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Konstantinos Georgalos, Indrajit Ray and Sonali Sen Gupta

The Department of Economics
Lancaster University Management School
Lancaster LA1 4YX
UK

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Coarse Correlation and Coordination in a Game: An Experiment*

Konstantinos Georgalos[†], Indrajit Ray[‡] and Sonali Sen Gupta[§]

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Abstract

In a coarse correlated equilibrium (Moulin and Vial 1978), each player finds it optimal to commit ex ante to the future outcome from a probabilistic correlation device instead of playing any strategy of their own. In this paper, we consider a specific two-person game with unique pure Nash and correlated equilibrium and test the concept of coarse correlated equilibrium with a device which is an equally weighted lottery over three symmetric outcomes in the game including the Nash equilibrium, with higher expected payoff than the Nash payoff (as in Moulin and Vial 1978). We also test an individual choice between a lottery over the same payoffs with equal probabilities and the sure payoff as in the Nash equilibrium of the game. Subjects choose the individual lottery, however, they do not commit to the device in the game and instead coordinate to play the Nash equilibrium. We explain this behaviour as an equilibrium in the game.

Keywords: Correlation, Coordination, Lottery.

JEL Classification Numbers: C72, C91, C92, D63, D83.

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[†]Department of Economics, Management School, Lancaster University, Lancaster LA1 4YX, UK. E-mail: k.georgalos@lancaster.ac.uk; Fax: +44.1524.594244.

[‡]*Author for Correspondences.* Economics Section, Cardiff Business School, Cardiff University, Colum Drive, Cardiff CF10 3EU, UK. E-mail: rayi1@cardiff.ac.uk; Fax: +44.2920.874419.

[§]Department of Economics, Management School, Lancaster University, Lancaster LA1 4YX, UK. E-mail: s.sengupta@lancaster.ac.uk; Fax: +44.1524.594244.

1 INTRODUCTION

A direct correlation device is simply a probability distribution over the strategy profiles of a given normal form game which can be used as a mediator who selects the strategy profiles according to this probability distribution, commonly known to the players, and sends to each player the private recommendation to play the corresponding realised strategy. A (direct) correlated equilibrium (Aumann, 1974, 1987) is a direct correlation device with the equilibrium property that each player finds it optimal to follow the individual recommendation from the device (mediator).

In a coarse correlated equilibrium (Moulin and Vial 1978) the mediator uses a direct correlation device, however requires more commitment from the players: it first asks the players, before the correlation device operates, to either commit to the device and thereby get the outcome that the device would select or to reject the device and subsequently play any strategy of their own, without learning anything about the outcome of the distribution. The equilibrium property is that each player finds it optimal to commit *ex-ante* to the device and thus accept the outcome selected by the device.

A fairly recent, however, well-established experimental literature deals with the notion of correlated equilibrium (see Cason and Sharma, 2007; Duffy and Feltovich, 2010; Bone *et al*, 2013; Duffy *et al*, 2016; Anbarci *et al*, 2017). The main message of these papers is that players follow recommendations from a correlated equilibrium, but do not if it is not an equilibrium. However, to the best of our knowledge, there have been no attempts to understand the notion of coarse correlation in an experimental laboratory set-up. In this paper, we test whether or not the solution concept of coarse correlated equilibrium is observed in a specific two-person game.

For the purpose of this study, we use a specific two-person game and a coarse correlated equilibrium introduced by Moulin and Vial (1978) in their original paper on this concept. This two-player game has three strategies for each player; we need more than two strategies for coarse correlation to have an effect as the set of coarse correlated equilibrium is same as the set of correlated equilibrium for 2 x 2 games. The game has a unique Nash equilibrium, with payoffs (3, 3), which also is the solution of the iterative elimination of (strictly) dominated strategies in this game. Therefore, the correlated equilibrium for this game is also unique, which is the device with probability 1 on the Nash outcome.

We consider a specific correlation device (as in Moulin and Vial, 1978) which is an equally weighted lottery over only three symmetric outcomes, including the Nash equilibrium, on the diagonal in the payoff table; two outcomes other than the Nash equilibrium have payoffs of (5, 2) and (2, 5) respectively. The (expected) payoff for each player from accepting this device is thus $\frac{10}{3}$ which is higher than the Nash payoff. One can easily show that this device is indeed a coarse correlated equilibrium for the game, that is, accepting the device is a Nash equilibrium of the extended game we consider; also, it

does improve upon (in terms of the expected payoffs) the Nash equilibrium. We test the concept of coarse correlated equilibrium for this game using this device, that is, whether the players do accept this correlation device.

Before testing for coarse correlation, we first run two baseline treatments with the game and the correlation device, namely, Treatment 1 ($T1$) in which the players just play the game, without any correlation device and Treatment 2 ($T2$) where the device sends (private) messages to the players before they play the game. It is expected that the players will play the Nash equilibrium in $T1$ and indeed they do so. We know that the device is not a correlated equilibrium (as for this game, the Nash point is the only correlated equilibrium). Thus in $T2$, we expect that only the Nash equilibrium to be played when recommended whereas the other two recommendations will not be followed. We do observe this behaviour in $T2$, as in the literature on correlated equilibrium.

Our main treatment, Treatment 3 ($T3$), tests the theory of coarse correlated equilibrium. We expect, as in the existing literature on correlated equilibrium, the theoretical prediction to be observed here. Moreover, the structure of our device is similar to “sunspots” (Ray 2002; Polemarchakis and Ray, 2006); thus, following the well-known experiment on sunspots (Duffy and Fisher, 2005), we believe that the theoretical notion will be validated by our experiment as well.

As mentioned already, the correlation device we are using to test the notion of coarse correlation can be viewed as a lottery over three outcomes. We thus form an individual choice between a lottery over the same payoffs as in the device with equal probabilities and the sure payoff as in the Nash equilibrium of the game. We call this treatment Treatment 0 ($T0$). Choosing the lottery over the sure outcome for an individual is comparable to accepting the device for a player; thus $T0$ and $T3$ should generate similar results. We expect agents to accept the lottery in $T0$ and accept the device in $T3$ as the expected payoffs are higher, assuming our subjects are either risk seeker or risk neutral (or even mildly risk averse, for who the certainty equivalent of this lottery is between 3 and $\frac{10}{3}$). We observe, in $T0$, individuals accept the lottery, however in $T3$, they do not commit to the device and instead coordinate to play the Nash equilibrium in the game. This behaviour is apparently contradictory to each other.

For each of the four treatments, we analyse some key factors behind the players’ behaviour within a treatment. We examine the significance of several factors using a standard Probit analysis and summarise our findings, for each of our treatments.

To our surprise, we observe a failure of the theoretical notion of coarse correlated equilibrium in our experiment. A naive explanation of rejecting the correlation device could be that the players are sufficiently risk averse to have rejected such a lottery. However, clearly, it can not be just due to risk-aversion as the individuals have chosen the lottery mimicking the outcomes from the device in

T0. One may also think that this failure is due to the specific choice of the device. We should stress that the chosen device is *Nash-centric* (Ray and Sen Gupta, 2013) and thus has desirable properties (Moulin, Ray and Sen Gupta, 2014).

We do offer a few interpretations of this apparent failure of the theoretical notion. First, we note that although the correlation device is procedurally fair, the outcomes are not fair (Bolton *et al*, 2005; Krawczyk, 2011; Trautmann and Vieider, 2012; Trautmann and van de Kuilen, 2016). It is a well-established fact that individuals are averse to randomisers (Keren and Teigen, 2010) and favour *ex-post* equality in outcomes (Cappelen *et al*, 2013). Our result is in line with Andreoni *et al* (2002) who found that the equilibrium prediction may fail when the equilibrium outcome consists of unequal payoffs.

Second, our players may not be sure of the probabilities in the device, that is, they may find the probability distribution ambiguous. They may use the *principle of insufficient reason* or the *principle of indifference* which implies that the players replace the given correlation device by a uniform probability distribution and hence, reject the device.

The most compelling interpretation however is an equilibrium behaviour, that is, the players are playing a different Nash equilibrium in the game. In a coarse correlated equilibrium, accepting the device is a Nash equilibrium of the extended game; however, this equilibrium may not be unique and there may be other (Nash) equilibria of the extended game. Indeed, we prove that not accepting the device by both players and subsequently playing the Nash equilibrium in the game is an equilibrium. All these interpretations are discussed in detail at the end of this paper.

2 MODEL

We present below the concept of (coarse) correlation used in our experiment, just for the sake of completeness. Here we closely follow the notations and definitions used in Moulin, Ray and Sen Gupta (2014), Ray and Sen Gupta (2013) and Kar, Ray and Serrano (2010) where more details can be found.

For any fixed finite normal form game, $G = [N, \{S_i\}_{i \in N}, \{u_i\}_{i \in N}]$, with set of players, $N = \{1, \dots, n\}$, finite pure strategy sets, S_1, \dots, S_n with $S = \prod_{i \in N} S_i$, and payoff functions, u_1, \dots, u_n , $u_i : S \rightarrow \mathfrak{R}$, for all i , a direct correlation device μ is simply a probability distribution over S . In this paper, we will consider direct devices only and therefore in the rest of the paper, we will call such a device just a correlation device (or a device, in short) for convenience.

A finite normal form game, G , can be extended by using a correlation device. For correlation *a la* Aumann (1974, 1987), the device first selects a strategy profile $s (= (s_1, \dots, s_n))$ according to μ , and then sends the private recommendation s_i to each player i . One may consider specific types of devices, such as, devices for which recommendations are “public”.

Definition 1 Given a correlation device μ , a strategy profile $s (= (s_1, \dots, s_n))$, is called a public recommendation, if $\mu(s) > 0$ and the conditional probability of (s_{-i}) given s_i is 1, for all i . A correlation device μ is called a public device if for all $s \in S$, either $\mu(s) = 0$ or s is a public recommendation.

