), in period 2 you choose (c) and in period 3 you choose (a). You have incorrectly determined your hat colour and your payoffs are therefore 150 ECU.
3. You hat is black. In period 1 you choose (c), in period 2 you (c) and in period 3 you choose (d). Your payoffs are therefore 600 ECU.

This completes the description of each experimental round. After the completion of 10 experiment rounds, we require you to complete a survey before you receive your cash payments. Please feel free to clarify any question or doubts you might have with regards to the instructions.

Table A1. BASE1: The 7 Possible Outcomes

Outcomes	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Chance	1/7	1/7	1/7	1/7	1/7	1/7	1/7
Hat A	B	R	B	B	B	R	R
Hat B	B	B	R	B	R	B	R
Hat C	B	B	B	R	R	R	B

B=BLACK and R=RED

Figure A1. Screen Shot (BASE1) - You see all other Hat colours

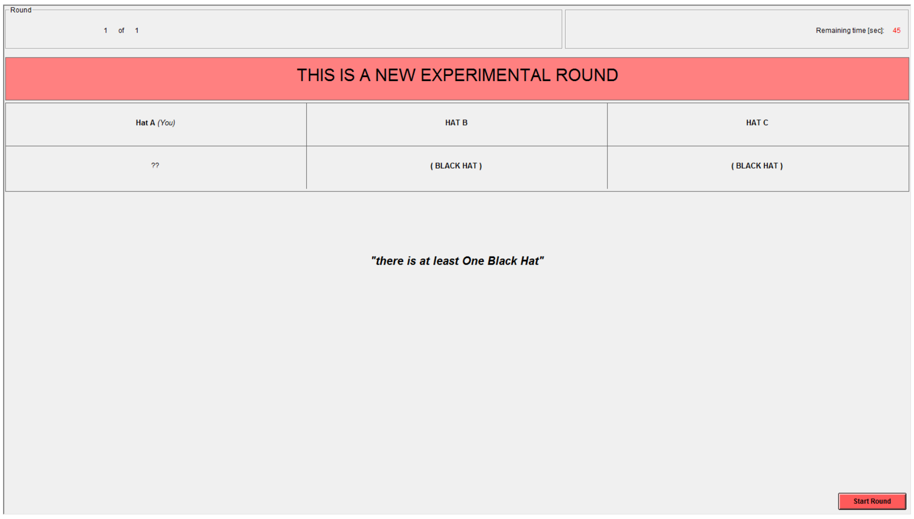


Figure A2. Screen Shot (BASE1) - Decision Stage Period 1

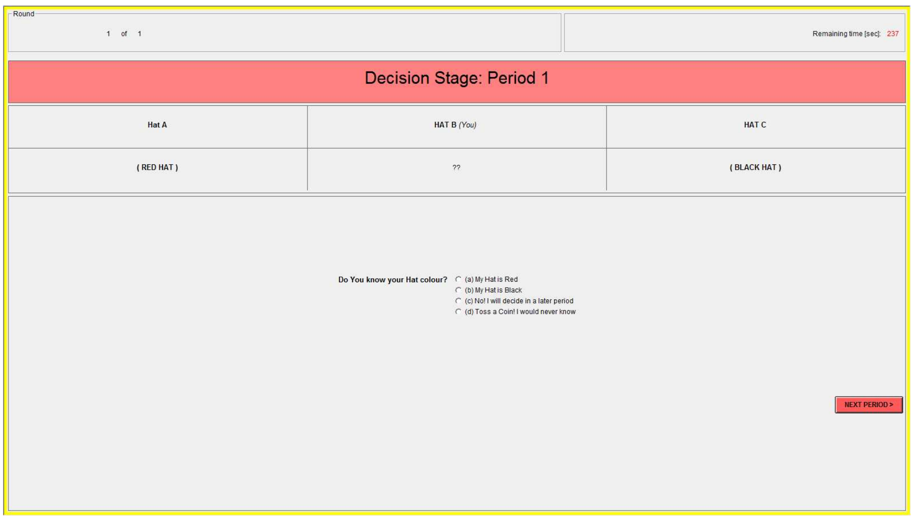


Figure A3. Screen Shot (BASE1) - Decision Stage Period 2

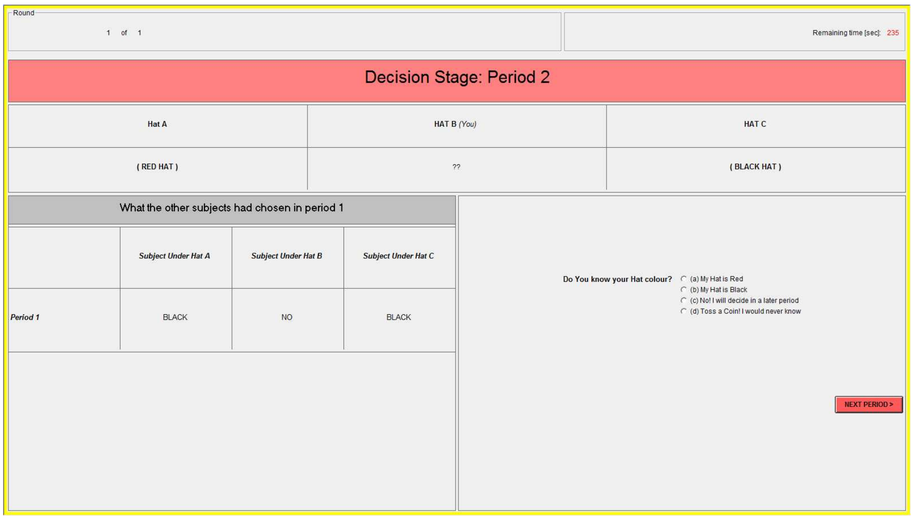


Table A2. BASE1: Payoffs with Choosing (a) or (b)

	Correct	Incorrect
“determined you hat colour” in Period 1	950 ECU	250 ECU
“determined you hat colour” in Period 2	900 ECU	200 ECU
“determined you hat colour” in Period 3	850 ECU	150 ECU
“determined you hat colour” in Period 4	800 ECU	100 ECU

Table A3. BASE1: Payoffs with Choosing (d)

“determined you hat colour” with (d) in Period 1	700ECU
“determined you hat colour” with (d) in Period 2	650ECU
“determined you hat colour” with (d) in Period 3	600ECU
“determined you hat colour” with (d) in Period 4	550ECU

Appendix B. Instructions BASE2

There will be 10 experiment rounds, where you receive a payoff (denoted in ECU) at the end of each round. Upon completion of all 10 rounds, your earnings for the experiment will be computed as the average over ten rounds and converted to cash at the exchange rate of 67 ECU to £1. In addition, you will also receive a £5 show up fee. We shall now describe each experimental round.

Each round will involve three coloured hats - A, B and C. Each hat can be either Red or Black, and there is exactly six players under each hat.

1. You will not be able to see your own hat colour.

2. You will see on your computer screens the other two hat colours.

3. There will always be one black hat.

