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Nash vs. Coarse Correlation*

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Abstract

We run a laboratory experiment with a two-person game with unique pure Nash equilibrium which is also the solution of the iterative elimination of strictly dominated strategies. The subjects are asked to commit to a device that randomly picks one of three symmetric outcomes in this game (including the Nash equilibrium) with higher ex-ante expected payoff than the pure Nash equilibrium payoff. We find that the subjects do not accept this lottery (which is a *coarse correlated equilibrium* as in Moulin and Vial, 1978), instead, they choose to play the game and then coordinate on the pure Nash equilibrium. However, given an individual choice between a lottery with equal probabilities of the same outcomes and the sure payoff as in the Nash equilibrium, the lottery is chosen by the individuals. The result is robust against variations like (i) a lottery choice for a pair of individuals, (ii) different payoffs in the game and (iii) the fixed-match between pairs.

Keywords: Correlation, Coordination, Lottery, Risk dominance.

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

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1 INTRODUCTION

Coordination in any game, even in a 2x2 game, can be an issue, as the game in question may not have one outcome for the players to naturally coordinate on (as the game may have no pure Nash equilibrium or multiple equilibria to choose from). Experimental research suggests that players in a game are able to coordinate on an outcome if they are helped to do so, possibly using a suitable scheme (see Devetag and Ortmann, 2007 for a survey). The issue of multiple equilibria and coordination in a game has been one of the major themes of research in experimental economics (Cooper *et al*, 1989, 1990, 1992; Van Huyck *et al*, 1990, 1991, 1992; Straub, 1995); the existing literature suggests that in games with multiple symmetric equilibria in which no outcome can be easily selected (for example, in the *Battle of the Sexes*, BoS henceforth), individuals coordinate using features such as, risk-dominance (Cabrales *et al*, 2000), pre-play non-binding communication (Crawford, 1998; Costa-Gomes, 2002; Camerer, 2003; Burton *et al*, 2005; Cabrales *et al*, 2018).

On the other side, there may be a different problem in a game where there is no issue of coordination at all as the game may have a clear unique pure Nash equilibrium outcome that players may easily choose to play; however, this equilibrium may be (payoff-)dominated and can be (ex-ante) improved upon by using a lottery involving several other outcomes if the players agree to commit to this plan.

Committing to a lottery in a game has been captured in the notion of coarse correlation. In a coarse correlated equilibrium (Moulin and Vial, 1978), a mediator first asks the players to either commit to a device (and thereby get the outcome that the device would select using a given probability distribution) or to reject the device (and subsequently play any strategy of their own in the game, without learning anything about the outcome from the device). 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 according to the given distribution.

The concept of coarse correlation for normal form games has a natural interpretation in many economic situations, such as the abatement game (Barrett, 1994) in environmental economics (see Forgó *et al*, 2005 and Forgó, 2011 who used notions of correlation in other environmental games). One may improve upon the Nash equilibrium payoff for oligopolies and other potential games (see Ray and Sen Gupta, 2013, Moulin *et al*, 2014 and Dokka *et al*, 2018 for details).

The purpose of this paper is to understand, using a laboratory experiment, whether individuals are willing to commit to a correlation device that improves upon the pure Nash outcome in a game or not. There is a recent literature (see Moreno and Wooders, 1998; Cason and Sharma, 2007; Duffy and Feltovich, 2010; Bone *et al*, 2013; Duffy *et al*, 2017; Anbarci *et al*, 2018) on experiments with correlated devices that recommend strategies to the players according to a probability distribution, to test the validity of the concept of correlated equilibrium (Aumann, 1974, 1987); however, to the best of our knowledge, there has been no attempt to understand the notion of coarse correlation in an experimental set-up.

We use a two-person game (introduced by Moulin and Vial, 1978) with unique pure Nash equilibrium which is also the solution of the iterative elimination of strictly dominated strategies (and therefore, the unique correlated equilibrium). We then take a lottery with equal probabilities of three symmetric outcomes (including the Nash equilibrium), which is a coarse correlated equilibrium with ex-ante expected payoff higher than the unique Nash equilibrium payoff. The question we ask is simple: which prevails – (playing the unique) Nash or coarse correlation (accepting the lottery)? We also contrast the choice of committing to the device for the game with an individual problem of choosing between a lottery with equal probabilities of these three payoffs and the sure payoff as in the Nash equilibrium of the game.

Our main result is that at the individual choice level, the lottery is chosen; however, in a game, we find that the players do not accept this lottery (the coarse correlation device). Instead, the players play the game and choose the Nash equilibrium. We also find that the proportion of the Nash equilibrium outcome is the highest in the treatment without any correlation. Thus, the answer to our question is: Nash prevails!

We also addressed three different issues as robustness checks for the main result. First of all, admittedly, one may find a lack of comparability between an individual lottery and the coarse correlation device. The results in these two are different from each other perhaps due to some sort of social preferences. We have thus checked our result using a lottery for a pair which is considerably closer to the coarse correlated equilibrium in the game and found very similar result. Second, one may ask whether committing to the device (to get higher expected payoffs) increases if the players' relationship were repeated, as each player is then likely to get the higher payoff sometimes (as shown in Kaplan & Ruffle, 2012). We however find no such indication from fixed-match pairs. Finally, we checked the robustness by varying payoffs using three other similar games, however we found results analogous to the main result.

We may explain the observed phenomenon of not committing to the device as an equilibrium behaviour as well. Accepting the device is a Nash equilibrium of the extended game, extended by the (coarse correlation) device; however, this equilibrium may not be unique and there may be other (Nash) equilibria of the extended game. Indeed, rejecting the correlation device and playing the unique Nash equilibrium of the game is a risk-dominant equilibrium in a modified version of the extended game. It is well-known in the literature that in such games (Aumann, 1990) risk-dominant outcomes are observed (Cabrales *et al*, 2000; Charness, 2000). Cason and Sharma (2007) also provide evidence consistent with our result; in their experiment on correlated equilibrium, if an agent does not follow recommendations from a correlated equilibrium, it is because she believes that her opponent will not follow the recommendation.

The implication of our main result is 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. The advantage of accepting the device (in terms of expected payoff) would disappear if the players are inequality-averse, as suggested by our experiment.

