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Co-ordination in 2 x 2 Games by Following Recommendations from Correlated Equilibria

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Coordination in 2 x 2 Games by Following Recommendations from Correlated Equilibria*

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Abstract

We consider three games, *Symmetric Battle of the Sexes*, *Modified Battle of the Sexes* and *Chicken* and two different correlation devices, *public* and *private*, with the same expected payoffs in equilibrium, which is also the best correlated equilibrium payoff for these games. Despite our choices of the payoffs in these games based on some theoretical criteria, we find that coordination and following recommendations vary significantly among our treatments. We explain these differences by analysing players' choices in cases when they do and do not follow recommendations in different games.

Keywords: Coordination, Public message, Recommendation, Correlated equilibrium.

JEL Classification Numbers: C72, C92, D83.

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1 INTRODUCTION

Many games of economic interest involve multiple (pure) Nash equilibria and it is therefore important to understand how, if at all, individuals coordinate to play a particular equilibrium outcome. This problem of equilibrium selection has been theoretically analysed using different criteria, such as, payoff-dominance, perfection, properness and risk-dominance (see van Damme 1987, Harsanyi and Selten 1988 and Myerson 1991, for details). The issues of multiple equilibria and coordination in games have also been one of the major themes of research in experimental economics (Cooper *et al.* 1989, 1990; Van Huyck *et al.* 1990, 1991). In the last two decades, a growing literature of experimental research suggests that individuals indeed are able to coordinate on a naturally selected outcome if they are helped to do so using some suitably chosen scheme.[1] The experimental literature also suggests that in games with multiple symmetric equilibria in which no outcome can be naturally selected (such as the Battle of the Sexes, henceforth, BoS), individuals fail to coordinate unless the game has an intrinsic feature, such as, risk-dominance (Cabrales *et al.* 2000) or there is a way to distinguish one of the outcomes (Van Huyck *et al.* 1992; Cooper *et al.* 1989, 1990, 1992; Straub, 1995).[2]

Seemingly orthogonal to the above literature on coordination, there is also a recent however thin literature (Moreno and Wooders 1998; Cason and Sharma 2007; Duffy and Feltovich 2010) on experiments with correlated devices *a la* Aumann (1974, 1987) that recommend strategies to the players according to a probability distribution. Clearly, any convex combination (public lottery) over pure Nash equilibrium outcomes can be viewed as a correlated equilibrium. Thus, combining the results from these two strands of literature, respectively on coordination and correlation, one may easily conjecture that in a symmetric 2 x 2 game like BoS, individuals can avoid coordination-failure by following a correlation device that randomly selects one of the two pure Nash equilibria. Indeed, such a conjecture has been confirmed as a result for this (public) correlated equilibrium in the game of Chicken by Cason and Sharma (2007) and Duffy and Feltovich (2010), and in other relevant papers on coordination.[3]

[1] Costless messages, announcements (Brandts and Macleod 1995; Blume 1998; Clark *et al.* 2001; Blume and Ortmann 2007; Manzini *et al.* 2009), information on other individuals' choices (Charness and Grosskopf 2004), history of play and observation of others' actions (Duffy and Feltovich 2002, 2006; Schmidt *et al.* 2003), attractiveness of the payoff-dominant outcome (Battalio *et al.* 2001) and advice on the desirable outcomes (Croson and Marks 2001; Chaudhuri *et al.* 2009; Chaudhuri and Paichayontvijit 2010), can facilitate coordination (see Devetag and Ortmann 2007 for a survey).

[2] Cheap-talk (as in Farrell 1987) and any pre-play non-binding communication can significantly improve coordination in games like BoS (Cooper *et al.* 1989; Crawford 1998; Costa-Gomes 2002; Camerer 2003; Burton *et al.* 2005).

[3] Duffy and Fisher (2005) introduced sunspots as coordination devices using randomisation over equilibria. Stahl (2009) and Camera *et al.* (2010) used randomised messages for cooperation in Prisoners' Dilemma, while Brandts and McLeod (1995) and Seely *et al.* (2005) analysed public recommendations. Experiments on public information (McKelvey and Page 1990; Marimon *et al.* 1993; McCabe *et al.* 2000; Anctil *et al.* 2004; Heinemann *et al.* 2004) are also related.

We, in this paper, take this connection between two strands of literature (on coordination and correlation) further by questioning the robustness of the above conjecture. We ask whether individuals coordinate in the same fashion in any 2 x 2 game similar to the BoS, using a public lottery that selects one of the two pure symmetric equilibria at random. To answer this question, we consider three different symmetric 2 x 2 games, each with two (pure) symmetric Nash equilibria (denoted by (X, Y) and (Y, X) in our games) and two other outcomes (denoted by (X, X) and (Y, Y) here). The games we use are identical in structure and differ just in one outcome, (Y, Y). There is no natural way to coordinate on one of the two pure Nash equilibria ((X, Y) and (Y, X)) in these games. Two games are common in the literature, namely, Symmetric BoS and Chicken, while the third lies in between (in terms of the payoffs from the outcome (Y, Y)) that we call the *Modified BoS*. As the games have the same structure and the same pure Nash equilibrium payoffs, our first prediction is that coordination achieved using a public lottery does not vary over these three games (Hypothesis 1).

Moreover, following the literature on correlation, we choose two different correlation devices for the game of Chicken. The first one, as explained, is a public lottery with equal probabilities over the two pure Nash equilibria of the games, (X, Y) and (Y, X). We formally call this randomised scheme a *public* correlation device. The second correlation device randomly selects three outcomes of the games, (X, Y), (Y, X) and (Y, Y) with equal probabilities $\left(\frac{1}{3}\right)$. Clearly, this device involves a simple posterior distribution (of equal probabilities) given the recommendation Y for an individual over the two possible recommendations for the other individual. We call this device the *private* correlation device. These two correlation devices have already been tested and compared in the literature (Cason and Sharma 2007 and Duffy and Feltovich 2010) to analyse players' behaviour of following recommendations from different types of correlation devices for the game of Chicken. However, these papers do not offer any specific reasons behind the choices of the payoffs in the game of Chicken. Therefore, not surprisingly perhaps, these papers found that different recommendations, involving different conditional expected returns, were followed with very different rates.

We choose two correlated equilibria (public and private) to have the same expected payoffs (when recommendations are followed) in all these games and also to be the best correlated equilibria in terms of *ex ante* expected payoffs for the corresponding games. Moreover, for the game of Chicken, we maintain the same conditional expected payoffs for the two recommendations (X and Y) from the private device. Unlike other papers in the literature, we have chosen the payoffs in our games based on these theoretical criteria (Criteria $1 - 6$ in Section 2). Hence we expect no differences among our games in terms of following recommendations (Hypothesis 2). Moreover, our choice of the payoffs in the game of Chicken theoretically confirms that there should not be any difference in following a particular recommendation from the private device (Hypothesis 3).

Our experimental design consists of four different treatments in total. Two treatments are assigned to the game of Chicken, one with the private device and the other with the public device; two other treatments use the public device for the two versions of the BoS. This experimental design with four treatments allows us to analyse the issues we are interested in: the effects of public randomisation on coordination (by comparing all three games with the public device), and the impact of different correlation devices on individuals' play (by comparing two treatments involving the game of Chicken). Note that we do not compare the effect of different correlation devices for the two BoS games as the private device is not a correlated equilibrium for these games. We already know from the literature (Cason and Sharma 2007 and Duffy and Feltovich 2010) that individuals do not usually follow recommendations from a correlation device that is not a correlated equilibrium.

In line with the existing literature on correlation, we do find that individuals achieve coordination by following recommendations from the public device; for example, 93% of all the recommendations from the public device have been followed in the Symmetric BoS and for this game, individuals actually coordinated in almost 88% of the cases. However, despite the theoretical choices of our payoffs, we find that coordination and following recommendations are not robust to our treatment variations and we reject Hypotheses 1 and 2.

Our main finding is that coordination and following recommendations vary significantly between the games of Symmetric BoS and Chicken. We find individuals follow recommendations (from a public device) and coordinate more in the Symmetric BoS than in the game of Chicken. At first sight, these differences in achieving coordination and following recommendations may appear to be surprising. However, our results can be explained by considering the observations where the recommendations are followed and when they are not followed.