To determine the hat colours, the computer randomly picks from 1 of the 7 possible outcomes (see Table B1). or example, in outcome 2, Hat A is red, Hat B is black and Hat C is black. The players under Hat A will see that: Hat B is Black and Hat C is Black. The players under Hat B will see that: Hat A is Red and Hat C is Black. Finally, the players under Hat C will see that: Hat A is Red and Hat B is Black. There is an equal chance for any one of these outcomes. Notice that at each outcome, there will always be at least one black hat. See Figure B1 for an example of what you might observe. Here you are under Hat A and you see that both Hat B and C are black.

Your task in each round is to determine the colour of your hat. You will do this in the decision stage that will consist of 4 period. At each period the computer will present you with the following question, to which you must choose from 4 possible actions (a), (b), (c) or (d).

Computer's question: *"Do You Know your hat colour?"*

Your actions (a) My Hat is RED, (b) My Hat is BLACK, (c) No! I will decide in a later period and (d)Toss a Coin, I would never know.

Here are some rules:

RULE 1: *At each period, you have a maximum of 4 minutes to choose an action*

RULE 2: *You will immediately end the decision stage if the actions (a), (b) or (d) were chosen*

RULE 3: *You will only go to the next period if you had chosen (c) in the previous period*

RULE 4: *If you arrive at period 4, you can only chose from the actions (a), (b) or (d)*

RULE 5: *If you had chosen (d) the computer will simulate a coin toss and choose on your BEHALF either option (a) or (b) with equal chances*

RULE 6: *Any action chosen will be known to all other players in the subsequent period. Note: If you had chosen (d) and the computer chooses (b) on your behalf, the other players will only see that you had chosen (b).*

You are said to have "determined you hat colour" when you choose (a), (b) or (d). This is why you will only go to the next period if you have chosen (c). For example, if you had chosen (a) in period 1, the decision stage immediately ends for you. In period 2, all other players will observe that you had chosen (a) in period 1. However, if you had chosen (c) in period 1, you go on to period 2, when you must again choose your action. All players will also observe that you had chosen (c) in period 1. Here, are some screenshots to help you understand the decision stage design (Figure B2, Figure B3 and Figure B4).