We do offer another interpretation of our main result. We note that although the correlation device is procedurally fair, the outcomes generated by the device are not fair (similar in nature to different strands of work such as Bolton *et al*, 2005; Krawczyk, 2011; Trautmann and Vieider, 2012; Trautmann and van de Kuilen, 2016). In our set-up, the coarse correlated equilibrium provides a fair process, however, two of three outcomes from the device are not fair; the players may have a social preference to coordinate on the Nash equilibrium outcome which is equal and fair. Thus, the socially preferred outcome here is indeed the Nash equilibrium outcome.

1.1 Related Literature

As already mentioned, a fairly recent, however, well-established experimental literature deals with the problem of coordination in a game using correlation devices. A correlated equilibrium (Aumann, 1974, 1987) can be interpreted as a mediator who selects and sends to each player a private recommendation to play a strategy that each player finds optimal to follow. The main message of this literature (see Moreno and Wooders, 1998; Cason and Sharma, 2007; Duffy and Feltovich, 2010; Bone *et al*, 2013; Duffy *et al*, 2017; Anbarci *et al*, 2018) is that the players do follow recommendations from a correlation device when the device is indeed a correlated equilibrium. Duffy and Feltovich (2010) also showed that the subjects learn to ignore the recommendations which are not based on the correlated equilibrium. Any convex combination over pure Nash equilibrium outcomes (thus a public lottery) can also be viewed as a correlated equilibrium. Indeed, Cason and Sharma (2007), Duffy and Feltovich (2010) and Bone *et al* (2013) used a (public) correlated equilibrium that randomly selects one of the two pure Nash equilibria in symmetric 2 x 2 games like BoS and showed that players do play the recommended strategies. The device we have used is a randomisation involving non-Nash outcomes, and thus is not a correlated equilibrium. We found very similar results using a treatment on correlated equilibrium in this paper.

Duffy *et al* (2017) studied normal form games with multiple Nash equilibrium; the main question addressed there is how players coordinate on any equilibrium, particularly when there are ex-ante symmetric equilibria to choose from. This paper used a version of BoS and considered different treatments to study coordination using perfectly correlated signals. In addition, the paper also asked how, if at all, players use different coded language (in terms of indirect messages that are not directly related to actions in the game) to achieve coordination. Anbarci *et al* (2018) provided a design to test how correlated equilibrium performs in BoS type games with different sets of payoffs. The main message of the paper is that the players do not like recommendations that lead to unequal payoffs, which is similar in nature to our main result.

The specific type of correlation device used in this paper relates to sunspots; thus, the experimental literature on public information (McKelvey and Page, 1990; Marimon *et al*, 1993; McCabe *et al*, 2000; Anctil *et al*, 2004; Heinemann *et al*, 2004) and that on sunspot equilibrium becomes relevant to our study. Duffy and Fisher (2005) introduced sunspots as coordination devices using randomisation over equilibria and provided a direct evidence of sunspot equilibria in markets. Stahl (2013) and Camera *et al* (2013) used randomised messages for cooperation in Prisoners' Dilemma; Brandts and McLeod (1995) and Seely *et al* (2005) analysed public recommendations while Fehr *et al* (2018) and Arifovic *et al* (2013) studied sunspot-driven strategies. Arifovic and Jiang (2014) studied the simple bank-run game by Diamond and Dybvig (1983) and analysed situations in which sunspots matter through a laboratory study. Kaplan and Ruffle (2012) investigated models of cooperation through a class of two-player games that requires the players to coordinate on which player cooperates and who gets to defect, so as to achieve the socially efficient outcome. Our set-up is similar to the above literature however provides a new result and insight.

In our set-up, accepting the device implies that an individual does not *win* in two out of three cases and perhaps thus the device is not accepted. This is similar in nature to the findings of Keren and Teigen (2010) who show aversion to use randomizers and of Cappelen *et al* (2013) who proved that most individuals favour some redistribution ex-post. Our result is connected 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. It is also analogous to Machina's (1989) parental example where the child (among the two children) who loses the toss does not like the outcome ex-post. Finally, our paper is related to 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).

2 EXPERIMENT

We first briefly recall some theoretical concepts behind our experiment. Here, we closely follow the notations and definitions of a few notions from Moulin *et al* (2014), Ray and Sen Gupta (2013) and Kar *et al* (2010), where more details can be found.

2.1 Theory

Consider any fixed finite normal form game, $G = [N, \{S_i\}_{i \in N}, \{u_i\}_{i \in N}]$, with set of players, $N = \{1, ..., n\}$, finite pure strategy sets, $S_1, ..., S_n$ with $S = \prod_{i \in N} S_i$, and payoff functions, $u_1, ..., u_n$, $u_i : S \to \Re$, for all i. A *direct correlation device*, μ, for such a game G, is simply a probability distribution over S. In this paper, we will consider direct correlation devices only and therefore in what follows, we will call such a device just a correlation device, or a device, in short, for convenience. G can be extended by using a device μ. An extended game G_μ is the game where the device selects a strategy profile s $(= (s_1, ..., s_n))$ according to the probability distribution and sends private recommendation s_i to each player i, and then the players play the original game G. μ is called a *correlated equilibrium* (Aumann, 1974, 1987) of the game G if following the recommendations forms a Nash equilibrium in the extended game G_μ, that is, following the recommendations is the best response for each player when all others are also following.

One may use a device, μ, in a different way for a finite normal form game to get a coarser notion of correlation. A game G may be extended to a game G'_μ in which the strategies of a player are to commit to the correlation device μ, 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. 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 $\mu'_i(s_{-i}) = \sum_{s_i \in S_i} \mu(s_i, s_{-i})$. μ is called a *coarse correlated equilibrium* of the game G if committing to the device forms a Nash equilibrium in the extended game G'_μ, that is, accepting the device is the best response for each player when all others are also accepting.[1]

One may consider specific types of correlation devices, such as, devices for which recommendations are "public". Given a correlation device μ, a strategy profile s $(= (s_1, ..., s_n))$, 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

[1] This 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 *et al* (2014), while Forgó (2010) called it a *weak correlated equilibrium*.

public device may even be considered as a "sunspot" device (Ray, 2002; Polemarchakis and Ray, 2006; Ray and Sen Gupta, 2013), as players may coordinate using such public recommendations as sunspots. Clearly, a public device is a correlated equilibrium if and only if all the public recommendations in the device are (pure) Nash equilibria.