We also find that individuals do follow the recommendation of strategy Y more than X in the game of Chicken with the private device, rejecting Hypothesis 3. On the other hand, recommendation of strategy X is more followed than Y in the Symmetric BoS. In the game of Chicken, players may be "procedurally rational" (Osborne and Rubinstein 1998) and may find the strategy Y more attractive than the strategy X, even though the conditional expected gains from following are the same.

We analyse the observations when the recommendations from the public device in these games are not followed. A pair of individuals may not both follow their recommendations and may still coordinate. However, when exactly one of the individuals in a pair does not follow, the outcomes may either be (X, X) or (Y, Y), regardless of their recommendations. Individuals may try to "coordinate" to achieve the outcome (Y, Y), as a "fair" and "cooperative" outcome, particularly in the game of Chicken. This interpretation does match with our findings. Result 4 confirms that the frequency of (Y, Y) is significantly higher in Chicken than that in the Symmetric BoS.

2 MODEL

2.1 Correlated Equilibrium

The concepts below are well-established in the literature, following the seminal work of Aumann (1974, 1987). We are presenting the definitions and notations we need in this paper (as presented in Ray 2002 and Ray and Sen Gupta 2013), just for the sake of completeness.

Fix any 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.

Definition 1 *A (direct) correlation device μ is a probability distribution over S.*

A normal form game, G, can be extended by using a direct correlation device. For correlation *a la* Aumann (1974, 1987), the device first selects a strategy profile s $(= (s_1, ..., s_n))$ according to μ, and then sends the private recommendation s_i to each player i. 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.

Definition 2 *Given a direct 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 direct correlation device μ is called a public device if for all $s \in S$, either $\mu(s) = 0$ or s is a public recommendation.*

Given a normal form game, G, and a correlation device, μ , a (pure) strategy for player i in the game G_μ is a map $\sigma_i : S_i \to S_i$ and the corresponding (ex-ante, expected) payoff is given by, $u_i^*(\sigma_1, ..., \sigma_n) = \sum_{s\in S} \mu(s)u_i(\sigma_1(s_1), ..., \sigma_n(s_n))$. The *obedient* strategy profile is the identity map $\sigma_i^*(s_i) = s_i$, for all i, with payoff to player i given by $u_i^*(\sigma^*) = \sum_{s\in S} \mu(s)u_i(s)$. The device is called a correlated equilibrium (Aumann 1974, 1987) if all the players follow the recommended strategies, i.e., the obedient strategy profile 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 3 *μ is a (direct) correlated equilibrium of the game G if $\sum_{s_{-i}\in S_{-i}} \mu(s_i, s_{-i})u_i(s_i, s_{-i}) \geq \sum_{s_{-i}\in S_{-i}} \mu(s_i, s_{-i})u_i(t_i, s_{-i})$, for all i, for all s_i, $t_i \in S_i$.*

For any normal form game G, let $NE(G)$ denote the set of all 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, while $P(G)$

denote the set of all direct correlated equilibria that are also public devices. It is obvious that any public direct correlated equilibrium must assign positive probabilities only on Nash equilibrium points. Hence, formally, $NE(G) \subseteq P(G) \subseteq CONV(G) \subseteq CE(G)$.

2.2 Games

In this paper, we use two well-studied 2 x 2 normal form games, namely the games of Chicken and the BoS. We first consider a parametric version of the two-person game of Chicken as presented in Kar *et al.* (2010) shown in Table 1 below, where, $a < b < c < d$. Each of the two players has two strategies, namely, X and Y.

	X	Y
X	a, a	d, b
Y	b, d	c, c

Table 1: The Parametric Version of the Game of Chicken

The above game has two pure Nash equilibria, namely, (X, Y) and (Y, X), and a mixed Nash equilibrium in which each player plays X with probability $\frac{(d-c)}{(d-c)+(b-a)}$.

We now present the two-person game of BoS, keeping it close to the above structure as much as possible, for the sake of comparing our results from these two games. Using the same parametric notations as in the game of Chicken, we construct a two-player game of BoS, as shown in Table 2 below, where $a \leq \acute{a} < b < d$. Here as well, each of the two players has two strategies, namely, X and Y. We call this game the *Symmetric BoS* when $a = \acute{a}$ and the *Modified BoS* when $a < \acute{a}$.

	X	Y
X	a, a	d, b
Y	b, d	$\acute{a}, \acute{a}$

Table 2: The Parametric Version of the Game of BoS

Like the game of Chicken, this game also has two pure Nash equilibria, namely, (X, Y) and (Y, X), and a mixed Nash equilibrium in which each player plays X with probability $\frac{(d-\acute{a})}{(d-\acute{a})+(b-a)}$.

2.3 Correlation Devices

As explained earlier in the Introduction, we focus on two particular direct correlation devices. The first one, as shown in Table 3 below, is a *public* device, following Definition 2.

	X	Y
X	0	$\frac{1}{2}$
Y	$\frac{1}{2}$	0

Table 3: The Public Device

Clearly, this correlation device is a direct correlated equilibrium for any parametric version of the games of Chicken and (Symmetric and Modified) BoS described above, as it is a convex combination of two pure Nash equilibria, (X, Y) and (Y, X), in either of these games. In the rest of the paper, we refer to this specific correlation device as the *public* device. The second correlation device we analyse is shown in Table 4 below.

	X	Y
X	0	$\frac{1}{3}$
Y	$\frac{1}{3}$	$\frac{1}{3}$

Table 4: The Private Device

This direct correlation device obviously is not a public device. Note that the posterior probabilities given the recommendation Y are $(\frac{1}{2}, \frac{1}{2})$ and hence are easy to understand and interpret. In the rest of the paper, we refer to this specific correlation device as the *private* device. This correlation device is a direct correlated equilibrium for Chicken with certain restrictions on the parameters, by Definition 3. This equilibrium will be used in this paper for the game of Chicken only, as we will explain later.

We now characterise the direct correlated equilibrium that maximises the sum of the expected payoffs, often called the *utilitarian correlated equilibrium*, for these two games.

It is clear that for the games of Symmetric and Modified BoS, regardless of the specific values of the parameters, any convex combination of the two pure Nash equilibria corresponds to a utilitarian correlated equilibrium, with the sum of the expected payoffs $(b + d)$.

Similarly, for the game of Chicken, under $b + d > 2c$, any element of $CONV(G)$ of the game corresponds to a utilitarian correlated equilibrium with the sum of the expected payoffs $(b + d)$. To characterise the utilitarian correlated equilibrium for the game of Chicken under $b + d < 2c$, consider the direct symmetric correlation device (following Kar *et al.* 2010) with $0 < p < \frac{1}{2}$, as in Table 5.

	X	Y
X	0	p
Y	p	$1 - 2p$

Table 5: The Utilitarian Correlated Equilibrium for the Game of Chicken

It can be checked that the above device is a direct correlated equilibrium for any parametric version of the game of Chicken when $\frac{(d-c)}{(b-a)+2(d-c)} \leq p$ $(< \frac{1}{2})$, using Definition 3. The payoff from this correlated equilibrium to either of the players is $c - p(2c - b - d)$, which is decreasing in p if and only if $2c - b - d > 0$. Hence, under $b + d < 2c$, the utilitarian correlated equilibrium of the game of Chicken is characterised by a device as in Table 5 with $p = \frac{(d-c)}{(b-a)+2(d-c)}$. Consequently, for a game of Chicken with $b + d = 2c$, the utilitarian correlated equilibrium is not unique. Indeed any element of $CONV(G)$ and any device as above with $\frac{(d-c)}{(b-a)+2(d-c)} \leq p < \frac{1}{2}$ is a utilitarian correlated equilibrium of the game.

2.4 Parameters

We now choose specific values of the parameters for our games of Chicken and (Symmetric and Modified) BoS satisfying certain criteria so that the public and private devices described above are appropriate for our analysis.

As we are going to use both the public and private devices for Chicken, we first impose some restrictions on the parameters of Chicken for our purposes. We start off with a stronger criterion than the standard requirement for the correlated equilibrium (as in Definition 3), stated below.