Figure B2 presents an illustration of the first period in the decision stage. You are under Hat B and you see the other hat colours. In addition the computer presents you with the question "Do you know you hat colour" to which you must reply with one of the 4 possible actions.

Figure B3 resents an illustration of the second period in the decision stage. You are under Hat A and you see the other hat colours. The computer again presents you with the question "Do you know you hat colour" to which you must reply with one of the 4 possible actions. In addition, you also see on your screen the actions chosen by the other players in the previous period. For the six players under Hat A, all of them had chosen (c) in period 1. For the six players under Hat B, one of them had chosen (a), one of them had chosen (b) and four of them had chosen (c) in period 1. Finally for the six players under Hat C, two of them had chosen (a), one of them had chosen (b) and three of them had chosen (c) in period 1.

Table B1. BASE2: The 7 Possible Outcomes

Outcomes	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Chance	1/7	1/7	1/7	1/7	1/7	1/7	1/7
Hat A	B	R	B	B	B	R	R
Hat B	B	B	R	B	R	B	R
Hat C	B	B	B	R	R	R	B

B=BLACK and R=RED

Table B2. BASE2: Payoffs with Choosing (a) or (b)

	Correct	Incorrect
"determined your hat colour" in Period 1	950 ECU	250 ECU
"determined your hat colour" in Period 2	900 ECU	200 ECU
"determined your hat colour" in Period 3	850 ECU	150 ECU
"determined your hat colour" in Period 4	800 ECU	100 ECU

Figure B4 presents an illustration of the third period in the decision stage. You are under Hat A and you see the other hat colours. The computer again presents you with the question "Do you know you hat colour" to which you must reply with one of the 4 possible actions. For the six players under Hat A, all of them had chosen (c) in period 2. For the six players under Hat B, two of them had chosen (b) in period 2, two of them had chosen (c) in period 2 and two of them had not participated in period 2 since they had ended the round in period 1 and are awaiting results. For the six players under Hat C, three of them had chosen (c) in period 2 and three of them had not participated in period 2 as they had ended the round in an earlier period.

After all players had ended the decision stage, your hat colour with be made known and your payoffs for the round will be determined. Your Payoffs depends on whether you had correctly determined you hat colour and the period which you had "determined your hat colour". If you had chosen (a) or (b), then your payoffs will depend on whether you are correct and the period which you had chosen them (see Table B2). If You had chosen (d), then your payoffs will only depend on the period which you had chosen (d) (see Table B3). Here are some examples to help you understand the payoffs:

The payoffs can be easily summarised as followed. You start the round with 950 ECU. You get 50 ECU deducted for each time you had chosen (c). In addition, you get 700 ECU deducted if you had chosen (a) or (b) and was found to be incorrect, or no deduction if found to be correct. If you had chosen (d), you'll get a fixed deduction of 250 ECU. Here are some examples to help you understand the payoff

1. You hat is black. In period 1 you choose (c), in period 2 you choose (c) and in period 3 you choose (b). You have correctly determined your hat colour and your payoffs are therefore 850 ECU.
2. You hat is black. In period 1 you choose (c), in period 2 you choose (c) and in period 3 you choose (a). You have incorrectly determined your hat colour and your payoffs are therefore 150 ECU.
3. You hat is black. In period 1 you choose (c), in period 2 you (c) and in period 3 you choose (d). Your payoffs are therefore 600 ECU.

This completes the description of each experimental round. After the completion of 10 experiment rounds, we require you to complete a survey before you receive your cash payments. Please feel free to clarify any question or doubts you might have with regards to the instructions.