2.2 Games and Equilibria

We consider the two-person game G_0 in Table 1 in which each player has three pure strategies; player 1's pure strategies are A, B and C while player 2's are X, Y and Z.

	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

(A, X) is the unique Nash equilibrium of the above game, with payoffs $(3, 3)$. Also note that the strategies C and Y are strictly dominated (by A and X for player 1 and 2 respectively). One can thus analyse the game by iterative elimination of dominated strategies and get the profile (A, X) as the unique outcome (having eliminated C and Y, in the reduced game A dominates B and X dominates Z).

We consider a specific correlation device which is an equally-weighted lottery of three outcomes including the Nash equilibrium, as in Table 2. This device is a public device as the probabilities are positive only for the outcomes (A, X), (B, Y) and (C, Z) that are public recommendations.

	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

The public device in Table 2 is 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). The Nash outcome (A, X), that is, the device with probability 1 on (A, X), is the only correlated equilibrium of the above game.

The device is indeed a coarse correlated equilibrium for the game, that is, committing to the device is the best response of a player when the other player is committing as well. 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 game, player 1 gets an expected payoff of $\frac{8}{3}$ $(= \frac{1}{3}(3+1+4))$ from choosing the pure strategy A, gets 2 $(= \frac{1}{3}(1+5+0))$ from B and 1 $(= \frac{1}{3}(1+0+2))$ from C.

It should be also noted that the device in Table 2 is not the unique coarse correlated equilibrium for our game; a (public) device which is a lottery with probability $\frac{1}{2}$ each over 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 chosen device (in Table 2) includes the Nash equilibrium; also, it picks outcomes that are either Nash or symmetric around the Nash point and thus is similar to a *Nash-centric* device.[2]

One may modify the payoffs in the game in Table 1 to get other similar games and use the above device as a coarse correlated equilibrium for those games. Below we present three such other payoff matrices, labelled respectively as G_1, G_2 and G_3 in Table 3.

G_1				G_2				G_3			
	X	Y	Z		X	Y	Z		X	Y	Z
A	2, 2	1, 1	3, 1	A	4, 4	1, 1	5, 1	A	5, 5	1, 1	6, 1
B	1, 3	4, 1	0, 0	B	1, 5	9, 3	0, 0	B	1, 6	13, 4	0, 0
C	1, 1	0, 0	1, 4	C	1, 1	0, 0	3, 9	C	1, 1	0, 0	4, 13

Table 3: Three further games

The structure of the above games is clearly very similar to that of the original game G_0; in all these games, strategies C and Y are strictly dominated and (A, X) is the unique Nash and correlated equilibrium. The device in Table 2 is a coarse correlated equilibrium for each of the games G_1, G_2 and G_3 with an expected payoff to each player of $\frac{7}{3}$, $\frac{16}{3}$ and $\frac{22}{3}$, respectively improving upon the respective Nash payoff of 2, 4 and 5.

[2] A "Nash-centric" device is a symmetric public distribution that picks only outcomes that are Nash and equi-distant from the Nash point; see Ray and Sen Gupta, 2013 and Moulin *et al*, 2014 for details.

In a coarse correlated equilibrium, committing to 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.[3] Indeed for the game G_0 (and G_1, G_2 and G_3, for that matter), the strategy profile of not committing to the device by both players and subsequently playing (A, X) in the game is also a Nash equilibrium. To see this, consider player 1(2) in G_0 and assume that player 2(1) is not committing to the device and is playing X (A); if now player 1(2) commits to the device, the device will pick any strategy for player 1(2) with probability $\frac{1}{3}$ each and thus the expected payoff of player 1(2) is $\frac{5}{3}$ $(= \frac{1}{3}(3+1+1))$ from committing to the device when player 2(1) is playing $X(A)$, which is less than 3 that player 1(2) would have got by not committing to the device and playing $A(X)$. This second Nash equilibrium (of not committing to the device) of the extended game is *ex-ante* sub-optimal as the payoff (3) for either player is less than the expected payoff from the coarse correlated equilibrium $(\frac{10}{3})$. Also, note that in the induced 2 x 2 game, as shown in Table 4 in which there are only two strategies for the players, namely, "commit to the device" and "do not commit and then play A (X)", (*Commit*, *Commit*) is payoff-dominant, however, (A, X) is risk-dominant (Harsanyi and Selten, 1988; Harsanyi, 1995).

	Commit	X
Commit	$\frac{10}{3}, \frac{10}{3}$	$\frac{5}{3}, \frac{8}{3}$
A	$\frac{8}{3}, \frac{5}{3}$	$3, 3$

Table 4: The induced 2 x 2 game from G_0

2.3 Treatments

We have three main treatments in which we deal with the game G_0 and the notions of correlation and coarse correlation. In the first of these three treatments, namely, the *Nash treatment*, we just use the game G_0 without any kind of correlation. In the second treatment, the *correlated treatment*, we use the device in Table 2 to send non-binding recommendations to the subjects to test whether these recommendations are followed or not. Finally, in the third treatment, the *coarse correlated treatment*, we use the same device as a commitment device, rather than for sending recommendations, to test the concept of coarse correlation.

On top of these three treatments, we do have an *individual lottery treatment*, in which the subjects are asked to choose among a sure outcome and a lottery to contrast with the coarse correlated treatment. We have designed two very similar individual choice problems that mirror the outcomes from

[3] The problem of multiple equilibria for correlated equilibrium has been well-established in the literature (Ray, 2002; Kar *et al* 2010).

the above coarse correlated equilibrium for the game G_0. In the choice problems, a participant has to choose between the lottery that picks one of three outcomes £2, £3 and £5 each with probability $\frac{1}{3}$ and the sure (with probability 1) outcome of £3; the only difference between the two choice problems used is the framing (the order) of the outcomes in the lottery.

The individual lottery treatment is not designed to measure subjects' risk preferences. Indeed, choosing the lottery for an individual in our individual lottery treatment can be viewed as similar to accepting the device for a player in the coarse correlated treatment. However, a potential criticism against our individual lottery treatment to be compared with the coarse correlated treatment is that due to the lack of interaction between players, there may be a discrepancy between the behaviour of the subjects in the individual lottery treatment and when a coarse correlation device is present. Therefore, we also run an extension of the individual lottery treatment that we call the *paired lottery treatment* to take into consideration the interactive nature of payoffs. In this treatment, subjects have to choose between a sure payment and a lottery as in the individual lottery treatment, however with the only difference that the outcomes of the lottery are for a pair. Each subject has to make a choice between a safe option that yields payoffs £3 for both individuals in the pair, or a lottery which yields either (£3, £3) or (£5, £2) or (£2, £5), with equal chances, for the two paired individuals respectively (see the Design subsection below).