Criterion 1 *For the game of Chicken, the private device is a correlated equilibrium and the equilibrium conditions (incentive constraints) are satisfied with strict inequalities.*

For the above criterion to hold, we need $b + c > a + d$, or, $b - a > d - c$. Note that the other equilibrium constraint is satisfied with strict inequality anyway, as $d > c$, in our game of Chicken. Also, this restriction is automatically satisfied for the public devices by the structure of the public device and the games considered here. Criterion 1 for the private device makes sure that individuals are not indifferent over following or not following a recommended strategy in the game of Chicken.

Criterion 2 *For the game of Chicken with the private device (at equilibrium), the conditional expected gains in payoffs from following a recommendation are the same, for both possible recommendations, X and Y.*

Criterion 2 can be translated as the expected payoff from playing X given the recommendation X minus the expected payoff from playing Y given X is equal to the expected payoff from Y given Y minus the expected payoff from X given Y. From the analysis in the previous subsection, for this criterion to hold, we require $b - a = 3(d - c)$. This criterion allows us to compare the results from two different recommendations for the private device in the game of Chicken. Note that we have not imposed such a criterion on the public device as the recommendations are symmetric for such a device.

Our next criterion requires that the expected payoffs from the different games and correlated equilibria we consider should be the same so that the results from three different games and two different equilibria can be compared. Moreover, the criterion enforces that we achieve the best possible correlated equilibrium payoffs in our set-up.

Criterion 3 *For the game of Chicken, both the public and the private devices are the utilitarian correlated equilibrium for the game (and have the same expected payoffs). For the games of Symmetric and Modified BoS, the public device is the utilitarian correlated equilibrium for the game with the same expected payoff as in the public and the private device for the game of Chicken.*

From the analysis in the previous subsection on the game of Chicken, it is clear that for Criterion 3 to hold, we must have $2c = b + d$ and $\frac{b+d}{2} = \frac{b+c+d}{3}$ (which also implies $2c = b + d$). Note that the private device cannot be the utilitarian correlated equilibrium for the games of Symmetric and Modified BoS as it picks a (Pareto-) dominated outcome, (Y, Y), with a positive probability and this is why we do not use the private device for the BoS.

Criterion 3 above also makes sure that correlation is better than independent individual randomisation, that is, the mixed strategy Nash equilibrium payoff is strictly less than the payoffs from the (public and private) devices we consider.

Our next criterion is indeed about mixed strategy equilibrium of the game and it requires that a naive randomisation with equal probability over two pure strategies does not constitute an equilibrium behaviour in the game.

Criterion 4 *The (mixed) strategy of $(\frac{1}{2}, \frac{1}{2})$ does not constitute the mixed Nash equilibrium in the games of Chicken and (Symmetric and Modified) BoS.*

Note that Criterion 4 follows from Criterion 1 for the game of Chicken. As $b + c > a + d$, playing Y is strictly better than playing X, against the opponent's (mixed) strategy of $(\frac{1}{2}, \frac{1}{2})$, in the game of Chicken. Similarly, for any parameter values, playing X is always strictly better than playing Y, against the opponent's (mixed) strategy of $(\frac{1}{2}, \frac{1}{2})$ in the game of Symmetric BoS.

In order to avoid the possible effect of individuals' aversion for negative and zero payoffs in experiments, we restrict our parameters to be (strictly) positive. Formally,

Criterion 5 $a > 0$.

Finally, we also impose the following restriction on our game of Chicken.

Criterion 6 *For the game of Chicken, d is sufficiently high, i.e., $d - c >> 0$.*

Criterion 6 deserves a clarifying remark. Although (Y, Y) is not a Nash equilibrium in the game of Chicken as long as $d > c$, the strategy of playing Y may appear to be a weakly dominant strategy, when $d - c$ is small. We thus have imposed the restriction stated in Criterion 6.

We now claim that the games of Chicken and the Symmetric BoS can be identified by two parameters, namely, a (> 0) and x $(>> 0)$, only. From Criterion 3, we need $(c - b) = (d - c) = x$ (say). Then, from Criterion 2, we must have $(b - a) = 3x$, which satisfies Criterion 1 as well. Hence, the parameters that satisfy Criteria 1, 2 and 3 are $a > 0$, $b = a + 3x$, $c = b + x = a + 4x$ and $d = c + x = a + 5x$.

It is easy to confirm that the expected payoffs from the public device for the games of Symmetric and Modified BoS and the expected payoffs from the private and public devices for the game of Chicken are all equal to $a + 4x$.

Given these parameters, the mixed strategy Nash equilibrium for the game of Chicken turns out to be $(\frac{1}{4}, \frac{3}{4})$ regardless of the specific values of a and x, as $\frac{(d-c)}{(d-c)+(b-a)} = \frac{x}{x+3x} = \frac{1}{4}$. Similarly, for the Symmetric BoS, the mixed strategy Nash equilibrium is $(\frac{5}{8}, \frac{3}{8})$, regardless of a and x. Finally, for the Modified BoS, in the mixed strategy Nash equilibrium, the probability of playing X is $\frac{5x-(a'-a)}{8x-(a'-a)}$.

For the Modified BoS, we need to choose a' such that $a' < c = a + 4x$, or, $a' - a < 4x$. However, note that if $a' = a + 2x$ (that is, $a' - a = 2x$) then the mixed strategy Nash equilibrium for the Modified BoS is indeed playing X (or Y) with probability $\frac{1}{2}$. Hence, a' should not be equal to $a + 2x$ to satisfy Criterion 4.

We now present the chosen values of a $(> 0$, to satisfy Criterion 5) and x $(>> 0$, to meet Criterion 6), for our experiment. We take $a = 2$ and $x = 3$. Thus, our game of Chicken is as shown in Table 6 below.

	X	Y
X	$2, 2$	$17, 11$
Y	$11, 17$	$14, 14$

Table 6: The Game of Chicken

We then use the same parameter values to identify the game of Symmetric BoS as indicated above. Thus, our game of Symmetric BoS is as shown in Table 7 below.

	X	Y
X	$2, 2$	$17, 11$
Y	$11, 17$	$2, 2$

Table 7: The Game of Symmetric BoS

Finally, the game of Modified BoS can be identified by choosing an appropriate $\acute{a}$, with $2 < \acute{a} < 14$. One would like to choose a value in the middle of admissible range, however, $\acute{a}$ can not be equal to $a + 2x$ (= 8, here). We have chosen $\acute{a} = 7$. Thus, our game of Modified BoS is as shown in Table 8.

	X	Y
X	$2, 2$	$17, 11$
Y	$11, 17$	$7, 7$

Table 8: The Game of Modified BoS

In all three games, the two pure Nash equilibrium payoffs are $(17, 11)$ and $(11, 17)$. The mixed strategy Nash equilibrium payoffs for the games of Symmetric BoS, Chicken and Modified BoS respectively are $(\frac{61}{8}, \frac{61}{8})$, $(\frac{53}{4}, \frac{53}{4})$ and $(\frac{173}{19}, \frac{173}{19})$. As noted earlier, the expected payoffs from the public device for the games of Symmetric and Modified BoS and the expected payoffs from the private and public devices for the game of Chicken are all the same and equal to $(14, 14)$, which is higher than the mixed Nash equilibrium payoffs in all the games.

A remark is in order regarding our choice of the values of a, $\acute{a}$ and x, and thus, our specific payoffs in the games. One may argue that the chosen value of x $(= d - c = 3)$ in the game of Chicken, is not big enough (Criterion 6); however, we believe that this value of x is sufficient to make the strategy X not weakly dominated by the strategy Y, for our experiment.

3 EXPERIMENT

3.1 Design and Procedures

As already mentioned in the previous section, we use three different games, namely, the games of Chicken, Symmetric BoS and Modified BoS, and two different correlation devices, namely, the public device and the private device. The public device is used with all three games to compare coordination in different games; however, the private device is used only for the game of Chicken to compare the effect of different correlation devices within one game.