A public device may even be considered as a “sunspot” as players may coordinate using such public recommendations (Ray 2002; Polemarchakis and Ray, 2006). The extended game G_μ is the game where the correlation device μ selects and sends recommendations to the players, and then the players play the original game G . A correlation device is called a correlated equilibrium (Aumann 1974, 1987) if all the players follow the recommended strategies, i.e., the obedient strategy profile (which is the identity map $\sigma_i^*(s_i) = s_i$, for all i , with payoff to player i given by $u_i^*(\sigma^*) = \sum_{s \in S} \mu(s)u_i(s)$) constitutes a Nash equilibrium of the extended game G_μ . Formally, with the notation $s_{-i} \in S_{-i} = \prod_{j \neq i} S_j$,

Definition 2 μ is a correlated equilibrium of the game G if for all i , for all $s_i, t_i \in S_i$,

$$\sum_{s_{-i} \in S_{-i}} \mu(s_i, s_{-i})u_i(s_i, s_{-i}) \geq \sum_{s_{-i} \in S_{-i}} \mu(s_i, s_{-i})u_i(t_i, s_{-i}).$$

For any finite normal form game G , let $NE(G)$ denote the set of all degenerate distributions that correspond to any pure Nash equilibrium point and $CONV(G)$ denote any convex combination of several pure Nash equilibria. Let $CE(G)$ denote the set of all direct correlated equilibria of a given game G . Clearly, $NE(G) \subseteq CONV(G) \subseteq CE(G)$. Moreover, a public device is a correlated equilibrium if and only if all the public recommendations in the device are (pure) Nash equilibria. Let $P(G)$ denote the set of all correlated equilibria that are also public devices. It is thus obvious that $P(G)$ must coincide with $CONV(G)$. Hence, $NE(G) \subseteq CONV(G) = P(G) \subseteq CE(G)$.

One may use a correlation device, μ , in a different way in a finite normal form game to get a coarser notion of correlation, *a la* Moulin and Vial (1978). A game G may be extended to a game G'_μ in which the strategies of a player is either to commit to the correlation device or to play any strategy in G . If all the players commit to the device, an outcome is chosen by the device according to the probability distribution μ . Thus, the expected payoff for any player i , when the device is accepted by all the players, is simply $\sum_{s \in S} \mu(s)u_i(s)$ (which is the same as the payoff of the obedient strategy profile under G_μ above). If one of the players unilaterally deviates, while the others commit to the device, the deviant faces the *marginal* probability distribution μ'_i over $s_{-i} \in S_{-i}$ which is given by $\mu'_i(s_{-i}) = \sum_{s_i \in S_i} \mu(s_i, s_{-i})$. The notion of coarse correlated equilibrium¹ requires all players to accept the device if the expected payoff from the device is at least as high as that from playing any other

¹This notion is due to Moulin and Vial (1978) who called this equilibrium concept a *correlation scheme*. Young (2004) and Roughgarden (2009) introduced the terminology of coarse correlated equilibrium that was later adopted by Ray and Sen Gupta (2013) and Moulin, Ray and Sen Gupta (2014), while Forgó (2010) called it a *weak correlated equilibrium*.

strategy (from the entire set of strategies); that is, accepting the device is a Nash equilibrium of the extended game G'_μ . Formally,

Definition 3 μ is a coarse correlated equilibrium of the game G if for all i , for all $t_i \in S_i$,

$$\sum_{s \in S} \mu(s) u_i(s) \geq \sum_{s_{-i} \in S_{-i}} \mu'_i(s_{-i}) u_i(t_i, s_{-i}).$$

From the system of inequalities² in Definitions 2 and 3, it is clear that the set of coarse correlated equilibria is indeed coarser than the set of correlated equilibria.³ Also, it is obvious that any Nash equilibrium and any convex combination of several Nash equilibria of any given game G is both a coarse correlated and a correlated equilibrium. Formally, let $CCE(G)$ denote the set of all coarse correlated equilibria for any game G . Clearly, $NE(G) \subseteq CONV(G) = P(G) \subseteq CE(G) \subseteq CCE(G)$.

2.1 Game

We consider the following two-person game in which each player has three pure strategies (originally used in Moulin and Vial (1978), as mentioned in Footnote 3). Player 1 has three pure strategies, namely A , B and C while player 2's pure strategies are X , Y and Z . The payoff matrix is given in the following table (Table 1).

	X	Y	Z
A	3, 3	1, 1	4, 1
B	1, 4	5, 2	0, 0
C	1, 1	0, 0	2, 5

Table 1: The Game

It is fairly easy to analyse the above game by iterative elimination of dominated strategies. First, note that the strategies C and Y are strictly dominated (by A and X respectively). Having eliminated C and Y , in the reduced game (with two strategies for each player), clearly the profile (A, X) is the unique outcome using dominant strategies (A dominates B and X dominates Z).

Obviously, (A, X) is the unique Nash equilibrium of the above game. It is easy to show that (A, X) is also the only correlated equilibrium of the above game; that is, the device with probability 1 on

²Following Aumann (1974) and Moulin and Vial (1978), we have used weak inequalities in our definitions (Definition 2 and Definition 3). We note that strict inequalities may be considered in these definitions; indeed, Gerard-Varet and Moulin (1978) did so in their definition of equilibrium.

³It is easy to prove that the set of correlated and coarse correlated equilibria coincide for the case of 2×2 games. However, as Moulin and Vial (1978) demonstrated, there are games, one of which we will use in this paper, involving 2 players and 3 strategies for each player for which the set of coarse correlated equilibria is strictly larger than the sets of correlated and Nash equilibria.

(A, X) is the only device which is a correlated equilibrium for this game. Therefore, for this game, G , we have $NE(G) = CONV(G) = P(G) = CE(G)$.

We now consider the following correlation device, as in Table 2, that we refer to as the *public* device in the rest of the paper. Clearly, the device is a public device as the probabilities are positive only for the outcomes (A, X) , (B, Y) and (C, Z) , all of which are public recommendations (as in Definition 1).

	X	Y	Z
A	$\frac{1}{3}$	0	0
B	0	$\frac{1}{3}$	0
C	0	0	$\frac{1}{3}$

Table 2: The (Public) Correlation Device

As already mentioned, we have a unique correlated equilibrium for the game. This public device is clearly not a correlated equilibrium, as not all three public recommendations in the device are Nash equilibria of the game. For example, if the outcome (B, Y) is selected by the device and players 1 and 2 are recommended to play B and Y respectively, then player 2 will not follow the recommendation Y (and play X instead); similarly, if the outcome (C, Z) is selected by the device, then player 1 will not follow the recommendation C (and play A instead).

However, this public device is indeed a coarse correlated equilibrium. To check if the device is a coarse correlated equilibrium or not, we need to check whether committing to the device is a Nash equilibrium or not, that is, to check whether committing is the best response of a player given that the other player is committing. Given that player 2 commits to the device, player 1 gets an expected payoff of $\frac{10}{3}$ ($= \frac{1}{3}(3 + 5 + 2)$) from committing. However, if player 1 decides not to commit and instead plays the pure strategy A , player 1 gets an expected payoff of $\frac{8}{3}$ ($= \frac{1}{3}(3 + 1 + 4)$) as the device picks all three strategies for player 2 with probability $\frac{1}{3}$ each; similarly, player 1 gets an expected payoff of 2 ($= \frac{1}{3}(1 + 5 + 0)$) from playing B and 1 ($= \frac{1}{3}(1 + 0 + 2)$) from C . Therefore, player 1 does not have an incentive to deviate from committing to the device, assuming player 2 does commit. Similarly, one may check that player 2 should commit given that player 1 commits to the device as well. Therefore, this public device is a coarse correlated equilibrium for the above game.

Clearly, this coarse correlated equilibrium improves over the Nash equilibrium payoff (as $\frac{10}{3} > 3$). However, this device is not the unique coarse correlated equilibrium; another public device with probability $\frac{1}{2}$ on each of the outcomes (B, Y) and (C, Z) is also a coarse correlated equilibrium for this game, giving an even higher payoff of 3.5 to each of the two players. The public device as shown in Table 2 includes the Nash equilibrium that can be tested as a (public) recommendation.

In this paper, we therefore use the public device as described in Table 2 as a coarse correlated equilibrium for the game in Table 1 to set up different treatments for our experiment.

2.2 Lottery

Based on the outcomes of the game as described in the previous subsection (Table 1), we now consider an individual choice between a lottery and a sure outcome. The coarse correlated equilibrium, as in Table 2, picks only three possible outcomes of the game with equal probabilities. In these three outcomes, player 1 gets respectively 3, 5 and 2 while player 2 gets 3, 2 and 5 respectively. In the Nash equilibrium of the game, each player gets 3. Using these three outcomes, we now construct the following two individual choice problems.

In the first choice problem, we ask an individual to choose between the lottery that picks one of three outcomes $\mathcal{L}3$, $\mathcal{L}5$ and $\mathcal{L}2$ each with probability $\frac{1}{3}$ and the sure (with probability 1) outcome of $\mathcal{L}3$. In our experiment (see below) a group of individuals (that we call the Red group) faces this choice problem. In our second choice problem, a group of individuals (that we call the Blue group) are asked to choose between the lottery that picks one of three outcomes $\mathcal{L}3$, $\mathcal{L}2$ and $\mathcal{L}5$ each with probability $\frac{1}{3}$ and the sure (with probability 1) outcome of $\mathcal{L}3$. Needless to say, these choices mimic the outcomes chosen by the coarse correlated equilibrium and the Nash equilibrium of the game; two different choice problems for two groups mirror the outcomes for players 1 and 2 respectively. The only difference between the two choice problems for two groups is the framing (the order) of the outcomes in the lottery; in the second lottery, the outcome $\mathcal{L}2$ (as opposed to $\mathcal{L}5$ in the first lottery) comes immediately after $\mathcal{L}3$, which is lower in value and thus may create an aversion that can be tested in the experiment. This is in line with the two types of players (row and column respectively) in the game and the three outcomes they get using the coarse correlated equilibrium.