Moreover, as a robustness check for the coarse correlated treatment, we run two additional treatments. The first aims to test whether behaviour changes when the interaction is repeated instead of an approximated one-shot interaction. To this end we run our *fixed-match coarse correlated treatment*, which follows the exact same structure as in the coarse correlated treatment, with the only difference being that the pair-matching remains fixed through all rounds. Finally, our last treatment, the *multi-game coarse correlated treatment* aims to test the validity of coarse correlation when the subjects face different games. Here, subjects face the games G_1, G_2 and G_3 as well as the original game G_0.

2.4 Hypotheses

Following the theoretical notions presented earlier, we here present, for each of our treatments, our own hypotheses, some of which are already confirmed in the existing literature. Our first hypothesis is about the strategies in the game G_0, played in the Nash treatment.

Hypothesis 1 *In the Nash treatment, subjects do not play the dominated strategies, C and Y; subjects play the unique Nash equilibrium (A, X) in the game G_0.*

Hypothesis 1 is fairly well-established in the existing literature for such games with unique equilibrium outcomes.

As already explained, the Nash point (A, X) is the only correlated equilibrium for the game G_0.

Hypothesis 2 *In the correlated treatment, subjects follow the recommendations to play (A, X) and do not follow the recommendations (B, Y) and (C, Z) in the game G_0.*

This behaviour is based on the results in the literature on correlated equilibrium (see Cason and Sharma, 2007; Duffy and Feltovich, 2010; Bone *et al*, 2013; Duffy *et al*, 2017; Anbarci *et al*, 2018).

Our main treatment tests the concept of coarse correlated equilibrium. One may expect, as in the existing literature on correlated equilibrium, the theoretical prediction to be observed here, that is, the device will be accepted.

Hypothesis 3 *In the coarse correlated treatment, subjects commit to the device for the game G_0.*

There could be a couple of justifications behind our Hypothesis 3. We expect individuals to accept the device with higher expected payoffs (than the Nash payoff). Also, as the structure of our device is similar to that of "sunspots" (Ray 2002; Polemarchakis and Ray, 2006), following the well-known experimental literature on sunspots (initiated by Duffy and Fisher, 2005), we hypothesise that the theoretical notion of coarse correlation will be validated by our experiment as well.

We draw a comparison between the choices made in the coarse correlated treatment with the individual lottery treatment. First note that in the individual lottery treatment, we are not testing whether the individuals are risk averse or not. Those who do accept the lottery (over the sure outcome of £3) are not necessarily risk-averse or risk-seeker; conversely, individuals who are risk-neutral or risk-seeker and even some risk-averse individuals (for whom the certainty equivalent is between £3 and £$\frac{10}{3}$) would accept the lottery. However, whatever be their risk-attitude, it is fair to assume that the choices for the subjects in the individual lottery treatment and in the coarse correlated treatment will be the same. Thus, one may have a hypothesis that the level of accepting the lottery and committing to the device in these two treatments respectively should be similar. However, an alternative hypothesis can also be put forward here.

Hypothesis 3a *In the coarse correlated treatment, subjects reject the device and then play (A, X) in the game G_0.*

As we explained earlier, the extended game has multiple equilibria; committing to the device is the payoff-dominant equilibrium whereas rejecting the device and playing (A, X) in the game is the risk-dominant equilibrium. Further, this Hypothesis 3*a* can be justified as the coarse correlated equilibrium results in unequal payoffs while the outcome (A, X) in the game may appear to be fair to the subjects. Along with this issue of *fairness* (Fehr and Schmidt, 1999), one may also note 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); 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.

Also, by the same token (using Hypotheses 3 and $3a$), one may test whether the level of accepting the lottery results from the paired lottery treatment are similar to those in the individual lottery treatment and thereby the coarse correlated treatment as well or not. Finally, in support of the robustness of our design, we expect our fixed-match coarse correlated treatment and the multi-game coarse correlated treatment both will have similar levels of committing to the device as in the coarse correlated treatment.

2.5 Design

In the Nash, correlated, coarse correlated, fixed-match coarse correlated and multi-game coarse correlated treatments involving the game(s), each subject was first assigned to a role of either a row or a column player, as the game(s) under investigation is (are) not symmetric. These roles were fixed throughout the experiment. We labelled the row and column players as Red and Blue individuals respectively.

In the individual lottery treatment, subjects had to choose between a sure payment of £3 or a lottery involving outcomes £2, £3 or £5 with equal chances. Here as well, subjects were split in two groups: Red and Blue. Red individuals could see the outcomes of the lottery in the order £3, £5, £2 while Blue individuals could see it in the form £3, £2, £5. In the paired lottery treatment, subjects were also split in two groups: Red and Blue and formed pairs. Each subject had to make a choice between a safe option that yields payoffs £3 for both individuals in the pair, or a lottery which yields either (£3, £3) or (£5, £2) or (£2, £5), respectively for the Red and Blue individuals, with equal chances. Both individuals submitted their choices and the choice of one of the two was implemented; the subjects knew that for every round there was a 50% chance that their choice will be implemented. In both these lottery treatments, the subjects' type (Blue or Red) was fixed between rounds.

In all our treatments, subjects interacted for a total of 20 rounds. In every treatment, except obviously in the fixed-match coarse correlated treatment, there was a new random matching of pairs in every round; participants interacted in groups of 6 (6 are assigned as Blue individuals and 6 as Red individuals). This 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 whom they were matched. In the multi-game coarse correlated treatment, each game was played for 5 rounds and the games appeared in random order in effort to mitigate potential order effects.

In our study, we have collected data from several sessions, with one matching group consisting of 12 subjects in each session. Each session has been devoted to a single treatment. Each matching group represents an independent observation. The overview of the experimental sessions is summarised in Table 5 below.