Figure B1. Screen Shot (BASE2) - You see all other Hat colours

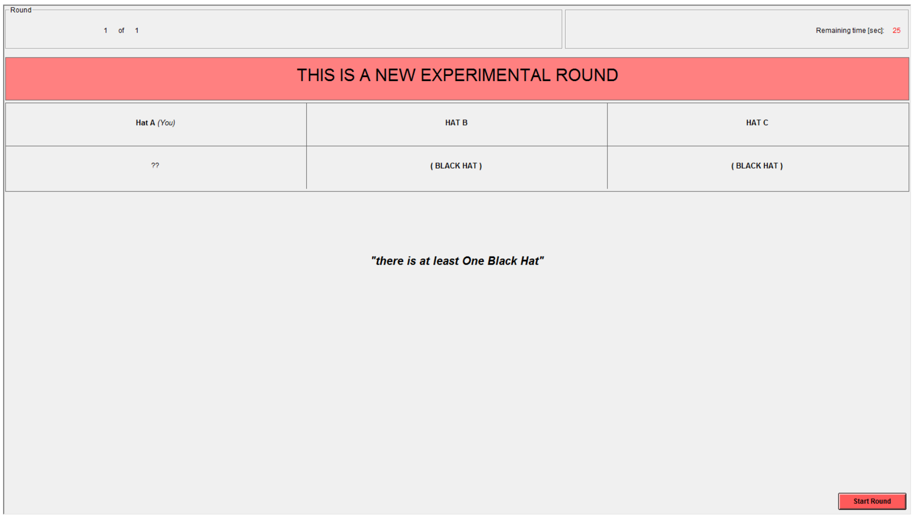


Figure B2. Screen Shot (BASE2) - Decision Stage Period 1

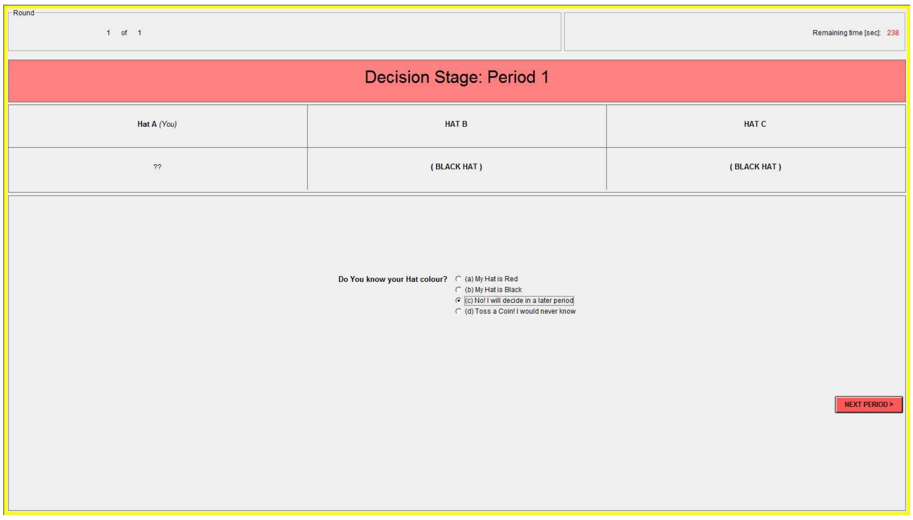


Table B3. BASE2: Payoffs with Choosing (d)

"determined your hat colour" with (d) in Period 1	700ECU
"determined your hat colour" with (d) in Period 2	650ECU
"determined your hat colour" with (d) in Period 3	600ECU
"determined your hat colour" with (d) in Period 4	550ECU

Figure B3. Screen Shot (BASE2) - Decision Stage Period 2

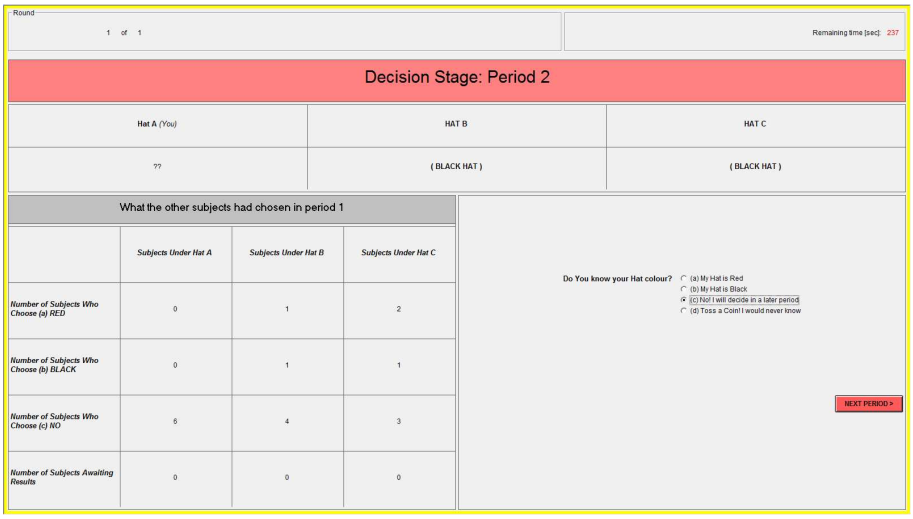
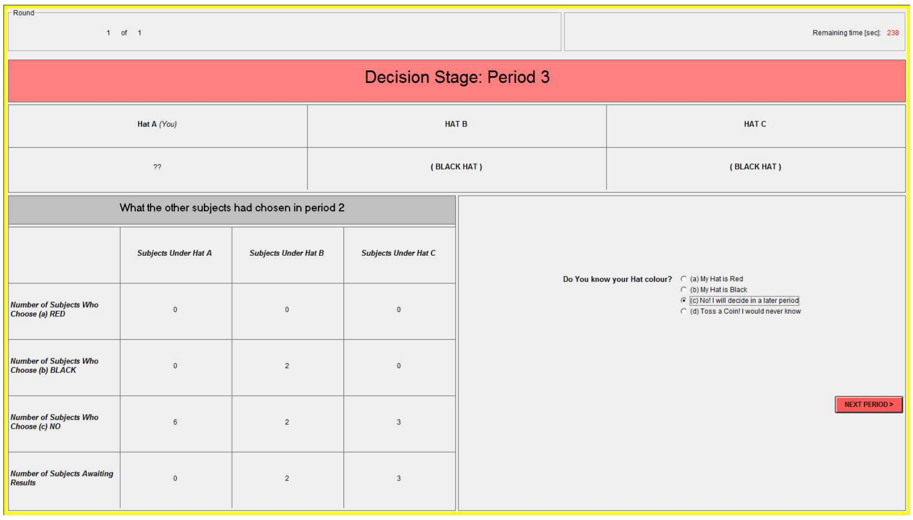