Note that we are not really testing whether the individuals are risk averse or not (as the sure outcome is $\mathcal{L}3$ and not the expected value of the lottery which is $\mathcal{L}\frac{10}{3}$). Those who accept the lottery (over the sure outcome of $\mathcal{L}3$) are not necessarily risk-averse or risk-seeker; clearly, for them, the certainty equivalent of the lottery is more than 3. Individuals who are risk-neutral or risk-seeker will certainly accept the lottery; even some risk-averse individuals (for whom the certainty equivalent is between $\mathcal{L}3$ and $\mathcal{L}\frac{10}{3}$) will accept the lottery. However, whatever be their risk attitude, it should be the same for the individual choice and for the coarse correlated equilibrium in the game, as the outcomes and the corresponding probabilities are identical in both set-up.

3 EXPERIMENTS

The main focus of our paper is on the validity of the coarse correlated equilibrium for a given game. Therefore, we have three main treatments in which we deal with the game and correlation.

In the first of the three treatments ($T1$), we just use the game (as in Table 1) without any kind of

correlation device or recommendations. In the second treatment ($T2$), we use the correlation device (as in Table 2) to send non-binding recommendations to the players to test whether these recommendations are followed or not. Finally, in the third treatment ($T3$), we use the device as a commitment device, rather than for sending recommendations, to test the concept of coarse correlation. On top of these, we do have an individual choice treatment ($T0$), in which the subjects are asked to choose among a sure outcome and a lottery as explained above. This individual treatment ($T0$) should contrast the treatment $T3$ as the outcomes of the lottery and that from the coarse correlated equilibrium are identical.

3.1 Design

The overview of the experimental sessions is summarised in Table 3 below.

Treatment	#Subjects	#Periods	#Observations
$T0$ (Individual Choice)	$12 \times 4 = 48$	20	960
$T1$ (Nash Equilibrium)	$12 \times 4 = 48$	20	960
$T2$ (Correlated Equilibrium)	$12 \times 4 = 48$	20	960
$T3$ (Coarse Correlated Equilibrium)	$12 \times 4 = 48$	20	960

Table 3: Experimental Design

In our study, we have collected data from 4 treatments with 4 sessions each. In total there were 16 sessions, 4 for each treatment, with 12 subjects participating at each session. Table 3 above provides a summary of the treatments and the sessions. Participants interact in groups of 6 (6 are assigned as Blue players and 6 as Red). In every round, every participant interacts with one of the six participants of the other group based on a random-matching protocol, as explained below.

As the game under investigation is not symmetric, each individual was first assigned to a role of either a row or a column player. These roles were fixed throughout the experiment, that is, a participant who was assigned to be a row player in the first round, remained a row player for all the rounds of the experiment. We labelled the row and column players as Red and Blue individuals respectively. In each session, a matching group participated; a matching group consists of 12 participants, out of which 6 belong to the Red group and the rest to the Blue. In the first round, every member of the Red group was randomly matched to a member of the Blue group. Then, before the start of any subsequent round, there was a re-matching of the pairs based on the random matching protocol. The latter was implemented, following the common practice, in order to create an environment as close as possible to a one-shot interaction between subjects. In addition, there was no way for a participant to identify the opponent with who they were matched. As was mentioned earlier, the groups remained fixed during

a session and a Red player could be matched with any of the six Blue players. We consider every matching group as an independent observation.

In $T1$, subjects simply clicked on their preferred choice and when they were happy with their decisions made, they could confirm their choice by clicking the “OK” button. In $T2$, the framework was the same as in $T1$ with the difference that now an individual recommendation was made to the pair on what action to choose. The software was programmed to generate i.i.d. recommendations for each pair, based on a uniform distribution over the three possible outcomes. The recommendations were uniquely generated for each session for $T2$. In $T3$, the choice was made in one or two stages, depending on whether subjects were willing to commit to the correlation device or not. During the first stage, the subjects could see the correlation device and were asked whether they would like to allow the computer to make a choice for them (equivalent to committing to the device). There are three possible cases: (1) if both members of the pair did not want to commit, then the second stage appeared to their screens which was identical to the framework of $T1$ (the game without any correlation device or recommendations). Then the subjects could choose their preferred action; (2) in the case where both members of the pair were willing to commit to the device, there was no second stage, the computer was randomly choosing one of the possible three outcomes and the subjects were receiving the corresponding payoff; (3) finally, if a member of the pair wanted to commit and the other did not, then the latter could see the second stage of the game and indicate her choice while for the former, the choice was randomly made by the computer based on the correlation device. The payoff was then determined by the combination of the randomly chosen action by the computer and the action that the other player picked.

In $T2$ and $T3$, the device is commonly known to the players (explained in the instructions and also read out loud before the experiment) and is implemented using a random number generator programmed to create recommendations or actions based on the probability distribution of the device.

In $T0$, subjects had to choose between a sure payment of $\pounds 3$ or a lottery involving outcomes $\pounds 2$, $\pounds 3$ or $\pounds 5$ with equal chances. Again, subjects were split in two groups: Red and Blue. Red individuals could see the outcomes of the lottery in the order $\pounds 3$, $\pounds 5$, $\pounds 2$ while Blue players could see it in the form $\pounds 3$, $\pounds 2$, $\pounds 5$. This was chosen in order to replicate the potential framing effects that could appear in the sessions, as the payoffs from the outcomes of the game for the row and the column players come in a different order. At each round, after the subjects have made and confirmed their choices, they were informed about their payoff in that round (either $\pounds 3$ if they have chosen the sure outcome or the outcome that was randomly chosen by the computer if the subject had chosen the lottery).

3.2 Procedures

The experiment was conducted at the Lancaster Experimental Economics Lab (LExEL). In total 192 subjects (out of which 52% were females) participated in four treatments. The participants were mostly undergraduate students from the Lancaster University, from various fields of studies and were invited using the ORSEE recruitment system (Greiner, 2015). The experiment was computerised and the experimental software was developed in Python. Each session was devoted to a single treatment, which implies that $\frac{1}{4}$ of the subject population participated in each of the four treatments.

All sessions used an identical protocol. Upon arrival at the lab, participants were randomly allocated to computer terminals. At the beginning of a session, subjects were seated and given a set of printed experimental instructions (see the Appendices) which were also read aloud so as to ensure common knowledge. After the instructions phase, the participants were asked to complete a brief comprehension test (see Appendix) to confirm that there were no misunderstandings regarding the game, the matching procedure, the correlation device and the payoffs. When the subjects had done the test, we made sure that they had all the answers correct. The experiment did not proceed until every subject had the correct answers to these questions. Subjects could not communicate with each other, neither could they observe the choices of other participants during the experiment.

Effort was made to use neutral language in the instructions and the wording during the experiment, to avoid potential connotations. The actions of the players were represented as choices A , B and C (X , Y and Z) for the row (column) player. The opponent player was labelled as the counterpart. Any recommendation in $T2$ was given in a way that it didn't imply whether it is better to follow. Similarly, in $T3$, the commitment choice was framed as whether a participant would like the computer to choose according to the device; it was made clear that the choice is entirely up to the participants.

In all treatments, subjects interacted for a total of 20 rounds. For each round, subjects had 1.5 minutes (2.5 in $T3$) for the first 10 rounds to confirm their choices and 1 minute (1.5 in $T3$) for the rest of the rounds. If no decision was made by that time, the software was programmed to randomly choose one of the three actions. At the end of every round, subjects received the following feedback: own and opponent's choice, own and opponent's payoff, own and opponent's recommendation (in $T2$), own and opponent's commitment choice (in $T3$).

At the end of round 20, the experimental session ended and the subjects were privately paid, according to their point earnings. In the treatments involving the game ($T1$, $T2$ and $T3$), we used an exchange rate of 1 : 1 (£1 per point). For the payment, the random incentive mechanism was implemented; two rounds out of the total 20 were randomly selected for all the participants. The payments were made in private and in cash directly after the end of the experiment. The average

payment was £9.62 including a show-up fee of £3.00 and the experimental sessions lasted less than 45 minutes that correspond to an approximate hourly rate of £12.83 (\$16.68) which is way higher than student-jobs in the UK that offer about £8.00 (\$10.40) per hour.

3.3 Hypotheses

In this subsection, we formally present our theoretical hypotheses, following the set-up in Section 2. For each of our four treatments, we expect the theoretical predictions to be observed. Thus, our hypotheses are the theoretical predictions, some of which are already confirmed in the existing literature. We present one hypothesis for each of our treatments.

Our first null hypothesis below is about the outcome played in the game in $T1$.

Hypothesis 1 *In $T1$, individuals do not play the dominated strategies (C and Y respectively) and they do play the unique Nash equilibrium (A, X) in the game.*

We expect Hypothesis 1 to be accepted based on the observation in $T1$ as it is fairly well established in the literature. Our second null hypothesis below is about correlated equilibrium in $T2$.

Hypothesis 2 *In $T2$, individuals play (A, X) in the game when recommended however do not follow the recommendations (B, Y) and (C, Z) and play (A, X) in the game instead.*

Once again, we expect Hypothesis 2 to be accepted, following the literature on correlated equilibrium (see Cason and Sharma, 2007; Duffy and Feltovich, 2010; Bone *et al*, 2013; Duffy *et al*, 2016; Anbarci *et al*, 2017).