Treatment	#Subs.	#Indep. Obs.	#Rounds	#Realised Obs.
Individual lottery treatment	48	4	20	960
Paired lottery treatment	24	2	20	480
Nash treatment	48	4	20	960
Correlated treatment	48	4	20	960
Coarse correlated treatment	48	4	20	960
Fixed-match coarse correlated treatment	24	2	20	480
Multi-game coarse correlated treatment	24	2	20	480

Table 5: Experimental Design

2.6 Procedures

The experiment was conducted at the Lancaster Experimental Economics Lab (LExEL). In total, 264 subjects (out of which 53% were females) participated in seven 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.

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 Appendix) which were also read aloud so as to ensure common knowledge. After the instructions phase, the participants were asked to complete a brief questionnaire (see the Appendix) to confirm that there were no misunderstandings regarding the game, the matching procedure, the correlation device and the payoffs. When the subjects had completed the questionnaire, 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 for the experiment, to avoid potential connotations. The actions in the games 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 the correlated treatment was given in a way that it didn't imply whether it is better to follow. Similarly, in the coarse correlated, fixed-match coarse correlated and the multi-game coarse correlated treatments, 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.

For each round, subjects had 1.5 minutes (2.5 minutes in the coarse correlated, fixed-match coarse correlated and the multi-game coarse correlated treatments) for the first 10 rounds to confirm their choices and 1 minute (1.5 minutes in coarse correlated, fixed-match coarse correlated and the multi-game coarse correlated treatments) for the remaining 10 rounds. If no decision was made by that time, the software was programmed to randomly pick one of the choices in the corresponding treatment.[4]

In the individual lottery, paired lottery and Nash treatments, subjects simply clicked on their preferred choice and when ready, they could confirm their choice by clicking the "OK" button. The framework in the correlated treatment was the same as in the Nash treatment 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 in the correlated treatment. In the correlated, coarse correlated, fixed-match coarse correlated and the multi-game coarse correlated treatments, the device is commonly known to the players and is implemented using a random number generator programmed to create recommendations or actions based on the probability distribution of the device.

In the coarse correlated, fixed-match coarse correlated and the multi-game coarse correlated treatments, 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 on their screens, identical to the framework of the Nash treatment (the corresponding game without any correlation device or recommendations), in which 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 individual picked.

[4] This happened overall only in 9 cases in various sessions. The results are identical even if we omit these observations.

At the end of each round, after the subjects have made and confirmed their choices, they were given the relevant feedback. In the individual and paired lottery treatments, the subjects were informed about their payoffs in that round; in the paired lottery treatment, the pair was also informed of whose choice was implemented by the computer. In the Nash, correlated, coarse correlated, fixed-match coarse correlated and the multi-game coarse correlated treatments, the subjects were informed of own and opponent's choice, own and opponent's payoff, plus, own and opponent's recommendation (in the correlated treatment), own and opponent's commitment choice (in the coarse correlated, fixed-match coarse correlated and the multi-game coarse correlated treatments).

At the end of round 20, the experimental session ended and the subjects were privately paid, according to their point earnings. In all the treatments, we used an exchange rate of 1 : 1 (£1 per point).[5] 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 £9.94 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 £13.25 ($17.23) which is considerably higher than usual student-jobs in the UK that offer about £8.00 ($10.40) per hour.

3 RESULTS

3.1 Nash Treatment

In the Nash treatment, overall, 433 out of 480 (90.2%) of the outcomes played is the Nash equilibrium outcome, (A, X). Table 6 presents the frequencies of all the outcomes of the game, divided into four equal five-round blocks (each out of 120) and the total for 20 rounds.

Frequencies in rounds (each out of 120)																Total frequency			
$1-5$				$6-10$				$11-15$				$16-20$				(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 6: Frequencies of outcomes played in the Nash treatment

[5] Due to the 1 : 1 exchange rate, no rounding of payments was needed; subjects were paid exactly what they had earned. This keeps the connection between real incentives and the incentives stated in the instructions, which is perhaps lost in many experiments using rounding, in the literature.

From Table 6, one can find, by adding up the numbers in relevant rows and columns, the frequencies of the individual strategies chosen 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) were chosen only in 10 (2.1%) and 5 (1.1%) cases, respectively. The frequencies in Table 6 also indicate that the Nash outcome (A, X) was played increasingly more over time. To confirm, we formally compared the frequencies of the outcome (A, X) and the individual choices of A and X in the first 5 rounds with that in the final 5 rounds using a suitable parametric t-test and found that the difference is indeed statistically significant.[6]

Result 1 *The dominated strategies, C and Y, have not been chosen by the subjects in the Nash treatment; the Nash equilibrium, (A, X), is played, with an increasing trend over time.*

In line with the existing literature, Hypothesis 1 finds support in our data; (A, X), 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.

3.2 Correlated Treatment

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 the correlated treatment, the correlation device first selected one of the three possible outcomes, namely (A, X), (B, Y) and (C, Z), 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. We do find that the Nash equilibrium outcome (A, X), when recommended, was followed, while the outcomes (B, Y) and (C, Z) were not; further, (A, X) was the most frequently chosen outcome in these two cases. Table 7 presents the frequencies of all the outcomes of the game, over 20 rounds, divided into three different recommendations ((A, X), (B, Y) and (C, Z)) from the device.

Frequencies (by recommendations)												Total frequency			
(A, X) (out of 163)				(B, Y) (out of 149)				(C, Z) (out of 168)				(out of 480)			
	X	Y	Z		X	Y	Z		X	Y	Z		X	Y	Z
A	145	2	7	A	101	15	3	A	111	2	40	A	357	19	50
B	5	0	0	B	21	8	1	B	3	0	3	B	29	8	4
C	4	0	0	C	0	0	0	C	5	1	3	C	9	1	3

Table 7: Frequencies of outcomes played in the correlated treatment

[6] As independent observations, here we considered the session averages of the frequencies and compared them. The p-value for the outcome (A, X) is 0.000 and those for the individual startegies A and X respectively are 0.004 and 0.048.

We note that overall A was chosen by the row players 426 times (88.8%) and X by column players 395 times (82.3%). One may be interested in checking whether following or playing (A, X) increased over time or not. To see this, we present below the frequencies of (A, X) over 20 rounds, divided into four equal five-round blocks. We present this frequency table (Table 8) in two parts; first, we present the frequencies of (A, X) when indeed (A, X) was recommended by the device (163 times in total) and then the frequencies of (A, X) following all possible recommendations (480 observations in total).