Figure B4. Screen Shot (BASE2) - Decision Stage Period 3



Appendix C. Instructions TRADE

There will be 10 experiment rounds, where you receive a payoff (denoted in ECU) at the end of each round. Upon completion of all 10 rounds, your earnings for the experiment will be computed as the average over ten rounds and converted to cash at the exchange rate of 100 ECU to £1. In addition, you will also receive a £8 show up fee. We shall now describe each experimental round.

Each round will involve three coloured hats - A, B and C. Each hat can be either Red or Black, and there is exactly six players under each hat.

1. You will not be able to see your own hat colour.

2. You will see on your computer screens the other two hat colours.

3. There will always be one black hat.

To determine the hat colours, the computer randomly picks from 1 of the 7 possible outcomes (see Table C1). or example, in outcome 2, Hat A is red, Hat B is black and Hat C is black. The players under Hat A will see that: Hat B is Black and Hat C is Black. The players under Hat B will see that: Hat A is Red and Hat C is Black. Finally, the players under Hat C will see that: Hat A is Red and Hat B is Black. There is an equal chance for any one of these outcomes. Notice that at each outcome, there will always be at least one black hat. See Figure C1 for an example of what you might observe. Here you are under Hat A and you see that both Hat B and C are black.

Overview of the Round

After you have observed the hat colours, the round will continued to the "trading stage" followed by the "decision stage". You begin the trading stage with 1 Token and a loan of 6000 ECU cash that must be returned at the end of the round. In the trading stage you have the opportunity to either buy more tokens or sell your token. You will only be trading with the other players under the same hat. After all transaction of tokens are completed, only players with at least one token will proceed to the decision stage - if you do not wish to participate in the decision stage, you should sell your token. In the decision stage, you will perform the task of determining your hat colour. After you have completed the decision stage, you will return the loan of 6000 ECU, and your tokens owned will redeemed by the computer (bought by the computer) at a rate that will depend on your behaviours in the decision stage. In the following, we shall first describe the design of the trading and decision stages. Thereafter, we will describe how you token redemption rate will be determined and finally we will describe your payoffs in the round.

Trading Stage

All players begin the trading stage with One Token and a loan 6000 ECU (Money) that must be paid back at the end of the round. Here you are permitted to buy or sell tokens, but only with the other players under the same hat. This implies that the market will consist of exactly 6 players and will last for 120 seconds. You will buy and sell tokens through a continuous double auction mechanism which we will now explain. See figure C2 for a screenshot of the trading stage.

The buy or sell tokens, you will need to first announce your "Ask" and "Bid" prices to all other players. Your Ask price (between 0 and 1200ECU) tells all other players how much you are willing to sell a token for. Your Bid price (between 0 and 1200ECU) tells all other players how much you are willing to buy a token for. The column "Market Ask Prices" reflects the ask prices of all six players you interact with. The column "Market Bid Prices" reflects the bid prices of all six players you interact with. To buy a token, simply select the price on the "Market Ask Prices" column and click "Buy". Likewise to sell tokens simply select the price on the "Market Bid Prices" column and click "sell". The column "Market Price" provides the history of all transaction prices for tokens. After 120 seconds, the trading stage will end and you will see on your screens the amount of money you have and the number of tokens you own. See figure C3 for a screenshot.