Note that we do not have any treatment on any particular game without correlation devices, as a possible benchmark. Such a benchmark has already been covered in the existing literatures on coordination (for example, by Cooper *et al.* 1989, for the game of BoS) and on correlation (for example, by Duffy and Feltovich 2010, for the game of Chicken). The main purpose of our paper is to analyse the robustness of coordination by following recommendations in different games. In total, we thus have four experimental treatments. These are: the Symmetric Battle of the Sexes game with the public device (*Symmetric-BoS*), the Modified Battle of the Sexes game with the public device (*Modified-BoS*), the game of Chicken with the public device (*Chicken-Public*) and the game of Chicken with the private device (*Chicken-Private*). The games and the devices in each treatment are summarised below.

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<tr><td>Symmetric-BoS</td><td>Modified-BoS</td></tr>
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<table><tr><td></td><td>X</td><td>Y</td></tr><tr><td>X</td><td>$2,2$</td><td>$17,11$</td></tr><tr><td>Y</td><td>$11,17$</td><td>$2,2$</td></tr></table>
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<tr><td>Mixed NE strategy: $(\frac{5}{8}, \frac{3}{8})$; payoff: $\frac{61}{8} \simeq 7.63$</td><td>Mixed NE strategy: $(\frac{10}{19}, \frac{10}{19})$; payoff: $\frac{173}{19} \simeq 9.11$</td></tr>
<tr><td>Player's payoff when device is followed: 14</td><td>Player's payoff when device is followed: 14</td></tr>
<tr><td>Chicken-Public</td><td>Chicken-Private</td></tr>
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<table><tr><td></td><td>X</td><td>Y</td></tr><tr><td>X</td><td>$2,2$</td><td>$17,11$</td></tr><tr><td>Y</td><td>$11,17$</td><td>$14,14$</td></tr></table>
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<table><tr><td></td><td>X</td><td>Y</td></tr><tr><td>X</td><td>$2,2$</td><td>$17,11$</td></tr><tr><td>Y</td><td>$11,17$</td><td>$14,14$</td></tr></table>
<table><tr><td></td><td>X</td><td>Y</td></tr><tr><td>X</td><td>0</td><td>$\frac{1}{3}$</td></tr><tr><td>Y</td><td>$\frac{1}{3}$</td><td>$\frac{1}{3}$</td></tr></table>
</td></tr>
<tr><td>Mixed NE strategy: $(\frac{1}{4}, \frac{3}{4})$; payoff: $\frac{53}{4} = 13.25$</td><td>Mixed NE strategy: $(\frac{1}{4}, \frac{3}{4})$; payoff: $\frac{53}{4} = 13.25$</td></tr>
<tr><td>Player's payoff when device is followed: 14</td><td>Player's payoff when device is followed: 14</td></tr>
</table>

Table 9: Overview of Experimental Treatments

We used the so-called "between subjects" design. In any of our experimental sessions, only one of the four treatments was run. For each of the treatments, we used 6 matching groups, each comprising of 8 subjects (i.e., 4 pairs). Each treatment lasted for 20 rounds. Because of the likely dependencies between decisions made within matching groups, we took one matching group as our unit of observations and treated these observations as independent data points for performing all our statistical tests.

We randomly re-matched the subjects in every round in order to create an environment as close as possible to a one-period interaction between subjects. Subjects were informed that they had been randomly paired with participants, different from one round to the next; however, they were not aware of the identity of the subjects they were matched with. The same matching protocol was used in all matching groups. The overview of the experimental design is summarised in Table 10 below.

Treatment	Game	Device	#Indep. Obs.	#Subjects	#Rounds
Symmetric-BoS	Symmetric BoS	Public	6	8 x 6 = 48	20
Modified-BoS	Modified BoS	Public	6	8 x 6 = 48	20
Chicken-Public	Chicken	Public	6	8 x 6 = 48	20
Chicken-Private	Chicken	Private	6	8 x 6 = 48	20

Table 10: Experimental Design

All sessions used an identical protocol. At the beginning of a session, subjects were seated and given a set of written instructions. We report the full instructions only for the Chicken-Private treatment in the Appendix of this paper. The instructions for other treatments are similar to those in Chicken-Private and hence have been omitted and are available upon request.

All subjects in a session had identical instructions and were given five minutes to read the written instructions and then, after reading the instructions, a few minutes to complete a brief comprehension test (see Appendix), to ensure that they have understood the instructions, before starting the experiment itself. When the subjects had done the test, we went round to them individually to make sure that they had all the answers correct. The experiment did not proceed until every subject had the correct answers to these questions. Subjects were not allowed to communicate with one another throughout the session, except via the decisions they made during the experiment.

Notice that all our games can be described without assigning the subjects to be a row or a column player. Hence, each pair of subjects was described as "you and your counterpart". Note also that we used a neutral terminology and avoided using any term that may have some other connotations, such as, "your opponent" or "your partner". Subjects were not given identifying information about their counterparts in any round to avoid any subject-specific reputation that may develop across the rounds.

At the beginning of a round, subjects were shown the payoff matrix corresponding to a game (depending on the treatment), along with their recommended action, which was randomly drawn from the appropriate probability distribution given by the device. We used a neutral framing to offer the recommendations by using the phrase "it is recommended that you choose ...". We also clearly explain (see the instructions in the Appendix) the probability distribution, the conditional probabilities and the expected payoffs in simple terms.

For any treatment, in all its sessions, we used the *same* random sequence of recommendations to reduce across-subject variation. After the subjects decided which action to choose, they were provided with the feedback on their own recommendation, own chosen action, counterpart's recommendation, counterpart's chosen action, own payoff and counterpart's payoff, after each round. Subjects were also given a record sheet (see Appendix) to keep track of the feedback information from previous rounds.

At the end of round 20, the experimental session ended. Subjects were asked to complete a brief on-screen questionnaire with some supplementary background information and then privately paid according to their point earnings from all 20 rounds, using an exchange rate of £0.03 per point. Average earnings per treatment were as follows: £7.53 for Symmetric-BoS, £7.29 for Modified-BoS, £7.82 for Chicken-Public and £7.50 for Chicken-Private.[4]

[4] There was no show-up fee for our experiment. Sessions lasted, on average, for 40 minutes. Our average payment over all treatments, £7.54 (approximately $12) is higher than student-jobs in the UK that offer about £7.00 per hour.

The experiment was programmed and conducted with the software *z-Tree* (Fischbacher, 2007). All the sessions were conducted at the laboratory of the Centre for Experimental Economics (EXEC) at the University of York. The subjects were recruited, using the ORSEE software (Greiner, 2004), from various fields of studies of the University of York, including, but certainly not confined to, Economics or other Social Sciences.

3.2 Hypotheses

In this subsection, we formally present our theoretical hypotheses, following the set-up in Section 2. First of all, based on the existing literatures on coordination and correlation, we can predict that individuals do follow the recommendations from the public device to coordinate on Nash outcomes in all three games. Our set-up from the previous section suggests that we should expect the rates of this coordination among the games, Symmetric BoS, Modified BoS and Chicken will be similar. Our first null hypothesis is:

Hypothesis 1 *The level of coordination achieved, using the public device, does not vary across the three games (Symmetric BoS, Modified BoS and Chicken).*

Having posed the first hypothesis, we also would like to formally test whether the frequencies of following recommendations vary among all our four treatments, using two different types of correlation devices. As we have chosen the parameters in the games (using Criterion 3) to maintain the same expected payoffs (when recommendations are followed) in all four treatments. Hence, our second null hypothesis is as follows.

Hypothesis 2 *There is no difference in the rates of following recommendations among four treatments.*

We will test null hypotheses 1 and 2 against the respective alternatives that following recommendations and coordination differ among treatments. In particular, an alternative hypothesis is that coordination (and also following recommendations) is higher in (either version of) the BoS than in the game of Chicken. As explained in the Introduction, this alternative is based on the fact that individuals may wish to achieve the outcome (Y, Y) in the game of Chicken. Also, the alternative hypothesis suggests that there may be differences in following recommendations from the public and private correlation devices in the game of Chicken.

Finally, Criterion 2 implies that for the game of Chicken using the private device, both recommendations, X and Y, should be equally followed. Thus, our last null hypothesis is as follows.