Frequencies of playing (A, X) in rounds (by recommendations)					Total frequency
	$1-5$	$6-10$	$11-15$	$16-20$	
After recommendation (A, X)					
(A, X)	29 out of 38 (76.3%)	34/40 (85%)	39/41 (95.1%)	43/44 (97.7%)	145/163 (89%)
After recommendation (B, Y)					
(A, X)	17 out of 37 (45.9%)	28/40 (70%)	28/38 (73.7%)	28/34 (82.4%)	101/149 (67.8%)
After recommendation (C, Z)					
(A, X)	22 out of 45 (48.9%)	27/40 (67.5%)	29/41 (70.7%)	33/42 (78.6%)	111/168 (66.1%)
Total: after any recommendation (AX, BY or CZ); each out of 120					
(A, X)	68 (56.7%)	89 (74.2%)	96 (80%)	104 (86.7%)	357 (74.4%)

Table 8: Frequencies of (A, X) played in the correlated treatment (by recommendations)

One may also see the data by individual round. The following chart (Figure 1) presents the average (over all three recommendations) number of times (A, X) was played, in each of the 20 rounds.

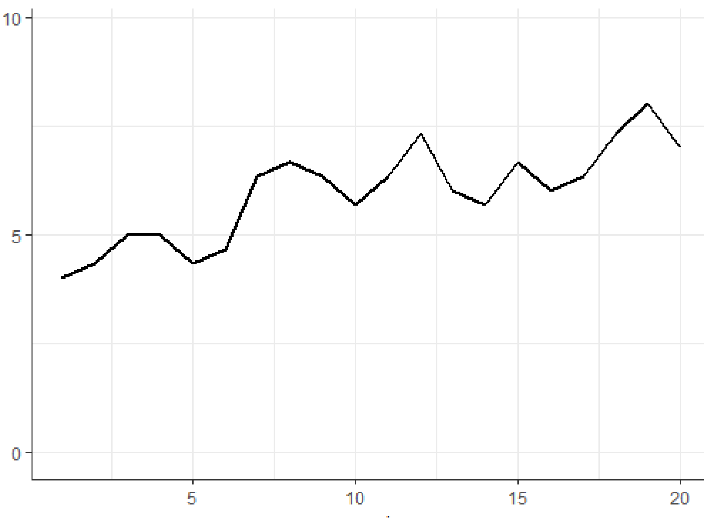

Figure 1: Average frequencies of (A, X) played in each round in the correlated treatment

From Table 8 and Figure 1, we do see an increasing trend of playing (A, X) over time. The difference in the percentages of playing (A, X) when (A, X) was recommended for rounds $1-5$ (76.3%) and for rounds $16-20$ (97.7%) is indeed statistically significant at 5% level ($p = 0.034$), based on a (parametric) t-test; similarly, the difference in the corresponding percentages from any recommendations (56.7% and 86.7%) is also statistically significant at 5% level ($p = 0.037$).[7]

Result 2 *The recommended outcome (A, X) has been followed while the recommendations (B, Y) and (C, Z) have not been and in all these cases, the strategy profile (A, X) has been played with an increasing trend over time.*

Based on Result 2 above, we can say that Hypothesis 2 (that the individuals follow *good* recommendations only) finds support in our data. As already mentioned, results similar to our Result 2 are 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*, 2017; Anbarci *et al*, 2018).

3.3 Individual Lottery Treatment

We observe that 681 out of 960 (70.9%) individual choices accepted the lottery in our individual lottery treatment. 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 group. 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. Table 9 below presents the frequencies (and the percentages) of accepting the lottery, over 20 rounds, divided into four equal five-round blocks (each out of 120), for two types of individuals separately.

Individuals' types	Frequencies in rounds (each out of 120)				Total frequency
	$1-5$	$6-10$	$11-15$	$16-20$	
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%)

Table 9: Frequencies of accepting the lottery (by types) in the individual lottery treatment

From Table 9, we observe that there are some mild differences between the two types in terms of accepting the lottery. However, based on a (parametric) paired t-test with the null hypothesis that

[7] As in the Nash treatment, here as well, we considered the session averages as independent observations.

the two (total) percentages in question are equal, we can report that the percentages of accepting the lottery are not statistically different between the two types.[8] Our conclusion in this subsection therefore is that most (7 out of 10) individuals preferred the given lottery with an expected payoff of $\frac{10}{3}$ to the sure outcome of 3 which indicates that 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.

3.4 Coarse Correlated Treatment

Having analysed the individual choice over lotteries, we now look at the game played with the coarse correlation device. Unlike the individual lottery treatment, in the coarse correlated treatment, only 31 out of 480 (6.5%) pairs committed (both individuals committed in a pair) to the device to get the expected payoff of $\frac{10}{3}$.[9] Table 10 below presents the frequencies (and the percentages) of individually committing to the device over 20 rounds, divided into four equal five-round blocks (each out of 120) for each of the two types of players separately.

Players' types	Frequencies in rounds (each out of 120)				Total frequency
	$1-5$	$6-10$	$11-15$	$16-20$	(out of 480)
Row (Red)	43 (35.8%)	34 (28.3%)	27 (16.7%)	15 (12.5%)	119 (24.8%)
Column (Blue)	33 (27.5%)	25 (20.8%)	20 (16.7%)	14 (11.7%)	92 (19.2%)

Table 10: Frequencies of committing (by types) in the coarse correlated treatment

Table 10 indicates a decreasing time-trend for the individuals committing to the device as rounds progressed. Also, we see a mild difference between the two types of subjects. The overall difference between two types (difference between 119 and 92) is however not significant ($p = 0.4823$), neither it is in any of the four five-round blocks, based on an appropriate (parametric) paired t-test.[10] Table 10 is very similar to Table 9, however with a very contrasting message as stated below.

Result 3 *A high proportion of individuals accepted the lottery in the individual lottery treatment, more so over time, however, in the coarse correlated treatment, a low proportion of subjects committed to the device, less so over time.*

[8] We considered the subject averages as independent observations to compare them. The p-value for the total frequency is 0.421.

[9] In these 31 cases, the chosen (picked by the computer at random) outcomes are: (A, X) in 10 cases, (B, Y) in 9 cases and (C, Z) in the rest 12 times. The average payoffs, in these 31 observations, are thus respectively 3.09 and 3.38 for the row and column players.

[10] As earlier, we considered the session averages as independent observations.