Decision Stage

Only players with at least one token can participate in the Decision Stage. If you do not have any tokens, you can observe the decision of all other players participating in the Decision Stage through your computer screens but may not yourself participate. You task in the decision stage is to determine the colour of your hat. The decision stage will consist of 4 periods. At each period the computer will present you with the following question, to which you must choose from 3 possible actions (a), (b) or (c).

Computer's question: *"Do You Know your hat colour?"*

Your actions (a) My Hat is RED, (b) My Hat is BLACK and (c) No! I will decide in a later period. Here are some rules:

RULE 1: *At each period, you have a maximum of 4 minutes to choose an action*

RULE 2: *You will immediately end the decision stage if the actions (a) or (b) were chosen*

RULE 3: *You will only go to the next period if you had chosen (c) in the previous period*

RULE 4: *If you arrive at period 4, you can only chose from the actions (a) or (b)*

RULE 5: *Any action chosen will be known to all other players in the subsequent period.*

Here, are some screenshots to help you understand the decision stage design (Figure C4, C5 and C6).

You are said to have "determined your hat colour" when you choose (a) or (b). This is why you will only go to the next period if you have chosen (c). To help you understand the experiment design we have include some screen shoots in Figures C4, C5 and C6.

Figure C4 presents an illustration of the first period in the decision stage. You are under Hat A and you see the other hat colours. In addition the computer presents you with the question "Do you know you hat colour" to which you must reply with one of the 3 possible actions.

Figure C5 presents an illustration of the second period in the decision stage. You are under Hat A and you see the other hat colours. The computer again presents you with the question "Do you know you hat colour" to which you must reply with one of the 3 possible actions. In addition, you also see on your screen the actions chosen by the other players in the previous period. Here there are only two players under hat A who had participated in the decision stage. One player has 4 tokens and the other player has 2 tokens. You see that the player with 4 tokens had chosen (c) in period 1 and the player with 2 tokens had chosen (c) in period 1. Under hat B, there are three players who had participated in the decisions stage. All three player have 2 tokens and had chosen (c) in period 1. Finally, under Hat C, there are 4 players who had participate in the decision stage, one of them has 3 tokens, whilst the other three have only one token. You see that the 3 token player had chosen (c) in period 1. Two of the players with one token had chosen (c) in period 1 whilst the last player, also with one token, had chosen (b) in period 1.

Figure C6 presents an illustration of the third period in the decision stage. You are under Hat A and you see the other hat colours. The computer again presents you with the question "Do you know you hat colour" to which you must reply with one of the 3 possible actions. There are two player under hat A. The two token player had chosen (c) in period 2. The four token player had chosen (b) in period 2. There are 3 players under hat B, each of them with two tokens. One of them had chosen (b) in period 2, whilst the other two had chosen (c) in period 2. There are four players under hat C. The three token player had chosen (c) in period 2. Amongst the one token players, one of them did not participate in period 2 as he had chosen either (a) or (b) in the period 1. Thus that player is said to have ended the game. However, the other two players with one tokens had chosen (b) in period 2.

Token Redemption Rate

After all players have completed the decision stage, your tokens will be redeemed by the computer. The redemption rate will depend on the period which you had "determined your hat colour" and whether you were correct. The payoffs can be easily summarised as followed. Each token is initially worth 950 ECU. The token's value decreases by 50 ECU for each time you had chosen (c). In addition, the tokens value decreases by 700 ECU if you had chosen (a) or (b) and was found to be incorrect, or 0 ECU if found to be correct. See Table C2 for an overview of the redemption rate. Here are some examples to help you understand the redemption rate:

1. You hat is black. In period 1 you choose (c), in period 2 you choose (c) and in period 3 you choose (b). You have correctly determined your hat colour and your token redemption rate is therefore 850 ECU.

Table C1. TRADE: The 7 Possible Outcomes

Outcomes	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Chance	1/7	1/7	1/7	1/7	1/7	1/7	1/7
Hat A	B	R	B	B	B	R	R
Hat B	B	B	R	B	R	B	R
Hat C	B	B	B	R	R	R	B

B=BLACK and R=RED

Table C2. TRADE: Token Redemption Rate

	Correct	Incorrect
"determined your hat colour" in Period 1	950 ECU	250 ECU
"determined your hat colour" in Period 2	900 ECU	200 ECU
"determined your hat colour" in Period 3	850 ECU	150 ECU
"determined your hat colour" in Period 4	800 ECU	100 ECU

2. You hat is black. In period 1 you choose (c), in period 2 you choose (c) and in period 3 you choose (a). You have incorrectly determined your hat colour and your token redemption rate is 150 ECU.