Hypothesis 3 *There is no difference between following recommendations X and Y in the game of Chicken.*

A possible alternative hypothesis to the above null hypothesis 3 is that recommendation Y will be followed more than X in the game of Chicken. As discussed in the Introduction, in the game of Chicken, strategy Y may be viewed as a weakly dominant strategy, under this alternative.

4 RESULTS

In this section, we present our findings from the experiment and subsequently test our hypotheses.

4.1 Hypothesis 1: Coordination

We first consider "coordination" in the first three treatments, namely, Symmetric-BoS, Modified-BoS and Chicken-Public, in which the public device has been used. We look at paired observations to measure "coordination" in the outcomes of the games. We define "coordination" as the union of the Nash equilibrium outcomes (X, Y) and (Y, X) (i.e., $\#(X, Y) + \#(Y, X)$). We present, in Table 11 below, the average frequencies of coordination over 20 periods, divided into five equal four-period blocks for each of the first three treatments separately.

Treatment/%Coordination in Periods	$1-4$	$5-8$	$9-12$	$13-16$	$17-20$	Total
Symmetric-BoS	80.21	86.46	89.58	94.79	88.54	87.92
Modified-BoS	71.88	75.00	85.42	87.50	84.38	80.83
Chicken-Public	61.46	60.42	66.67	66.67	70.83	65.21

Table 11: Average Frequencies of Coordination Using the Public Device in Games

From Table 11, we observe that the average frequency of coordination over 20 periods is quite high for all three games.[5] Table 11 clearly indicates that the frequencies of coordination for (both versions of) the BoS are higher than those in the game of Chicken.

We now formally examine whether these differences in the observed frequencies in our treatments are significant or not. We present our analysis in two parts. First, we use a couple of non-parametric tests, namely, Kruskal-Wallis test and Wilcoxon ranksum test.

[5] We are not reporting the frequencies of coordination for the Chicken-Private treatment as the private device (which is assumed to be followed) recommends the players to play the outcome (Y, Y) with probability $\frac{1}{3}$. For the sake of completeness, the overall average frequency of Coordination in Chicken-Private is only 52.08%.

Based on a Kruskal-Wallis test, we find that the frequencies of coordination are significantly different across treatments (p-value = 0.0001). We then run a Wilcoxon ranksum test, performed for each pairwise comparison. Table 12 below reports the corresponding p-values for each pairwise comparison.

Treatment (Average Frequency of Coordination)	Symmetric-BoS	Modified-BoS
Symmetric-BoS (87.92%)	–	
Modified-BoS (80.83%)	0.0776	–
Chicken-Public (65.21%)	0.0104	0.0364

Table 12: p-values for Differences in Coordination for Each Pair of Treatments

From Table 12, we find significant differences among all the three games (treatments) in this respect, at least at 10% level of significance (the game of Chicken is different from the two versions of BoS at 5% level of significance), thus indicating a rejection of our first null hypothesis.

As the non-parametric statistical tests do not control for other characteristics that may affect an individual's decision, we also use multivariate regressions to test the robustness of Hypothesis 1.

To assess the differences in Coordination among the above three treatments, we run a Probit regression with robust standard errors clustered on independent matching groups, using 1440 (24 x 20 x 3) paired observations from 20 periods of three treatments pooled together.

In this Probit regression, our dependent variable is a binary variable called *Coordination*, which takes value 1 if the paired observation is either (X, Y) or (Y, X) and takes 0, otherwise. We have used the Symmetric-BoS treatment as the baseline for comparison. Our main independent variables are two dummy variables called *ModifiedBoS* and *ChickenPublic*, each of which takes a value of 1 if the paired observation belongs to the corresponding treatment and 0 otherwise. The variable *Period* takes integer values from 1 to 20 for different rounds, while the variable *PairedRecommendation* is a binary variable that takes value 0 when the recommendations for the matched pair is (X, Y) and 1 when it is (Y, X) (note that these are the only possible paired recommendations from the public device). Finally, *ModifiedBoS*Period* and *ChickenPublic*Period* are the products of two named variables to capture the interaction between the respective treatment and period.

Table 13 presents the marginal effects from this Probit regression.

Dependent Variable: *Coordination* = 1, if (X, Y) or (Y, X); = 0, otherwise			
Number of Observations: 1440; Pseudo $R^2 = 0.0640$			
Independent Variables	Marginal Effects	Robust Standard Errors	p-values
ModifiedBoS	-0.07	0.07	0.263
ChickenPublic	-0.18^{*}	0.10	0.074
Period	0.01^{**}	0.00	0.030
*ModifiedBoS*Period*	-0.00	0.01	0.775
*ChickenPublic*Period*	-0.01	0.01	0.273
PairedRecommendation	0.05^{**}	0.03	0.046
Note: * denotes significance at the 10% level, ** at the 5% level and *** at 1% the level.			

Table 13: Probit Regression on Differences in Coordination Among Treatments

Table 13 clearly indicates significant differences between treatments Symmetric-BoS and Chicken-Public. Our Hypothesis 1 thus has been rejected as we find supporting evidence for the alternative hypothesis that individuals coordinate more in the game of Symmetric BoS than in the game of Chicken. We summarise our main finding below.

Result 1 *There are significant differences in coordination by following the public device between the games of Symmetric BoS and Chicken; individuals coordinate significantly more in Symmetric BoS than in Chicken.*

4.2 Hypothesis 2: Following recommendations

As mentioned earlier, from the literature on correlation (Cason and Sharma 2007, Duffy and Feltovich 2010) we expect that individuals actually follow their recommendations from a correlated equilibrium. Based on our choices of the games and the devices, we also hypothesise (Hypothesis 2) that the rate of following should not vary among our four treatments. We check whether or not this is indeed the case. In Figure 1, we present the average frequencies of the subjects who followed their recommendations, over 20 periods in five equal four-period blocks, in all four treatments.

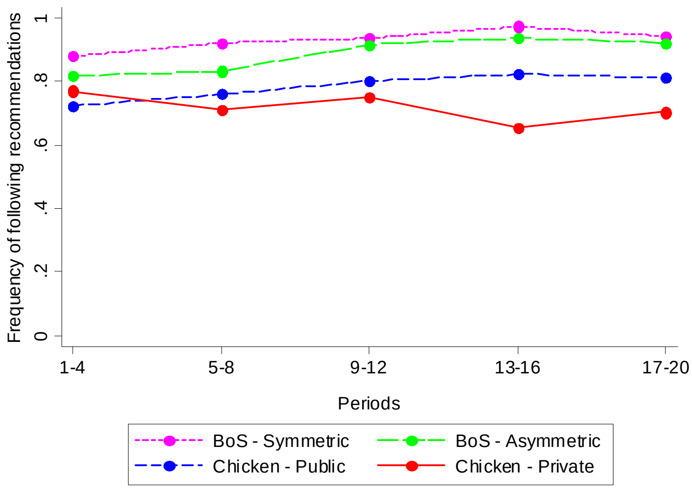


Figure 1: Average Frequencies of Following Recommendations in all Treatments

Table 14 below shows the exact frequencies plotted above and also the frequencies of following two different recommendations, X and Y, in each treatment.

Treatment/%Following in Periods	$1-4$	$5-8$	$9-12$	$13-16$	$17-20$	Total
Symmetric-BoS (Follow X)	90.63	96.88	97.92	100.00	94.79	96.04
Symmetric-BoS (Follow Y)	85.42	87.50	89.58	94.79	93.75	90.21
Symmetric-BoS (Follow All)	88.02	92.19	93.75	97.40	94.27	93.13
Modified-BoS (Follow X)	82.29	85.42	90.63	93.75	93.75	89.17
Modified-BoS (Follow Y)	81.25	81.25	92.71	93.75	90.63	87.92
Modified-BoS (Follow All)	81.77	83.33	91.67	93.75	92.19	88.54
Chicken-Public (Follow X)	60.42	66.67	70.83	72.92	75.00	69.17
Chicken-Public (Follow Y)	84.38	85.42	89.58	91.67	87.50	87.71
Chicken-Public (Follow All)	72.40	76.04	80.21	82.29	81.25	78.44
Chicken-Private (Follow X)	69.44	72.22	77.27	52.56	56.67	65.15
Chicken-Private (Follow Y)	81.67	71.01	73.81	74.56	76.52	75.40
Chicken-Private (Follow All)	77.08	71.35	75.00	65.63	70.31	71.88

Table 14: Average Frequencies of Following Different Recommendations in all Treatments

The average frequencies of following recommendations are indeed quite high in all treatments, as we expected. However, Table 14 indicates that there are differences in following recommendations among our treatments; individuals follow recommendations more in both versions of the BoS than in either treatments involving the game of Chicken, suggesting a rejection of our Hypothesis 2.