We now focus on the $T0$ and $T3$. These two treatments are similar; choosing the lottery in $T0$ and committing to the device in $T3$ result in the same outcomes with the same probabilities; thus the risk attitude in the individual choice should be the same, on average, to that in the game. Therefore, we expect that the results should be similar in these two treatments.

We expect coarse correlated equilibrium to be observed in $T3$; the incentive constraints behind coarse correlated equilibrium involving expected payoffs assume risk-neutrality; that is, risk-neutral players will accept the device. As mentioned earlier, risk-neutral or risk-seeker will certainly accept the lottery in $T0$; even mildly risk-averse individuals (with certainty equivalent between £3 and £ $\frac{10}{3}$) will accept the lottery. We however do not expect any framing effect among the two different specifications of the same lottery used for two groups in $T0$. Thus our last two hypotheses are as below.

Hypothesis 3 *Individuals choose the lottery in $T0$; there is no difference among the two groups, that is, there is no framing effect.*

Hypothesis 4 *In $T3$, individuals commit to the correlation device for the game.*

4 ANALYSIS

In the first two subsections, we first analyse the data obtained from the treatments $T1$ and $T2$ involving the unique Nash and correlated equilibrium for our game. As mentioned earlier, following the existing literature, there should not be any surprises here; our Hypotheses 1 and 2 should be accepted based on the observations in $T1$ and $T2$.

4.1 $T1$: Nash Equilibrium

In this subsection, our main concern is whether the individuals coordinated on the unique Nash equilibrium outcome (AX) of the game or not. We thus first look at the observed frequencies of the outcomes (strategy profiles played) in the game. Overall, as expected, a huge proportion (433 out of 480, that is, 90.2%) of the outcomes played is indeed the Nash equilibrium outcome (AX). The following table (Table 4) presents the frequencies of all the outcomes of the game, divided into four equal five-period blocks (each out of 120) and the total for 20 periods.

Periods (each out of 120)															Frequency				
1 – 5			6 – 10			11 – 15			16 – 20			All (out of 480)							
	X	Y	Z		X	Y	Z		X	Y	Z		X	Y	Z		X	Y	Z
A	90	2	8	A	111	1	1	A	115	0	1	A	117	2	0	A	433	5	10
B	14	0	1	B	4	0	1	B	1	0	0	B	1	0	0	B	20	0	2
C	5	0	0	C	2	0	0	C	3	0	0	C	0	0	0	C	10	0	0

Table 4: Frequencies of outcomes played in the game in $T1$

The frequencies in Table 4 also indicate that the Nash outcome AX was played increasingly more over time. To confirm this time-effect, we compared the frequencies of AX in the first 5 rounds ($90/120 = 75\%$) with that in the final 5 rounds ($117/120 = 97.5\%$) using a suitable non-parametric (Chi-squared) test. Based on the p -value ($p = 0.000$), we may conclude that this difference is indeed statistically significant even at 1% level.

From Table 4, one can also easily find, by adding up the numbers in relevant rows and columns, the frequencies of the individual strategies played in the game. We note that the two strictly dominated strategies in the game, C (for the row player) and Y (for the column player) was chosen in 10 (2.1%) and 5 (1.1%) cases, respectively; we thus accept the first part of our Hypothesis 1. Strategy A was played 448 (93.3%) times by the row players while the strategy X was played 463 (96.4%) times by the column players. One may ask whether there is any increasing trend over time in the choice of A (X) by the row (column) players. For row players, we compared the percentage of A in rounds 1 – 5 (100

out of 120, that is, 83.3%) with that in rounds 16 – 20 (119 out of 120, that is, 99.2%). This difference is statistically significant at all levels ($p = 0.000$). Similarly, for the column players, we compared the percentages of X in rounds 1 – 5 ($109/120 = 90.8\%$) with that in rounds 16 – 20 ($118/120 = 98.3\%$) and found that the difference is statistically significant at 5% level ($p = 0.0103$).

To analyse the choice of playing A (X) by the row (column) players, we ran a Probit regression with robust standard errors clustered on independent matching groups, using 912 ($24 \times 2 \times 19$) observations pooled together. The dependent variable is an indicator of playing the Nash equilibrium strategy (A or X) and thus takes the value 1 if the player played A or X and 0 otherwise. The independent variables are (i) *Round*, that takes integer values from 2 to 20 for different rounds, (ii) *Row*, a dummy variable that takes value 1 when the individual is a row player (iii) *Past*, an indicator of the player’s last action, with value 1 if the strategy of A or X was played by the player in the previous round and (iv) *OppoPast*, with value 1 if the strategy of A or X was played by the opponent in the previous round. Table 5 below presents the marginal effects from this Probit regression.

Dependent Variable: <i>Play</i> = 1, if A or X is played; = 0, otherwise			
Number of Observations: 912; Pseudo $R^2 = 0.135$			
Independent Variables	Marginal Effects	Robust Standard Errors	p -values
<i>Round</i>	0.0057***	0.001	0.000
<i>Row</i>	-0.0321***	0.011	0.004
<i>Past</i>	-0.0060	0.015	0.692
<i>OppoPast</i>	0.0087	0.026	0.740
Note: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% level.			

Table 5: Probit regression on playing the equilibrium strategy in $T1$

Table 5 clearly indicates that the Nash equilibrium strategies A and X are played significantly more over time; also, column players play X more than row players play A . We thereby accept our Hypothesis 1 and conclude this subsection with our first result.

Result 1 *The unique Nash equilibrium, AX , is played with an increasing trend over time in the game by both groups of individuals, more so by the column players.*

Result 1 is well-known in the literature. There is absolutely no surprise here to observe that AX , which is the unique outcome of the iterative elimination of strictly dominated strategies and thus the unique Nash equilibrium outcome, is played in this game.

4.2 *T2*: Correlated Equilibrium

Having analysed the game, we now look at the correlation device used in the game and check whether the individuals followed the recommendations from the device or not. In this treatment (*T2*), the correlation device first selected one of the three possible outcomes, namely *AX*, *BY* and *CZ*, in the game, with probability $\frac{1}{3}$ each; however, the actual frequencies of these recommendations in the treatment were 163 (34%), 149 (31%) and 168 (35%), respectively.

The correlation device considered in this paper is not a correlated equilibrium for our game; the recommendations *BY* and *CZ* should not be followed while *AX* should be followed, as indeed observed here. We do find that the Nash equilibrium outcome *AX*, when recommended, was mostly followed; however, the outcomes *BY* and *CZ* were not; further, *AX* was the most frequently chosen outcome in these two cases. The following table (Table 6) presents the frequencies of all the outcomes of the game, over 20 periods, divided into three different recommendations (*AX*, *BY* and *CZ*) from the device.

Recommendations												Frequency			
<i>AX</i> (out of 163)				<i>BY</i> (out of 149)				<i>CZ</i> (out of 168)				Total (out of 480)			
	<i>X</i>	<i>Y</i>	<i>Z</i>		<i>X</i>	<i>Y</i>	<i>Z</i>		<i>X</i>	<i>Y</i>	<i>Z</i>		<i>X</i>	<i>Y</i>	<i>Z</i>
<i>A</i>	145	2	7	<i>A</i>	101	15	3	<i>A</i>	111	2	40	<i>A</i>	357	19	50
<i>B</i>	5	0	0	<i>B</i>	21	8	1	<i>B</i>	3	0	3	<i>B</i>	29	8	4
<i>C</i>	4	0	0	<i>C</i>	0	0	0	<i>C</i>	5	1	3	<i>C</i>	9	1	3

Table 6: Frequencies of outcomes played in the game in *T2*

From Table 6 above, we may also find out the frequencies of individual strategies *A* and *X* played by the row and column players; over 20 periods (out of 480 observations), *A* was chosen by the row players 426 times (88.8%) and *X* by column players 395 time (82.3%).

One may be interested in checking whether following or playing *AX* increased over time or not. To see this, we present below the frequencies of *AX* over 20 periods, divided into four equal five-period blocks. We present this frequency table (Table 7) in two parts; first, we present the frequencies of *AX* when indeed *AX* was recommended by the device (163 times in total) and then the frequencies of *AX* following all possible recommendations (480 observations in total).

From Table 7, we do see an increasing trend of playing *AX* over time. The difference in the percentages of playing *AX* when *AX* was recommended for rounds 1–5 (76.3%) and for rounds 16–20 (97.7%) is indeed statistically significant ($p = 0.000$); similarly, the difference in the corresponding percentages from any recommendations (56.7% and 86.7%) is also statistically significant ($p = 0.000$).

Playing <i>AX</i>	Periods				Frequency
	1 – 5	6 – 10	11 – 15	16 – 20	Total
Recommendation: <i>AX</i>					
Played	29 (76.3%)	34 (85%)	39 (95.1%)	43 (97.7%)	145 (89%)
Out of	38	40	41	44	163
Recommendation: Any (<i>AX</i> , <i>BY</i> or <i>CZ</i>)					
Played	68 (56.7%)	89 (74.2%)	96 (80%)	104 (86.7%)	357 (74.4%)
Out of	120	120	120	120	480

Table 7: Frequencies of *AX* played in the game in *T2*

As in the previous subsection, here as well we ran a Probit regression to analyse the choice of the players to play *A* and *X*. Along with the independent variables as explained earlier, *Round*, *Row*, *Past* and *OppoPast*, we here included two further dummy variables related to the recommendations *BY* and *CZ* (as it is not possible to include all three recommendations due to perfect collinearities, we set the recommendation *AX* as the baseline and controlled for the other two); we call these independent variables *Reco2* (takes value 1 if the recommendation is to play *B* or *Y*) and *Reco3* (takes value 1 if the recommendation is to play *C* or *Z*). We also used two further independent variables *Round*Reco2* and *Round*Reco3* to capture the interaction between two named variables respectively. Table 8 below presents the marginal effects from this Probit regression.