We ran a Probit regression to assess the choice of committing to the device. The independent variables here are *Round* that takes integer values from 2 to 20 for different rounds and three other dummy variables, namely, *Row* (takes value 1 when the individual is a row player), *PastCommit* (takes value 1 when the device was committed to in the previous round) and *PastOppoCommit* (takes value 1 when the device was committed to by the opponent in the previous round). To control for correlation due to repeated observations by the same individual, as well as correlation within each matching group, we adjusted the robust standard errors for one-way clustering, first at the individual level and then at the session level. Table 11 below presents the marginal effects from this Probit regression.[11]

Dependent Variable: *Commit* = 1, if the device is committed to; = 0, otherwise			
Number of Observations: 912; Pseudo $R^2 = 0.3044$			
Independent Variables	Marginal Effects	Robust Standard Errors	p-values
Round	-0.0091^{***}	0.001	0.000
Row	0.0486	0.064	0.446
PastCommit	0.2738^{***}	0.055	0.000
PastOppoCommit	0.1334^{***}	0.034	0.000
Note: * denotes significance at the 10% level, ** at the 5% level and *** at the 1% level.			

Table 11: Probit regression on accepting the device in the coarse correlated treatment

From Table 11, we conclude that subjects do not commit to the device and this behaviour significantly increases with time; a subject is more likely not to commit in a round if the subject or the opponent has not committed in the previous round.[12] We now consider subjects' choices in the game having rejected the device. 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 the Nash treatment). Table 12 presents the frequencies of all the outcomes of the game, after a pair rejected the device, over 20 rounds, divided into four equal five-round blocks and the total for 20 rounds.

[11] This regression uses one-way clustering, nested only at the session level; there is no further benefits in doing two-way clustering as our session-clustering takes care of all individual correlation and generates virtually the same results both in terms of estimates and of standard errors.

[12] Note that both variables *PastCommit* and *PastOppoCommit* are lagged and thus we also ran a couple of more regressions, one without the *PastCommit* variable and the other without both *PastCommit* and *PastOppoCommit* and obtained very similar results (such as, *Round* is significant with p-value 0.000).

Frequencies in rounds (for pairs not committing to the device)																Total frequency			
1 – 5 (57/120)				6 – 10 (73/120)				11 – 15 (81/120)				16 – 20 (94/120)				(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 12: Frequencies of outcomes having rejected the device in the coarse correlated treatment

Result 3a *Having rejected the coarse correlation device, subjects played the Nash equilibrium* (A, X)*, with an increasing trend over time.*

Based on Results 3 and 3a, we can reject Hypothesis 3 and instead conclude that Hypothesis 3a finds support in our experiment. As explained earlier, this observed phenomenon of not committing to the device can be explained as an equilibrium behaviour as well.

One can also compare the frequencies of the outcome (A, X) played in the game in our Nash, correlated and coarse correlated treatments. Table 12 above shows that once a pair did not commit to the device, they chose the outcome (A, X) in 238 out of 305 cases (78.03%) in the coarse correlated treatment while in the Nash treatment the percentage of playing (A, X) was 90.21% (as shown in Table 6). Similarly, from Table 8, we observe that having received recommendations of either (B, Y) or (C, Z), the individuals chose the outcome (A, X) in 212 out of 317 cases (66.88%). We do find a difference in these percentages. Based on an appropriate test with the null hypothesis that the two percentages in question are equal, we can report that the percentage of playing (A, X) in the Nash treatment is statistically higher than those in the correlated and coarse correlated treatments.

3.5 Paired Lottery Treatment

We observe that 317 out of 480 (66%) accepted the paired lottery and asked the computer to make the choice for them and their counterpart. This is in comparison to 681 out of 960 (70.9%) in the individual lottery treatment; the difference (between these two percentages) is indeed not statistically significant ($p = 0.057$). As in Table 9, we present the frequencies (and the percentages) of accepting the lottery, over 20 rounds, divided into four equal five-round blocks (each out of 120), for two types of individuals separately in Table 13 below.

Individuals' types	Frequencies in rounds (each out of 60)				Total frequency
	1 – 5	6 – 10	11 – 15	16 – 20	
Red	42 (70%)	44 (73.3%)	42 (70%)	38 (63.3%)	166 (69.2%)
Blue	34 (56.7%)	37 (61.7%)	42 (70%)	38 (63.3%)	152 (63.3%)

Table 13: Frequencies of accepting the lottery (by types) in the pair lottery treatment

As in the individual lottery treatment, we find that the percentages of accepting the lottery are not statistically different between the two types. Also, there is no significant difference between the percentages in the first and the last five rounds for either types in Table 13. Finally, to compare with the regression results for the coarse correlated treatment (as presented in Table 11), here as well we ran a Probit regression with very similar variables (*Round*, *Type*, *PastChoice*, *PastWho*, *PastOppoChoice*) and found that only *PastChoice* is significant ($p = 0.000$), that is, an individual is more likely accept the lottery in a round if the lottery was chosen in the previous round by that individual. We thus conclude that the observations from the paired lottery treatment is very similar to those in the individual lottery treatment.

3.6 Fixed-Match Coarse Correlated Treatment

We first observe that only 22 out of 240 (9.2%) pairs committed to the device in the fixed-match, compared to 31 out of 480 (6.5%) in the main coarse correlated treatment; the difference (between these two percentages) is indeed not statistically significant ($p = 0.1896$). As in Table 10, we present the frequencies (and the percentages) of individually committing to the device over 20 rounds, divided into four equal five-round blocks by two types of players separately in Table 14 below.

Players' types	Frequencies in rounds (each out of 60)				Total frequency
	1 – 5	6 – 10	11 – 15	16 – 20	(out of 240)
Row (Red)	15 (25%)	12 (20%)	9 (15%)	5 (8.3%)	41 (17.1%)
Column (Blue)	15 (25%)	10 (16.7%)	9 (15%)	8 (13.3%)	42 (17.5%)

Table 14: Frequencies of committing (by types) in the fixed-match coarse correlated treatment

In Table 14, the differences between the percentages for two types for all cases (in total and in four blocks), are not significant. As in the coarse correlated treatment (reported in Table 11), here as well we ran a Probit regression to assess the choice of committing to the device using the same independent variables and found that *Round* is negative but not significant however as earlier both *PastCommit* and *PastOppoCommit* are significant. We also pooled the data from the coarse correlated treatment and this fixed-match coarse correlated treatment for treatment effects with an appropriate dummy and found no significant treatment effect; the variables *Round*, *PastCommit* and *PastOppoCommit* are now significant. Following Table 12, here we found both players did not commit to the device in 179 pairs out of 240 (74.6%), compared to 305 pairs out of 480 (63.5%) in the coarse correlated treatment. Having rejected the device, these pairs played the outcome (A, X) in 138 out of 179 cases (77.1%), compared to 238 out of 305 cases (78%) in the coarse correlated treatment. Results 3 and 3a for the coarse correlated treatment are thus robust against a change of our design to a fixed-match.