We now test Hypothesis 2 more formally. A Kruskal-Wallis test suggests that the frequencies of following recommendations across treatments are significantly different from each other (p-value = 0.0001). We then run a Wilcoxon ranksum test for each pairwise comparison, p-values from which are presented in Table 15 below.

Treatment (Average Frequency of Following)	Symmetric-BoS	Modified-BoS	Chicken-Public
Symmetric-BoS (93.13%)	–		
Modified-BoS (88.54%)	0.1986	–	
Chicken-Public (78.44%)	0.0161	0.0542	–
Chicken-Private (71.88%)	0.0039	0.0065	0.1994

Table 15: p-values for Differences in Following Recommendations for Each Pair of Treatments

Table 15 indicates significant differences between the games of Chicken and (both versions of) the BoS, at least at 10% level of significance. Chicken-Private is different from the two treatments involving the BoS at 1% level of significance. However, there is no difference between the two versions of BoS, and also between two treatments involving the game of Chicken.

To test the possible differences among the treatments, we run a Probit regression with robust standard errors clustered on independent matching groups, using 3840 (48 x 20 x 4) individual observations from 20 periods of all four treatments. Our dependent variable here is a binary variable called *Follow* that takes value 1 if the recommendation is followed in the data and 0 otherwise. Keeping the Symmetric-BoS as the baseline for comparison as earlier, the independent variables involving three treatments are dummy variables called *ModifiedBoS*, *ChickenPublic* and *ChickenPrivate*. The variable *Period* takes integer values from 1 to 20 while *Recommendation* takes value 0 when the recommendation for any individual is X and 1 when it is Y. The variables *ModifiedBoS*Period*, *ChickenPublic*Period* and *ChickenPrivate*Period* are products of the two named variables. We report the marginal effects from this Probit regression in Table 16 below.

Dependent Variable: *Follow* = 1, if recommendation is followed; = 0, otherwise			
Number of Observations: 3840; Pseudo $R^2 = 0.0711$			
Independent Variables	Marginal Effects	Robust Standard Errors	p-values
ModifiedBoS	-0.07	0.06	0.221
ChickenPublic	-0.13^{*}	0.07	0.069
ChickenPrivate	-0.11^{*}	0.06	0.084
Period	0.01^{**}	0.00	0.014
*ModifiedBoS*Period*	0.00	0.00	0.942
*ChickenPublic*Period*	-0.00	0.00	0.219
*ChickenPrivate*Period*	-0.01^{***}	0.00	0.003
Recommendation	0.05^{*}	0.02	0.050
Note: * denotes significance at the 10% level, ** at the 5% level and *** at 1% the level.			

Table 16: Probit Regression on Differences in Following Recommendations Among Treatments

From Table 16, we observe significant differences among our four treatments, from the marginal effects of the variables *ModifiedBoS*, *ChickenPublic* and *ChickenPrivate*. The signs of these effects suggest that following recommendations significantly decreases from the Symmetric-BoS to the Chicken-Public and Chicken-Private treatments. Our second null hypothesis, thus hereby, has been rejected; we provide evidences in favour of the alternative hypothesis that individuals follow recommendations more in the game of Symmetric BoS than in the game of Chicken. We also note that the Probit regression does not indicate any statistical significance of the differences between two versions of the BoS. We summarise our main finding below.

Result 2 *There are significant differences in following recommendations between the games of Symmetric BoS and Chicken. Individuals follow recommendations more in the game of Symmetric BoS than in the game of Chicken.*

4.3 Hypothesis 3: Following X or Y

Our results (Results 1 and 2) from the previous subsections indicate that there are significant differences in coordination and in following recommendations between the games of Symmetric BoS and Chicken. Table 14 in the previous subsection indeed indicates that there are differences between following two different recommendations in each of the treatments; recommendation Y appears to be followed more than X from either devices for the game of Chicken, whereas recommendation X seems to be followed more than Y in both versions of the BoS.

We now focus on the factors that may have affected the individuals' decisions to follow recommendations, within each treatment. For this exercise, we have run three Probit regressions with robust standard errors clustered on independent matching groups, using the 960 (48 x 20) individual observations for each treatment separately.

In each regression, the dependent variable is *Follow* which is a binary variable that takes value 1 if the recommendation is followed and 0 otherwise, while the independent variables are *Period*, *Recommendation* and *Recommendation*Period*, as described in the previous subsection. Table 17 presents the marginal effects for all the independent variables (with the respective robust standard errors in parentheses) for each regression.

No. of Obs. (each): 960; Dependent Variable: Follow = 1 if recommendation followed and = 0 ow				
Ind. Var./Mar. Eff. (se)	Symmetric-BoS	Modified-BoS	Chicken-Public	Chicken-Private
Period	0.00^{**} (0.00)	0.01^{***} (0.00)	0.01 (0.00)	−0.01 (0.01)
Recommendation	-0.06^{*} (0.03)	−0.01 (0.03)	0.21^{*} (0.11)	0.24^{***} (0.09)
*Recommendation*Period*	−0.00 (0.00)	0.00 (0.00)	−0.00 (0.01)	0.52^{***} (0.14)
Pseudo R^2	0.0521	0.0250	0.0522	0.0355

Table 17: Probit Regressions on Following Recommendations within Each Treatments

What clearly stands out from Table 17 is that the variable *Recommendation* is statistically significant in all treatments apart from the Modified-BoS. One should particularly note here the signs for this variable that indicate that the probability of following recommendation Y (compared to X) significantly increases in the game of Chicken (with the private device) and significantly decreases in the Symmetric BoS, as also noted earlier in Table 14.

Results 1 and 2 regarding the differences among the treatments can thus be explained based on the individuals' behaviour when they do follow recommendations. Individuals overall do achieve coordination by following recommendations in all three games; however, they follow a specific recommendation more than the other in different games (X in the Symmetric BoS and Y in the game of Chicken).

From the above analysis, we clearly reject our Hypothesis 3. Moreover, we note that marginal effects of the variable *Period* are significant in both versions of BoS. We state these results below.

Result 3a *Individuals follow recommendation Y more than X from the private device in the game of Chicken.*

Result 3b *Individuals follow recommendation X more than Y from the private device in the game of Symmetric BoS.*

Result 3c *Individuals follow recommendations more as the time progresses in both versions of BoS.*

4.4 Not Following: (X, X) or (Y, Y)

We now analyse Result 1 focusing on individuals' behavior when they do not follow recommendations from the public device in three different games. Consider a pair of individuals in any of these games. They may not both follow recommendations and may still coordinate. Indeed, the "disobedient" strategy of choosing just the opposite of the recommended actions and thereby coordinating is also a Nash equilibrium in the extended game (Ray 2002). To note this, we first present the average frequencies of observations in which both individuals actually followed over 20 periods, divided into five equal four-period blocks for each of the first three treatments separately in Table 18 below.

Treatment/%Both Follow in Periods	$1-4$	$5-8$	$9-12$	$13-16$	$17-20$	Total
Symmetric-BoS	78.13	85.42	88.54	94.79	88.54	87.08
Modified-BoS	67.71	70.83	84.38	87.50	84.38	78.96
Chicken-Public	53.13	56.25	63.54	65.63	66.67	61.04

Table 18: Average Frequencies of Coordination Using the Public Device in Games

Table 18 indicates that indeed both individuals follow and thus coordinate in all these games. From the figures in Tables 11 and 18, we can precisely find the frequencies of coordination in these games without following recommendations from the public device by playing the "disobedient" strategy. For example, in the game of Chicken, both players do not follow and still coordinate only in 4.17% of observations.