Dependent Variable: <i>Play</i> = 1, if <i>A</i> or <i>X</i> is played; = 0, otherwise			
Number of Observations: 912; Pseudo $R^2 = 0.155$			
Independent Variables	Marginal Effects	Robust Standard Errors	<i>p</i> -values
<i>Round</i>	0.0156***	0.005	0.001
<i>Row</i>	0.0540***	0.019	0.004
<i>Reco2</i>	-0.0364	0.064	0.569
<i>Reco3</i>	-0.0395	0.059	0.506
<i>Past</i>	0.1723***	0.041	0.000
<i>OppoPast</i>	0.0699**	0.034	0.041
<i>Round*Reco2</i>	-0.0098*	0.005	0.068
<i>Round*Reco3</i>	-0.0105**	0.005	0.044
Note: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% level.			

Table 8: Probit regression on playing the strategy profile in *T2*

Table 8 shows that the coefficients for *Round*, *Row* and *Past* are clearly significant. We thus accept our Hypothesis 2 and conclude this subsection with the following result.

Result 2 *The recommended outcome AX is followed while the recommendations BY and CZ are not and in those cases, the strategies A and X are played with an increasing trend over time, more so if played in the previous round; also, row players play A more than column players play X.*

As already mentioned, Result 2 is well-established in the experimental literature on correlated equilibrium (see Cason and Sharma, 2007; Duffy and Feltovich, 2010; Bone *et al*, 2013; Duffy *et al*, 2016; Anbarci *et al*, 2017).

4.3 $T0$: Individuals' Risk Attitude to Lottery

In this subsection, we analyse the data obtained from our treatment involving the individual lottery ($T0$) while in the next subsection we focus on the notion of coarse correlation ($T3$). We first consider the number (proportion) of individuals accepting the lottery over the sure outcome in our first treatment ($T0$).

We observe that a huge proportion of individuals accepted the lottery in $T0$; 681 out of 960 (70.9%) individual choices accepted the lottery. 345 out of 480 (71.9%) individual choices of the Red type and 336 out of 480 (70%) Blue individual choices accepted the computerised lottery. The realised average payoffs from the lottery for these individuals respectively were £3.32 for the Red group and £3.34 for the Blue. Among the Red individual choices that accepted the lottery, 121 received a realisation of £2, 109 got £3 and the rest 115 had £5, whereas among the Blue individual choices, these frequencies (for £2, £3 and £5) are 105, 121 and 110, respectively. We do note that those who have accepted the lottery over the sure outcome of £3 are not necessarily risk-seeker or risk-averse; as the expected value of the lottery is £3.33, all we can conclude is that the certainty equivalent for any such individual is more than £3. Table 9 below presents the frequencies (and the percentages) of accepting the lottery over 20 periods, divided into four equal five-period blocks (each out of 120) for two types of individuals separately.

Individuals' types	Periods (each out of 120)				Frequency
	1 – 5	6 – 10	11 – 15	16 – 20	Total
Red	89 (74.2%)	85 (70.8%)	84 (70%)	87 (72.5%)	345 (71.9%)
Blue	78 (65%)	77 (64.2%)	88 (73.3%)	93 (77.5%)	336 (70%)
p -values for difference	0.123	0.27	0.567	0.371	0.522

Table 9: Frequencies of accepting the lottery and the p -values for differences between types in $T0$

From Table 9, we observe that there are some mild differences between the two types in terms of accepting the lottery. However, there is no statistically significant difference between the frequencies for the two types of individuals (in any of the five columns in Table 9 above), as indicated by the

corresponding p -values from a test with the null hypothesis that the two percentages in question are equal. We may conclude that the percentages of accepting the lottery are not statistically different between the two types (in each of the four five-period blocks and in total). As the outcomes of the lotteries for the two types were identical and only different in the order they were presented in, we thus conclude that there is no framing effect in the choice of the lottery in our set-up.

One may also ask if there is any “time-effect” in the rate of accepting. We performed the same kind of non-parametric analysis as in the previous subsections, for each type, to test whether the rate of acceptance in rounds 1 – 5 is significantly different from the rate of acceptance in rounds 16 – 20. Based on the p -values, we conclude that these percentages are different at the 5% level of significance for the Blue individuals, but not for Red ($p = 0.032$ for Blue and $p = 0.77$ for Red).

To assess the choice of accepting the lottery, we ran a Probit regression, using 912 ($24 \times 2 \times 19$) observations pooled together. In this Probit regression, our dependent variable is *Commit*, which takes value 1 if the lottery is accepted and takes 0, otherwise. Our independent variables are *Round*, *Red* and *PastAccept*. The variable *Round* takes integer values from 2 to 20 for different rounds. *Red* and *PastAccept* are both dummy variables each of which takes a value of 1 or 0; *Red* takes value 1 when the individual is of red type and *PastAccept* takes value 1 when the lottery was accepted in the previous round. Table 10 below presents the marginal effects from this Probit regression.

Dependent Variable: <i>Commit</i> = 1, if the lottery is accepted; = 0, otherwise			
Number of Observations: 912; Pseudo $R^2 = 0.027$			
Independent Variables	Marginal Effects	Robust Standard Errors	p -values
<i>Round</i>	0.0048*	0.002	0.079
<i>Red</i>	-0.0510	0.031	0.104
<i>PastAccept</i>	0.1771***	0.034	0.000
Note: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% level.			

Table 10: Probit regression on accepting the lottery in T_0

Table 10 clearly indicates that the past choices are massively significant in accepting the lottery; in any given round, the probability of accepting increases significantly if the lottery was accepted in the previous round. We summarise our main finding below.

Result 3 *A lottery over £2, £3 and £5 is chosen instead of a sure outcome of £3 by both groups of individuals, without any significant difference between groups; individuals accept the lottery significantly more if accepted in the previous round.*

Our conclusion in this section therefore is that we accept Hypothesis 3 that individuals preferred the given lottery with an expected payoff of $\frac{10}{3}$ to the sure outcome of 3 as they are either risk-neutral

or risk-seeker or at best mildly risk averse; we also confirm that there is no framing effect in this case as the individuals of Blue type did not find the lottery less attractive than the individuals of Red type did.

4.4 $T3$: Coarse Correlated Equilibrium

Having analysed the individual choice over lotteries in $T0$, we now look at the game where the same outcomes appear in the device. In $T3$, the correlation device was used to test the notion of coarse correlation. The device indeed is a coarse correlated equilibrium for the game; surprisingly however, only 31 out of 480 (6.5%) pairs committed (both players committed in a pair) to the device. In these 31 cases, the chosen (picked by the computer at random) outcomes are: AX in 10 cases, BY in 9 cases and CZ in the rest 12 times. The average payoffs, in these 31 observations, are respectively 3.09 and 3.38 for the row and column players.

Table 11 below presents the frequencies (and the percentages) of individually committing to the device over 20 periods, divided into four equal five-period blocks (each out of 120) for each of the two types of players separately.

Players' types	Periods (each out of 120)				Frequency
	1 – 5	6 – 10	11 – 15	16 – 20	Total
Row	43 (35.8%)	34 (28.3%)	27 (16.7%)	15 (12.5%)	119 (24.8%)
Column	33 (27.5%)	25 (20.8%)	20 (16.7%)	14 (11.7%)	92 (19.2%)

Table 11: Frequencies of committing to the device among two types of players in $T3$

From Table 11, we observe a clear decreasing trend indicating that the players are committing even less over time. Also, we see a difference between the two types of players. The overall difference (difference between 119 and 92) is significant at 5% level ($p = 0.035$), however it is not significant in any of the four five-period blocks, based on an appropriate test.

Table 11 is very similar to Table 9 with a very contrasting message; in Table 9, we observed that a huge proportion of individuals accepted the lottery, more so over time, while, here very low proportion of players committed to the device, less so over time.

As in the previous subsection, here as well we ran a Probit regression to assess the choice of committing to the device. The independent variables here are *Round* and *Row* as before, along with *PastCommit* that takes value 1 when the device was committed to in the previous round and *PastOppoCommit* that takes value 1 when the device was committed to by the opponent player in the previous round. Similar to Table 10, Table 12 below presents the marginal effects from this Probit regression.

Dependent Variable: $Commit = 1$, if the device is committed to; $= 0$, otherwise			
Number of Observations: 912; Pseudo $R^2 = 0.289$			
Independent Variables	Marginal Effects	Robust Standard Errors	p -values
<i>Round</i>	-0.0106***	0.002	0.000
<i>Row</i>	0.0494*	0.026	0.061
<i>PastCommit</i>	0.2612***	0.037	0.000
<i>PastOppoCommit</i>	0.1276***	0.036	0.000
Note: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% level.			

Table 12: Probit regression on accepting the device in $T3$

Table 12 clearly indicates that the past choices by the player and the opponent are massively significant in committing, as in accepting the lottery in $T0$; however, just the opposite as in $T0$, in any given round, here the probability of committing to the device decreases significantly over time. We summarise our main finding below.

Result 4 *The coarse correlation device is not committed to by either type of players, more so over time; players commit to the device significantly more if committed to in the previous round (by the player and the opponent).*

Our conclusion in this section therefore is that the correlation device is not accepted by the players as a coarse correlated equilibrium in the game; therefore, we cannot accept Hypothesis 4.

5 DISCUSSION: REJECTING COARSE CORRELATION

In this paper, we test the notion of coarse correlated equilibrium for our game using a specific correlation device. We find that the (coarse correlated) equilibrium was not observed, that is, the device was not accepted by the players.