End of Round Payoff

Your payoffs at the end of each round will be determined as followed:

Payoffs = (Money After Trading Stage - 6000) + (Tokens) x (Redemption Rate)

If your payoffs will found to be negative, we will round it off to 0 ECU. This completes the description of each experimental round. After the completion of 10 experiment rounds, we require you to complete a survey before you receive your cash payments. Please feel free to clarify any question or doubts you might have with regards to the instructions.

Figure C1. Screen Shot (TRADE) - You see all other Hat colours

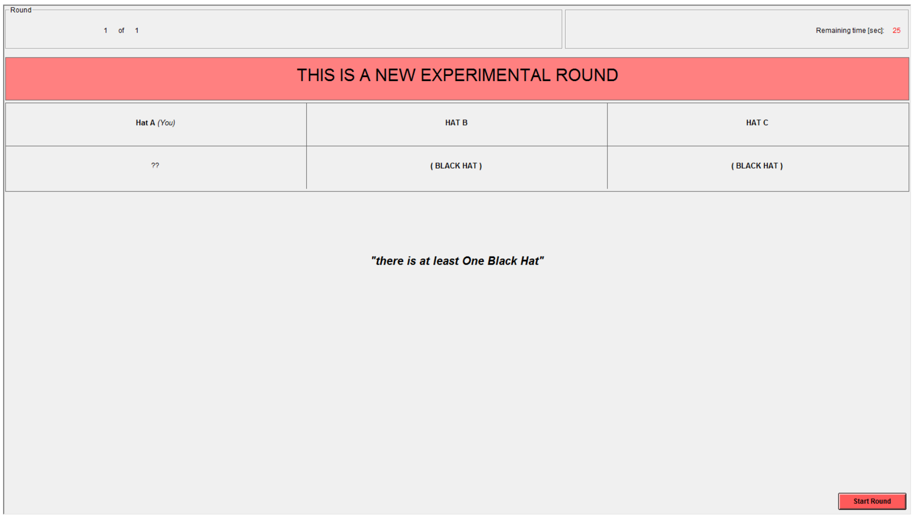


Figure C2. Screen Shot (TRADE) - Trading Stage

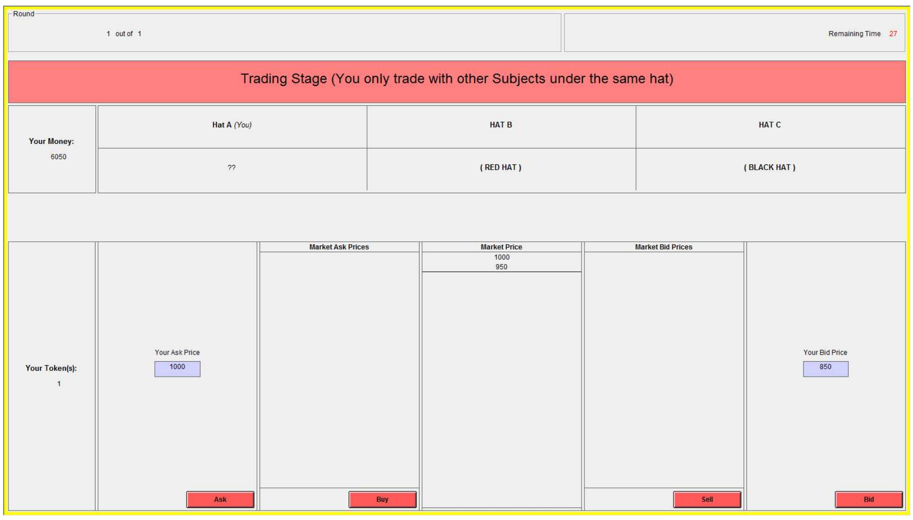


Figure C3. Screen Shot (TRADE) - Trading Stage Results

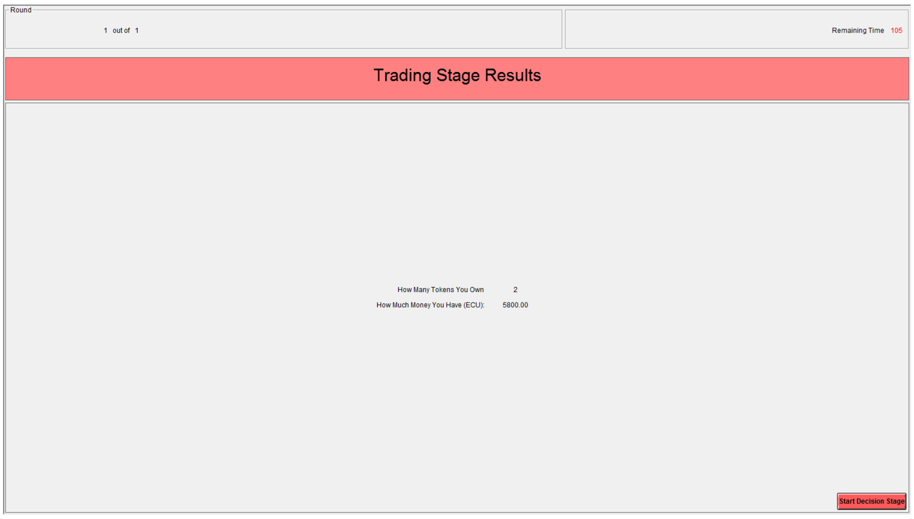


Figure C4. Screen Shot (TRADE) - Decision Stage Period 1

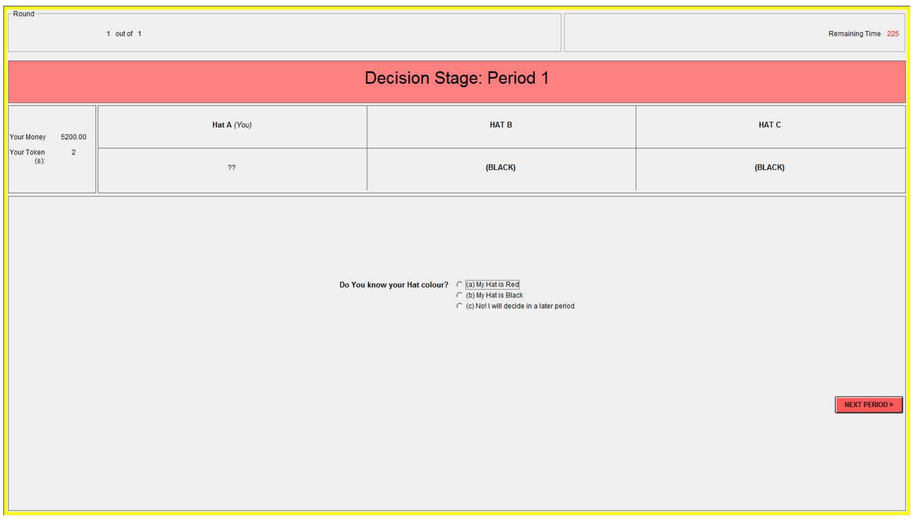


Figure C5. Screen Shot (TRADE) - Decision Stage Period 2

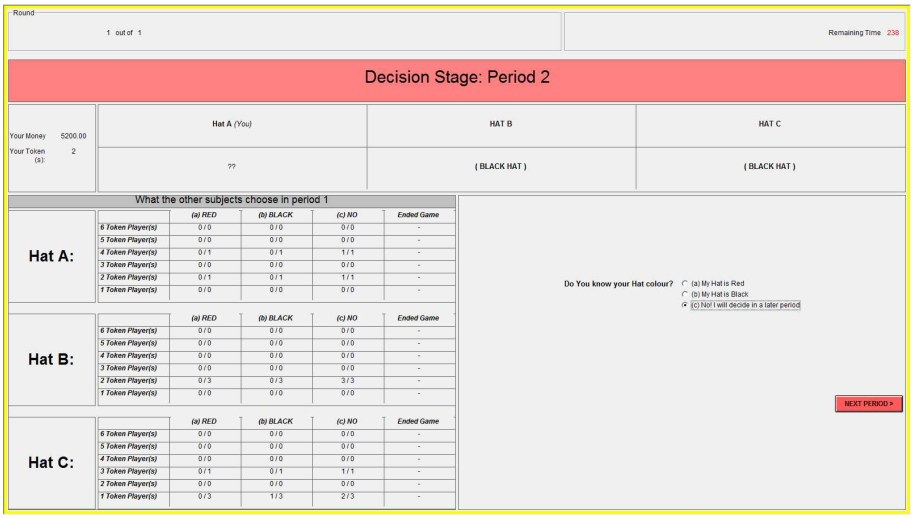


Figure C6. Screen Shot (TRADE) - Decision Stage Period 3