Now let us consider the paired observations in which exactly one of the individuals does not follow recommendation. In such a case, the outcomes may either be (X, X) or (Y, Y), regardless of the recommendation.

We are interested in the observed frequencies of (Y, Y), as it may be viewed as a "cooperative" alternative to the (pure) Nash outcomes in these games. As a complement to our Result 1 above, we now consider the frequencies of (Y, Y) in the first three treatments.[6] Figure 2 plots the average frequencies of the outcome (Y, Y), over 20 periods, divided into five equal four-period blocks.

[6] As earlier, we are not reporting the frequencies for the Chicken-Private treatment here as the private device recommends (Y, Y) (with probability $\frac{1}{3}$). For the sake of completeness, the overall average frequency of (Y, Y) in Chicken-Private is 35.42%.

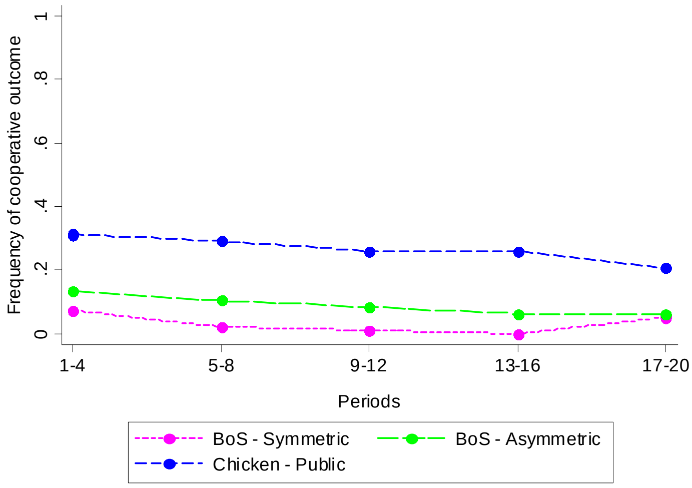


Figure 2: Average Frequencies of the Outcome (Y, Y) in all Games with the Public Device

The exact frequencies are presented in Table 19 below.

Treatment/%Cooperation in Periods	$1-4$	$5-8$	$9-12$	$13-16$	$17-20$	Total
Symmetric-BoS	7.29	2.08	1.04	0	5.21	3.13
Modified-BoS	13.54	10.42	8.33	6.25	6.25	8.96
Chicken-Public	31.25	29.17	26.04	26.04	20.83	26.67

Table 19: Average Frequencies of the Outcome (Y, Y) in all Games with the Public Device

It is clear from Figure 2 and Table 19 that the outcome (Y, Y) has been selected more often in the game of Chicken (26.67%) than in (either version of) the BoS (3.13% and 8.96%, respectively, for the Symmetric and Modified BoS). As expected, the overall frequencies are very low for the Symmetric BoS.

Based on a Kruskal-Wallis test, we first find that the frequencies of cooperation are significantly different among these treatments (p-value $= 0.0001$).Table 20 below reports the corresponding p-values from a Wilcoxon ranksum test performed for each pairwise comparison.

Treatment (Average Frequencies of (Y, Y))	Symmetric-BoS	Modified-BoS
Symmetric-BoS (3.13%)	–	
Modified-BoS (8.96%)	0.0222	–
Chicken-Public (26.67%)	0.0038	0.0080

Table 20: p-values for Differences in (Y, Y) for Each Pair of Treatments

Clearly, from Table 20, there are significant differences between the game of Chicken and (both versions of) the BoS, at 1% level of significance, while two versions of BoS are significantly different from each other at 5% level of significance. As earlier, to assess the differences among the treatments, we then run a Probit regression with robust standard errors clustered on independent matching groups, using 1440 (24 x 20 x 3) paired observations from 20 periods of three treatments pooled together. Our dependent variable here is a binary variable called *Cooperation* which takes value 1 if the paired outcome is (Y, Y) and takes 0, otherwise. Table 21 reports the results from the Probit regression using the same independent variables as in the regression presented in Table 13.

Dependent Variable: *Cooperation* $= 1$, if (Y, Y); $= 0$, otherwise			
Number of Observations: 1440; Pseudo $R^2 = 0.1221$			
Independent Variables	Marginal Effects	Robust Standard Errors	p-values
ModifiedBoS	0.09	0.06	0.127
ChickenPublic	0.25^{**}	0.10	0.016
Period	-0.01	0.00	0.157
*ModifiedBoS*Period*	0.00	0.00	0.792
*ChickenPublic*Period*	0.00	0.00	0.562
PairedRecommendation	0.01	0.02	0.817
Note: * denotes significance at the 10% level, ** at the 5% level and *** at 1% the level.			

Table 21: Probit Regression on Differences in Cooperation Among Treatments

Table 21 above presents a mirror image of Result 1; the marginal effect of the variable *Chicken-Private* suggests that cooperation significantly increases from the Symmetric-BoS to the game of Chicken. We summarise this result below.

Result 4 *There are significant differences in achieving "cooperation" between the games of Symmetric BoS and Chicken, using the public device; individuals "cooperate" significantly more in Chicken than in Symmetric BoS.*

5 CONCLUSION

In this paper, we have asked whether coordination can be achieved using recommendations from a correlation device and have analysed whether or not players followed these randomised recommendations in order to avoid coordination-failure in 2 x 2 games. Our work has contributed to two distinct literatures, one on coordination and the other on correlation by assessing the role of recommendations in enhancing coordination in different 2 x 2 games, using different correlated equilibria.

Our paper added to the existing literatures mainly in two respects. First, we have studied a possible way of coordinating in the well-known paradigm of games like the BoS and Chicken by public randomisation. The existing literature on coordination problems in games like BoS suggests that the players require some scheme to coordinate. We have contributed to this literature by analysing the scheme of a public lottery for three games. Second, we have extended the investigation of the empirical validity of the concept of correlated equilibrium in different 2 x 2 games. We have tested the robustness of coordination by following recommendations by using different games and different types of correlated equilibria. Moreover, we have chosen the correlation devices and the parameters in our games so that we can compare the individuals' behaviour in different treatments. We have provided a full explanation of the required criteria and thereby completely characterised the payoff parameters in our chosen games. Based on our set-up, our null hypotheses are that we should not observe any differences among our treatments in terms of coordination and in following recommendations.

We have found that overall coordination was achieved and individuals did follow recommendations, as in the existing literature. However, we have rejected all of our hypotheses, as we have found significant differences in coordination and following recommendations between the games of Symmetric BoS and Chicken. We have also analysed some of the factors that may have affected individuals' decisions to follow recommendations in our experiment and thus have explained our results. We have observed players follow recommendation Y more than X in the game of Chicken with the private device, and X more than Y in both versions of BoS. We also have considered the frequencies of the outcome (Y, Y) in different games and have noted that the differences in these games indeed have come from the outcome (Y, Y) that may seem to be a "cooperative" outcome, particularly in the game of Chicken. Our finding suggests that when the players do not follow recommendations, they perhaps try to achieve the "cooperative" outcome (Y, Y) in different games, particularly, in the game of Chicken. The outcome (Y, Y) thus causes the differences documented in Results 1 and 2.

For future research, one may consider a few different directions. First, this paper considers only direct or canonical correlation devices. Ray (2002) analyses different non-canonical correlation devices to implement a correlated equilibrium. In our framework, one may wish to run further experiments with recommendations from such non-direct correlation devices. Second, one may consider running similar treatments using a coarser notion of correlation, such as, the coarse correlated equilibrium (as introduced by Moulin and Vial 1978 and recently used by Ray and Sen Gupta 2013) in which the players are given a choice of committing to the correlation device. Finally, the games discussed here may be useful to analyse direct communication (Moreno and Wooders 1998) between the two players.

6 APPENDICES

We report the full instructions only for the Chicken-Private treatment here. The instructions for the Chicken-Public differ from that for the Chicken-Private only in the *Recommendations* section, as reported below, while the instructions for the Symmetric-BoS and the Modified-BoS differ from that for the Chicken-Public only in the *Your Decision Problem* section (and subsequently, in the *Computer Screen*), in an obvious way. These instructions have been omitted here and are available upon request.