One may ask whether this failure is because of the choice of the specific device. The structure of the device is *Nash-centric* (Ray and Sen Gupta, 2013; Moulin, Ray and Sen Gupta, 2014); the device has a sunspot structure that it selects only public recommendations with positive probability. A naive explanation of rejecting such a device is that the players are sufficiently risk averse to have rejected such a lottery. Clearly, it's not due to risk-aversion as the individuals have chosen the lottery mimicking the outcomes from the device; results 3 and 4 appear to be contradictory at a first glance. We can however interpret this apparent failure of the equilibrium concept.

Below, we offer a few reasons why the players do not accept the device, play the game instead and then successfully coordinate on the Nash equilibrium outcome. However, we first focus on what

strategies were played when the players did not commit to the device.

5.1 Playing AX in $T3$

We first note that in 305 pairs out of 480 (63.5%), both players did not commit to the device; having rejected the device, these pairs thereby played the game as in $T1$. The following table (Table 13) presents the frequencies of all the outcomes of the game, after they both rejected the device, over 20 periods, divided into four equal five-period blocks and the total for 20 periods.

Periods (for pairs who did not commit to the device)																Frequency			
1 – 5 (57/120)				6 – 10 (73/120)				11 – 15 (81/120)				16 – 20 (94/120)				Total (305/480)			
	X	Y	Z		X	Y	Z		X	Y	Z		X	Y	Z		X	Y	Z
A	34	2	10	A	55	3	4	A	67	2	5	A	82	1	8	A	238	8	27
B	6	1	1	B	8	0	2	B	5	0	0	B	3	0	0	B	22	1	3
C	3	0	0	C	1	0	0	C	2	0	0	C	0	0	0	C	6	0	0

Table 13: Frequencies of outcomes played in the game having rejected the device in $T3$

Table 13 shows very similar frequencies as in treatment $T1$ (as shown in Table 4). Once the players did not commit to the device, they chose the outcome AX in 238 out of 305 cases (78.03%) which is similar to that in $T1$ in which the percentage of playing AX was 90.21%.

As in $T1$, here we ran the identical Probit regression on the choice of playing A (X) by the row (column) players with the same independent variables, $Round$, Row , $Past$ and $OppoPast$, using only the sub-sample where both players of the pair did not commit to the device which accounts for only 590 (= 610 – 20) observations. Table 14 presents the marginal effects from this Probit regression (as in Table 5).

Dependent Variable: $Play = 1$, if if A or X is played; = 0, otherwise			
Number of Observations: 590; Pseudo $R^2 = 0.0812$			
Independent Variables	Marginal Effects	Robust Standard Errors	p -values
$Round$	0.0085***	0.003	0.001
Row	0.0456*	0.026	0.080
$Past$	0.1093***	0.041	0.008
$OppoPast$	0.0542*	0.032	0.090
Note: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% level.			

Table 14: Probit regression on playing the equilibrium strategy in the game having rejected the device in $T3$

Table 14 clearly indicates that the coefficients for *Round* and *Past* are significant. We can thus conclude that the players, having rejected the device, played *A* and *X* more over time and more having played so in the previous round.

5.2 Fairness

The outcomes and their corresponding probabilities from the individual lottery (*T0*) and those from the device (*T3*) are identical for an individual, even then we observe that the lottery is accepted in *T0* but the device is not in *T3*. The device picks outcomes from the game that indicate payoff profiles consisting of a payoff for player 1 and one for player 2. Hence, the lottery (for an individual) is not really the same as the device (for the players).

The issue now is how one can interpret this behavior by the players in *T3*. The first explanation that comes to mind is perhaps the issue of fairness (Fehr and Schmidt, 1999). The expected payoff for an individual from the lottery is the same as that from the device in the game; however, the outcomes in the game have consequences (Hammond, 1988). Clearly, two of the three outcomes chosen by the device involve some inequality, in each of which a player, randomly chosen, gets more payoff than the other. This problem is very similar to Machina's (1989) parental example where the child (among the two children) who loses the toss does not like the outcome *ex-post*; in our set-up, accepting the device implies that a player does not win in two out of three cases.

There is a literature (Bolton *et al*, 2005; Krawczyk, 2011; Trautmann and Vieider, 2012; Trautmann and van de Kuilen, 2016) that distinguishes between preferences for outcome fairness (where the agent is concerned about the actual distribution of payoffs) and preferences for process fairness (where the agent is concerned about the random process by which outcomes are created, but not what these outcomes actually are). Clearly, in our set-up, the coarse correlated equilibrium provides a fair process; but players may have preference over the realised outcomes being fair. Two of three outcomes from the device are not fair whereas, in contrast, the Nash equilibrium outcome is equal and fair. Thus, the *socially* preferred outcome here is indeed the Nash equilibrium outcome.

In our experiment, players in *T3* rejected the device to get the equal payoff (from the Nash outcome) which is similar in nature to the findings of Keren and Teigen (2010) who show aversion to use randomizers and Cappelen *et al* (2013) who proved that most individuals favour some redistribution *ex-post*.

Finally, our result is similar to the work by Andreoni *et al* (2002) who found that the equilibrium prediction may fail when the equilibrium results in unequal distributions of payoffs, and there are alternative outcomes involving equality.

5.3 Principle of Insufficient Reason

One may possibly justify⁴ the behaviour of not accepting the device by using the Principle of Insufficient Reason (attributed to Bernoulli, 1738; see Sinn, 1980 for a formal axiomatic development, also, Weisstein, 2002 and Albarede, 2005 for recent formulation) which suggests that there is no logical or empirical reason for an individual to favour a particular event over a set of mutually exclusive events. In our situation, one may apply this principle to understand the behaviour of the players; given the device, the players may use the principle of insufficient reason over all the outcomes in the game (not just the three chosen by the device).

Keynes (1921) raised several objections to the above principle and proposed the Principle of Indifference which can be formulated as events being held to be equiprobable by an individual. In our set-up, players may use this principle to assign equal probabilities over all the outcomes in the game.

The above two principles essentially lead to the concept of ambiguity (see Machina and Siniscalchi 2014 for a detailed survey) in this context; one may think that the players are not sure of the probabilities mentioned in the device.

All these imply that the players replace the given correlation device and assume a uniform probability distribution over all the outcomes as presented below.

	X	Y	Z
A	$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
B	$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$
C	$\frac{1}{9}$	$\frac{1}{9}$	$\frac{1}{9}$

Table 15: The Uniform Device

As each outcome has a probability of $\frac{1}{9}$, the expected payoff of either player therefore is $\frac{17}{9}$ ($= \frac{1}{9}(1 + 1 + 1 + 2 + 3 + 4 + 5)$) from accepting the device which clearly is less than 3. Therefore, assuming that the players are using the Principle of Insufficient Reason or the Principle of Indifference, the device is rejected and the players play the game to achieve the Nash equilibrium payoff of 3.

5.4 Multiple Equilibrium

We may explain the observed phenomenon of not committing to the device as an equilibrium behavior⁵ as well. Note that, as mentioned in Section 2 above, in a coarse correlated equilibrium, accepting the device is a Nash equilibrium of the extended game G'_μ ; however, this equilibrium may not be unique and indeed there may be other (Nash) equilibria of the extended game. Such a problem of multiple

⁴We sincerely thank David Cooper for suggesting this.

⁵We sincerely thank Friederike Mengel for suggesting this.

equilibria has been well-established in the literature for correlated equilibrium (Ray, 2002; Kar, Ray and Serrano, 2010).

We now show that not committing to the device does constitute a Nash equilibrium in extended game G'_μ , as described in Section 2. Consider the strategy profile of not accepting the device by both players and subsequently playing (A, X) in the game; we prove that this profile is a Nash equilibrium. Take player 1 and assume that player 2 is not accepting the device and is playing X . If now player 1 accepts the device, the device will then pick a strategy for player 1 (with probability $\frac{1}{3}$ each); thus the expected payoff of player 1 is $\frac{5}{3}$ ($= \frac{1}{3}(3 + 1 + 1)$) from accepting the device (assuming player 2 is playing X) which is less than 3 (what player 1 would have got by not accepting the device and playing A). Thus, not accepting the device and playing A is the best response for player 1. Similarly, the expected payoff of player 2 is $\frac{8}{3}$ ($= \frac{1}{3}(3 + 1 + 4)$) from accepting the device (assuming player 1 is playing A) which is less than 3 (what player 2 would have got by not accepting the device and playing X). Thus, not accepting the device and playing X is the best response for player 2. Hence this profile is a Nash equilibrium of the extended game. We summarise this as our final result.

Result 5 *The players play the Nash equilibrium of not accepting the device and playing (A, X) in the extended game, extended by the (coarse correlation) device.*

Note that this second Nash equilibrium (of not accepting the device) of the extended game is *ex-ante* sub-optimal as the payoff for either player (3) is less than the expected payoff from the coarse correlated equilibrium ($\frac{10}{3}$). However, this payoff is clearly equal for both players and thus fair and perhaps therefore is chosen by the players.

6 CONCLUSION

In this paper, we report the observations from an experiment to test the concept of coarse correlated equilibrium. Our treatments involving Nash equilibrium, correlated equilibrium and individual choice over lotteries offer no surprises at all; however, the main treatment suggests that the device is not accepted by the players.

It is tempting to conclude that the theoretical concept of coarse correlated equilibrium fails here. However, we do not believe that the theory has failed here; we do offer a variety of reasons to justify this apparent failure of the concept. Clearly, in this game, the device picks two unfair outcomes. Moreover, the players have a social preference to coordinate on the Nash equilibrium outcome which is equal and fair.⁶

⁶We sincerely thank Antonio Cabrales for suggesting this.

Finally, we would derive from our results that the concept of coarse correlation requires a lot of trust in the device in order to be implemented. In our set-up, it is clear that the deterministic Nash equilibrium in the game has a strong *incumbent advantage*. Probably, coarse correlated equilibrium would fare better when the Nash outcome is completely mixed as in the following game⁷ (Table 16).