3.7 Multi-Game Coarse Correlated Treatment

Only 11 out of 240 (4.6%) pairs committed to the device in the multi-game treatment, compared to 31 out of 480 (6.5%) in the main coarse correlated treatment which is not significantly different ($p =$ 0.3116). As in Table 10, we present the frequencies (and the percentages) of individually committing to the device over 20 rounds, divided into four equal five-round blocks (each out of 120) for each of the two types of players separately in Table 15 below.

Players' types	Frequencies in rounds (each out of 60)				Total frequency
	$1-5$	$6-10$	$11-15$	$16-20$	(out of 240)
Row (Red)	15 (25%)	19 (31.7%)	13 (21.7%)	11 (18.3%)	58 (24.2%)
Column (Blue)	15 (25%)	15 (25%)	8 (13.3%)	5 (8.3%)	43 (17.9%)

Table 15: Frequencies of committing (by types) in the multi-game coarse correlated treatment

In Table 15, the difference between the total percentages for two types (24.2% and 17.9%) is statistically significant however they are not for the four blocks. Here as well we ran a Probit regression to assess the choice of committing to the device using the same independent variables and found that only *Round* and *PastCommit* are significant. We also pooled the data from the coarse correlated treatment and this multi-game coarse correlated treatment for treatment effects with an appropriate dummy and found no significant treatment effect; the variables *Round*, *PastCommit* and *PastOppoCommit* are now significant. We also ran a regression with dummies on which of the three games (one discarded due to collinearity) is played and found no game effect. Finally, here we found both players did not commit to the device in 150 pairs out of 240 (62.5%); having rejected the device, these pairs played the outcome (A, X) in 127 cases (84.6%). We thus conclude that Results 3 and 3a for the coarse correlated treatment are robust even when we change the payoffs in the game suitably.

4 CONCLUDING REMARKS

In this paper, we report the observations from an experiment to compare the level of the Nash equilibrium outcome played by the subjects in a game with unique pure Nash equilibrium, with and without the help of a specific correlation device. Our results from the treatments involving Nash and correlated equilibrium are in line with the existing literature; however, the main treatment testing the concept of coarse correlated equilibrium suggests that a public device is not accepted by the subjects. We also find that the choice of Nash equilibrium outcome is the highest in the treatment without any correlation device.

We observe that the individuals accept the individual lottery; however in the coarse correlated treatment, they, as the players in a game, do not accept the device, play the game instead and choose the Nash equilibrium outcome. These may appear to be contradictory to each other; however, one may explain this behaviour in the game as a risk-dominant equilibrium. We also believe another good reason why the players rejected the device is the issue of fairness (Fehr and Schmidt, 1999).

One may wonder whether this apparent failure of the theoretical concept of coarse correlated equilibrium is because of the choice of the specific device; admittedly, the concept of coarse correlation here requires a lot of trust in the device in order to be implemented, although, our chosen public device is similar to a *Nash-centric* device (Ray and Sen Gupta, 2013; Moulin *et al*, 2014) with a sunspot structure. 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 game (Table 16).[13]

	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

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) 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). One may run such an experiment in future.

[13] We sincerely thank Hervé Moulin for suggesting this example.

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6 APPENDIX

We first report below the full set of instructions including record sheet and the test only for our coarse correlated treatment. The instructions (and subsequently the record sheet and the questionnaire) for other treatments involving the game(s) 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 individual lottery treatment.

6.1 Instructions (Coarse Correlated Treatment)

All participants in a session (in the coarse correlated treatment) 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 session 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.

6.2 Record Sheet (Coarse Correlated Treatment)

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					

6.3 Questionnaire (Coarse Correlated Treatment)

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 £) 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.

6.4 Instructions (Individual Lottery Treatment)

All participants in a session (in the individual lottery treatment) 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 session 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: "£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 £3, £5 or £2"; and if you are in the Blue group the Option B is: "Computer picks at random with equal chance £3, £2 or £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.

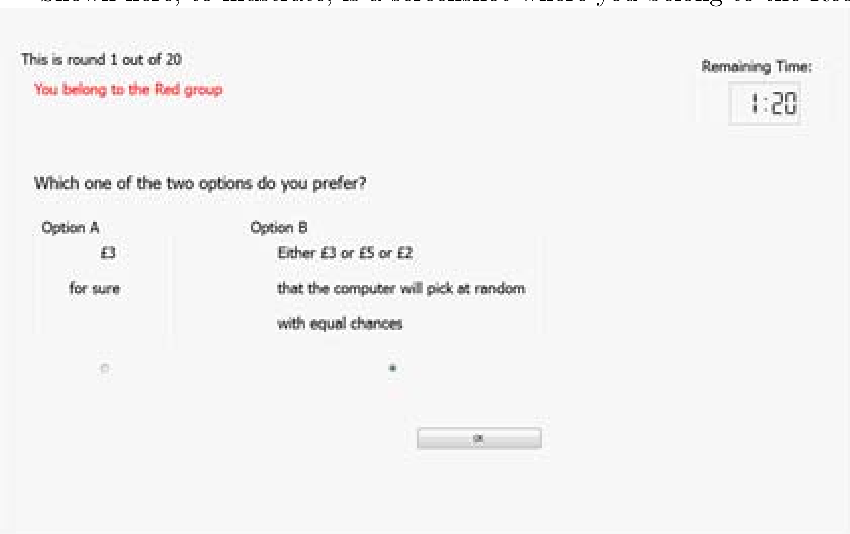
Scenario 2 – 'Choose Option B'

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 £$\frac{10}{3}$ (= £3($\frac{1}{3}$) + £5($\frac{1}{3}$) + £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.