	X	Y	Z
A	3, 2	2, 0	0, 3
B	0, 3	3, 2	2, 0
C	2, 0	0, 3	3, 2

Table 16: Another Game

Clearly, in the above game, there is no pure Nash equilibrium (none of the diagonal elements in the payoff matrix with payoffs (3, 2) is a Nash equilibrium). The only Nash outcome is the completely mixed equilibrium in which the players play each strategy with probability $\frac{1}{3}$, with payoffs $(\frac{5}{3}, \frac{5}{3})$. For this game, our public device (as in Table 2) can be used as an experiment. This device is clearly not a correlated equilibrium but it is indeed a coarse correlated equilibrium with payoffs (3, 2) which improves upon the Nash payoffs for both players (although player 1 gets more than player 2). We postpone this issue for future work.

⁷We sincerely thank Herve Moulin for suggesting this example.

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8 APPENDICES

We first report below the full set of instructions including record sheet and the test only for our Treatment 3 (*T3*) involving coarse correlation. The instructions (and subsequently the record sheet and the questionnaire) for Treatments 1 and 2 differ in a natural way. Thus, for obvious reasons, these have been omitted here and are available upon request. We then provide just the instructions for our Treatment 0 (*T0*) involving the individual's choice over lottery.

8.1 Instructions (*T3*)

All participants in a session (in *T3*) have the following identical instructions.

Welcome to this experiment and thank you for participating. Please read the following instructions carefully. From now on, please do not talk to any other participants until this session is finished. You will be given 15 minutes to read these instructions. Please read them carefully because the amount of money you earn will depend on how well you understand these instructions. After you have read these instructions, we will ask you to complete a brief questionnaire to ensure that you completely understand the instructions. If you have a question at any time, please feel free to ask the experimenter.

In this experiment, you will face a simple decision problem, in each of the successive 20 rounds. Before the first round begins, all the participants will be randomly divided into two equal-sized groups. One group is called Red and the other is called Blue. Your computer screen will tell you which group you are in; you will remain in the same group throughout this session.

In each round, you will be randomly matched with a person from the other group. You have an equal chance of being matched with any particular person from the other group. Both your identities will remain concealed throughout the session and you will have no direct contact with each other during the experiment. Your earnings for this experiment will depend on the choices you make as well as the choices made by the persons you are matched with.

SEQUENCE OF THE PLAY:

1. You are randomly allocated to a group: Red or Blue, with equal chance. You will remain in the same group for the whole session.
2. The session will have 20 identical rounds.
3. At the start of each round, you are randomly matched to another participant (your counterpart), who belongs to the other group.
4. The computer program asks you (and your counterpart) whether or not you accept the computer to make a choice for you (and your counterpart), using a specific device (explained later in detail).
5. You and your counterpart both decide (independently) whether to accept or not.

6. There are two possible situations for you:
 - a. If you accept, there is nothing else for you to do in this round.
 - b. If you do not accept, then you will make a choice (as explained below).
7. In the first 10 rounds, you will have 2.5 minutes per round to make a choice, and thereafter 1.5 minutes per round. If you do not choose within this time, the computer will automatically choose (at random) one of the three choices.
8. You find out the choice of your counterpart, as well as your earnings for that round.
9. You proceed to the second round and steps 3 – 7 above are repeated.
10. The sessions ends after the 20th round.

CHOICES:

Both you and the person you are matched with will have three different choices available, depending on which group you belong to. Each participant in the Red group has three alternatives, A , B and C while each participant in the Blue group has three alternatives, X , Y and Z . Each of the choice combinations have corresponding points allocated for the Red and Blue participant and the points table below summarises all the possible combinations and points achievable.

		Blue		
		X	Y	Z
Red	A	3, 3	1, 1	4, 1
	B	1, 4	5, 2	0, 0
	C	1, 1	0, 0	2, 5

If you are in the Red group, your choice determines a row, and the choice of the person of the Blue group you are matched with determines a column of the points table above. If you are from the Blue group, this is reversed. Each box in the table contains two numbers. The first of these numbers represent the Red person's earnings (in points), and the second number represents the Blue person's earnings (in points). For example, suppose you are from the Red group and in some round you choose A while your counterpart from the Blue group chooses Z , then from that round you will earn 4 points and your counterpart will earn 1 point.

COMMITMENT:

The computer can choose an alternative for you and your counterpart and the computer is programmed in such a way that there are only three equally-likely choice combinations.

There is a $\frac{1}{3}$ rd chance that the computer chooses A for the Red person and X for the Blue person.

There is a $\frac{1}{3}$ rd chance that the computer chooses B for the Red person and Y for the Blue person.

There is a $\frac{1}{3}$ rd chance that the computer chooses C for the Red person and Z for the Blue person.

The above mentioned three options can be the only possible combinations the computer chooses,

and no other combination (of Red and Blue groups' choices), other than the above three mentioned, will be chosen. For example, it will never happen that the computer chooses A for the Red participant and Z for the Blue. This is summarised in the following Device:

		Blue		
		X	Y	Z
Red	A	$\frac{1}{3}$	0	0
	B	0	$\frac{1}{3}$	0
	C	0	0	$\frac{1}{3}$

At the start of each round, the computer program asks you and your counterpart the following question: ‘Would you like the computer to choose for you according to the device?’ It is entirely up to you, in any round, whether or not to accept the computer to make a choice for you. The choice you make is independent and without any communication with your counterpart in the other group. So, at the moment you decide whether or not to accept the computer to make your choice, you do not know what your counterpart’s decision is. Depending on what you and your counterpart’s response to the question, there are three possible scenarios, as discussed below in detail.

Scenario 1 – ‘Both choose Yes’:

If you and your counterpart both answer ‘Yes’ to this question, then the computer chooses one of the three possible alternatives at random as explained above and you both earn the points of the chosen combination, as described by the points table. For example, if you are from the Red group and you decide to accept the computer to choose for you and your counterpart in the Blue group also accepts, and the computer randomly chooses B for you (and therefore chooses Y for your Blue counterpart), then from the points table, you will receive 5 and your counterpart receives 2. Therefore by accepting the computer to make a choice for you, you will receive 2, 3 or 5 and thus on average you will receive $\frac{10}{3}$ ($= 2(\frac{1}{3}) + 3(\frac{1}{3}) + 5(\frac{1}{3})$).

Scenario 2 – ‘One chooses Yes and other chooses No’:

Suppose you do not want the computer to make a choice for you and thus answer ‘No’ to this question, however your counterpart answers ‘Yes’, then you will have to choose among the three possible alternatives available for you, i.e., if you are from the Red group then you will have to choose between A , B and C and if you are from the Blue group you will have to choose between X , Y and Z . Once you have made your choice, you receive your points according to the points table, determined by your choice and the outcome of the computer’s random choice for your counterpart. For example, if you are from the Red group and you answer No to the question and choose to play C , and your counterpart from the Blue group answers yes and the computer randomly chooses Z , then you will receive 2 points and your counterpart will receive 5 points. Note that any of the three (X , Y and Z)

alternatives for your counterpart can be chosen by the computer and therefore by choosing alternative C you will receive 1, 0 or 2 and thus on average you will receive $1 (= 1(\frac{1}{3}) + 0(\frac{1}{3}) + 2(\frac{1}{3}))$.

Similarly, if you answer ‘Yes’ to this question, however your counterpart answers ‘No’, then you will not have to do anything more at this stage (the computer will make a choice for you) but your counterpart will be asked to choose among the three possible alternatives.

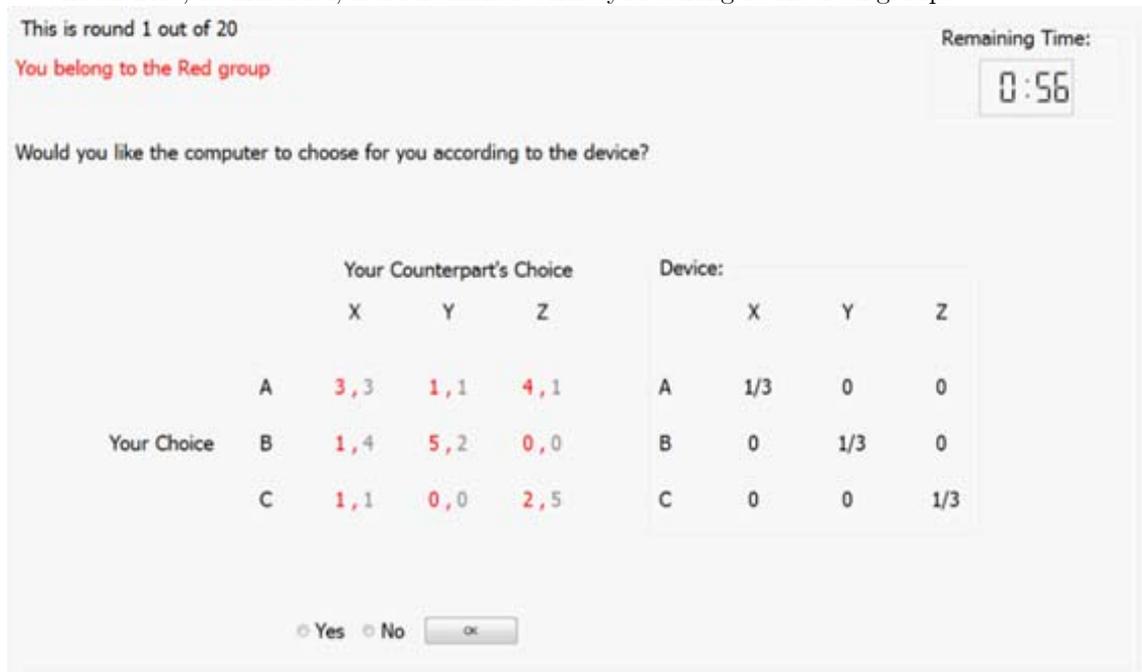
Scenario 3 – ‘Both choose No’:

If both of you answer ‘No’, then each of you will have to choose among the three possible alternatives, i.e., if you are from the Red group then you will have to choose between A , B and C and your counterpart from the Blue group will have to choose between X , Y and Z . Once you both have made your choices, you receive your points determined by the points table. For example, if you are from the Red group and you answer No and choose to play A , and your counterpart from the Blue group also answers No and chooses to play Z , then you will receive 4 points and your counterpart will receive 1 point.

THE COMPUTER SCREEN:

The main screen of each round looks like as follows. It will mention which group (Red or Blue) you belong to. On the top right corner the remaining time will be mentioned. In each round you will be asked the following question: Would you like the computer to choose for you according to the device? You will also see the points table and the Device, which will remain the same for all the rounds. Followed by these, you will have two options: Yes or No, to choose.

Shown here, to illustrate, is a screenshot where you belong to the Red group.



Depending on what you choose there are two possibilities:

If you choose 'Yes', the round ends for you.

If you choose 'No', you will be given a choice to choose among your three available alternatives (as illustrated by the following screenshot).



To make a choice you simply have to select the appropriate button and then click OK. You may then have to wait a few moments until all participants have made their choices, after which the on-screen results for you and your counterpart will appear in that round. On your desk is a Record sheet on which you are requested to keep a note of these results. After all the participants have read their results (15 seconds), the main screen for the next round will appear again, as shown above.

RECORD SHEETS:

You have been given a record sheet to keep a record of the results at the end of each round. During each round, you should write whether you (and your counterpart) committed (i.e. asked the computer to make a choice) or not, choice you (and your counterpart) made or the choice made by the computer for you (or your counterpart). Finally, please record the points you earned in each round.

PAYMENTS:

For showing up on time and completing the experiment, you will earn £3. In addition, at the end of the experimental session, we will randomly select two (out of 20) rounds. The total number of points you earn in these two rounds will be converted into cash at an exchange rate of £1 per point. For example, if out of the 20 rounds, we randomly select Round 5 and Round 18, and in those two rounds you have earned 2 and 5 points respectively, your final cash payment will be £10 in total including

the show-up fee. You will be paid, individually and privately, your total earnings at that time. Please complete the receipt form which you will also find on your desk. We need these receipts for our own accounts.

QUESTIONNAIRE:

We will now pass around a questionnaire to make sure all the participants have understood all the instructions and how to read the points table. Please fill it out now. Do not put your name on the questionnaire. Raise your hand when finished, and the experimenter will collect it from you. If there are any mistakes in any of the questionnaires, we will go over the relevant part of the instructions once again. You may look again at the instructions while answering these questions.

Thank you for participating. We hope that you enjoyed the experiment, and that you will be willing to participate again in our future experiments.

8.2 Record Sheet (T3)

Subject Number:

I am a (circle one) RED BLUE player.

Round	Commit?	Counterpart commit?	Choice	Counterpart's choice	Points
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

8.3 Questionnaire (T3)

After reading the instructions you will be asked to complete this brief questionnaire, to ensure you have understood them, before starting the experiment itself.

You may look again at the instructions while answering these questions.

For questions 1 – 4, write the answers in the corresponding boxes.

1. If you belong to the Blue group and you choose not to commit to the computer and choose X and your counterpart in the Red group also does not commit and choose B , how many points do you earn in that round?

2. If you belong to the Red group and you choose to commit to the computer and your counterpart in the Blue group also commits and then the computer chooses B for you, what will be the choice made by the computer for your counterpart in the Blue group?

3. If you belong to the Blue group and you choose to commit to the computer but your counterpart in the Red group does not commit and chooses A and then the computer chooses X for you, how many points do you earn in that round?

4. At the end of the experiment, if out of the 20 rounds, we randomly select Round 2 and Round 17, and in those two rounds you have earned 3 and 5 points respectively, what is your final cash payment in total (in \pounds) for the experiment?

For questions 5 – 8, circle either True or False.

5. If you are in the Blue group and you do not commit and instead choose Y , while your counterpart from the Red group commits and computer chooses A for him/her, then you will earn 1 point in that round. True or False.

6. If you are in the Red group and you do not commit and instead choose B , while your counterpart from the Blue group does not commit and chooses X , then your counterpart will earn 4 points in that round. True or False.

7. Your counterpart is the same person in each round. True or False.

8. In any publications arising from this experiment the participants will be completely anonymous. True or False.

Thank you for completing this questionnaire. Please leave this completed sheet face up on your desk.

The experimenter will come round to check that you have the correct answers. If any of your answers are incorrect then the experimenter will give you some explanatory feedback.

8.4 Instructions (T_0)

All participants in a session (in T_0) have the following identical instructions.

Welcome to this experiment and thank you for participating. Please read the following instructions carefully. From now on, please do not talk to any other participants until this session is finished. You will be given 10 minutes to read these instructions. Please read them carefully because the amount of money you earn will depend on how well you understand these instructions. After you have read these instructions, we will ask you to complete a brief questionnaire to ensure that you completely understand the instructions. If you have a question at any time, please feel free to ask the experimenter.

In this experiment, you will face a simple decision problem, in each of the successive 20 rounds. Before the first round begins, all the participants will be randomly divided into two equal-sized groups. One group is called Red and the other is called Blue. Your computer screen will tell you which group you are in; you will remain in the same group throughout this session.

In each round, you will be asked to choose between two options. Your earnings for this experiment will depend on the choices you make.

SEQUENCE OF THE PLAY:

1. You are randomly allocated to a group: Red or Blue, with equal chance. You will remain in the same group for the whole session.
2. The session will have 20 identical rounds.
3. You face two choices: Option A and Option B .
4. In the first 10 rounds, you will have 1.5 minutes per round to make a choice, and thereafter 1 minute per round. If you do not choose within this time, the computer will automatically choose (at random) one of the three choices.
5. You find out your earnings for that round.
6. You proceed to the second round and steps 3 – 5 above are repeated.
7. The sessions ends after the 20th round.

CHOICES:

You will have two choices available: Option A and Option B . For both groups Option A remains the same: “ $\mathcal{L}3$ for sure”. Depending on which group (Red or Blue) you belong to, your Option B will slightly vary. If you are in the Red group the Option B is: “Computer picks at random with equal chances $\mathcal{L}3$, $\mathcal{L}5$ or $\mathcal{L}2$ ”; and if you are in the Blue group the Option B is: “Computer picks at random with equal chance $\mathcal{L}3$, $\mathcal{L}2$ or $\mathcal{L}5$ ”. Please note that the option you choose is not affected by any other participant’s choice in the room.

The points you earn depends on the option you choose in each round, as described below.

Scenario 1 – ‘Choose Option A’

If you choose Option A, then you choose ‘£3 for sure’, and therefore earn 3 points, irrespective of which group you belong.

Scenario 2 – ‘Choose Option B’

If you choose Option B, then the computer chooses one of the three possible amounts at random and you will earn the amount chosen by the computer for that round. If you are in the Red group, the computer chooses £3, £5 or £2 with a chance of $\frac{1}{3}$ rd each. If you are in the Blue group, the computer chooses £3, £2 or £5 with a chance of $\frac{1}{3}$ rd each. Please note that in a particular round, the computer can choose only one of these three amounts, and the amount it chooses is the point you receive for that round. For example, if you are in the Red group and you choose Option B, i.e., accept the computer to make a choice for you, and the computer chooses £5, then the points you receive in that round is 5. Please note that the computer could have chosen £3, £5 or £2 with a chance of $\frac{1}{3}$ rd each, and therefore on average you will receive $\pounds \frac{10}{3}$ ($= \pounds 3(\frac{1}{3}) + \pounds 5(\frac{1}{3}) + \pounds 2(\frac{1}{3})$). Please note that the average point you may receive is the same for Red and Blue group.

THE COMPUTER SCREEN:

The main screen of each round looks like as follows. It will mention which group (Red or Blue) you belong to. On the top right corner the remaining time will be mentioned. In each round you will be faced with two options: Option A and Option B. You will see the two options (Option A and Option B), and this will remain the same for all the rounds.

Shown here, to illustrate, is a screenshot where you belong to the Red group.



To make a choice you simply have to select the appropriate button and then click OK, after which the on-screen results for you will appear in that round (as shown in the screenshot below).



On your desk is a Record sheet on which you are requested to keep a note of these results. After you note down the results, click Next Round and the main screen for the next round will appear again, as shown in the first screenshot.

RECORD SHEETS:

You have been given a record sheet to keep a record of the results at the end of each round. During each round, you should write whether you chose Option *A* or Option *B*; the choice made by computer in case you chose Option *B*. Finally, please record the points you earned in each round.

PAYMENTS:

For showing up on time and completing the experiment, you will earn £3. In addition, at the end of the experimental session, we will randomly select two (out of 20) rounds. The total number of points you earn in these two rounds will be converted into cash at an exchange rate of £1 per point. For example, if out of the 20 rounds, we randomly select Round 5 and Round 18, and in those two rounds you have earned 2 and 5 points respectively, your final cash payment will be £10 in total including the show-up fee. You will be paid, individually and privately, your total earnings at that time. Please complete the receipt form which you will also find on your desk. We need these receipts for our own accounts.

QUESTIONNAIRE:

We will now pass around a questionnaire to make sure all the participants have understood all the instructions and how to read the points table. Please fill it out now. Do not put your name on the questionnaire. Raise your hand when finished, and the experimenter will collect it from you. If there are any mistakes in your questionnaire answers, we will go over the relevant part of the instructions with you once again. You may look again at the instructions while answering these questions.