6.1 Instructions (for the Chicken-Private Treatment)

All participants in this session have the following identical instructions.

Welcome to this experiment, and thank you for participating. From now onwards please do not talk to any other participants until the experiment is finished. You will be given five minutes to read these instructions. Then we will ask you to complete a brief test to ensure that you have understood them, before starting the experiment itself.

Your Decision Problem

In this experiment, you are asked to make a simple choice, in each of 20 successive rounds. In each round you earn a number of points, as described below. The total number of points you accumulate over the 20 rounds determines your final money payment, at a conversion rate of 10 points = 30 pence.

In each round, you are randomly paired with another participant, different from one round to the next, whom we call your counterpart for that round. You and your various counterparts remain anonymous to each other at all times, and you have no direct contact with each other during the experiment. In each round, you and your counterpart each have to choose one of two alternatives, X and Y. You do so independently of each other and without any communication. So, at the moment you make your own choice, you do not know what is your counterpart's choice. You and your counterpart's choices together determine the points you each earn from that round, as in the following table.

		Your Counterpart's Choice	
		X	Y
Your Choice	X	$2, 2$	$17, 11$
	Y	$11, 17$	$14, 14$

The first number in each cell indicates your points, and the second your counterpart's points. For example, if in some round you choose X while your counterpart chooses Y then from that round you will earn 17 points and your counterpart will earn 11 points. Notice that, whatever your counterpart's choice, you earn more points by choosing differently from your counterpart. Thus, if your counterpart's choice is X then you earn more points by choosing Y rather than X (giving you 11 points rather than 2), while if your counterpart's choice is Y then you earn more points by choosing X rather than Y (17 points rather than 14). Notice also that if your counterpart's choice is equally likely to be X or Y, then you earn more points on average by choosing Y (12.5 being the average of 11 and 14) rather than X (9.5 being the average of 2 and 17). As you can see from the table, everything is symmetric between you and your counterpart. So, exactly the same considerations as above apply for your counterpart, to whom of course you are the counterpart, and who will have read these exact same instructions.

Recommendations

At the start of each round, you and your counterpart are each given *recommendations* for your choices, generated randomly by the computer. It is entirely up to you, in any round, whether or not to follow the recommendation you are given. The points that you earn depend only on the actual choices made by you and your counterpart, as described on the previous page, irrespective of the recommendations. In each round, you are informed of only of the recommendation for you. But, as explained below, you may be able to infer something about your counterpart's recommendation.

The recommendations are generated randomly by the computer in each round, programmed such that there are only three equally-likely possibilities:

- there is a $\frac{1}{3}$ chance that you are recommended to choose X, and your counterpart recommended to choose Y;
- there is a $\frac{1}{3}$ chance that you are recommended to choose Y, and your counterpart recommended to choose X;
- there is a $\frac{1}{3}$ chance that you are both recommended to choose Y.

It will never happen that you are both recommended to choose X. These possibilities are summarised as follows:

Recommendation for You	Recommendation for Your Counterpart	Probability
X	X	0
X	Y	$\frac{1}{3}$
Y	X	$\frac{1}{3}$
Y	Y	$\frac{1}{3}$

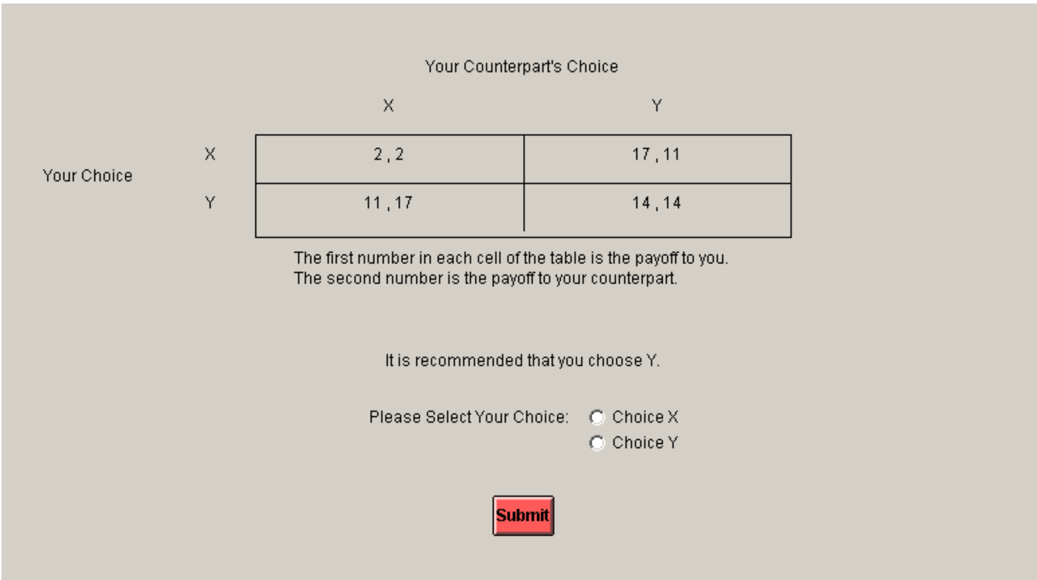
Notice that if the recommendation for you is X then you can infer that the recommendation for your counterpart is Y, and if the recommendation for you is Y then you can infer that the recommendation for your counterpart is equally likely to be X or Y. It is entirely up to you whether or not to follow your recommendation in any round. But notice that if your counterpart follows his or her recommendation then (on average) you earn more points by following yours, than by not doing so. This is because:

- if your recommendation is X then your counterpart's must be Y, and if your counterpart chooses Y then you earn more points by choosing X rather than Y;
- if your recommendation is Y then your counterpart's is equally likely to be X or Y, and if your counterpart is equally likely to choose X or Y then you earn more points on average by choosing Y rather than X.

However, if your counterpart does *not* follow his or her recommendation then it is possible that you will earn more points by also not following yours. This is because, in any round, it is always better for you to choose differently from your counterpart, as explained on the previous page, whatever the recommendations you have each received.

The Computer Screen

The main screen for each round looks like this. It includes the payoff table, which is the same in each round, and below it the recommendation for you in that round, which is random and may vary from one round to the next. Shown here, to illustrate, is a recommendation for you to choose Y.



To make your choice you simply select the appropriate button and then click on Submit. You may then have to wait a few moments until all participants have made their choices, after which will appear on-screen the results for you and your counterpart in that round. On your desk is a Record Sheet on which you can keep a note of these results, if you wish to. After all the participants have read their results and clicked Continue, the main screen for the next round will appear, again as shown above.

At the End of the Experiment

When all 20 rounds have been completed, you will be asked to complete a brief on-screen questionnaire, which provides useful supplementary (anonymous) information for us. Having completed the questionnaire, you will see a final screen reporting your total points accumulated over the 20 rounds and the corresponding £ payment. Please then wait for further instructions from the experimenter, who will pay you in cash before you leave. While waiting, please complete the receipt form which you will also find on your desk. We need these receipts for our own accounts.

The results from this experiment will be used solely for academic research. Participants will remain completely anonymous in any publications connected with this experiment. Thank you for participating. We hope that you enjoy the experiment, and that you will be willing to participate again in our future experiments.

6.2 Test

After reading the instructions, you will be asked to complete this brief test, 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.

1. If you choose Y and your counterpart chooses X, how many points do you earn in that round?

2. If you choose Y and your counterpart chooses X, how many points does your counterpart earn in that round?

3. If you choose X and your counterpart chooses X, how many points do you earn in that round?

4. If over the 20 rounds you accumulate a total of 100 points, what is your final cash payment (in £) for the experiment?

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

5. Your counterpart is the same person in each round. True / False

6. If the recommendation for you is Y, then your counterpart's recommendation must be X. True / False

7. Whatever your counterpart chooses, you always get more points by following your recommendation. True / False

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

Thank you for completing this test. 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.

6.3 Record Sheet

Use of this sheet is optional. It is provided so that you can keep a record of the results in each round, as reported on your computer screen at the end of the round. This may be useful to you in considering your decisions in subsequent rounds. In each cell in the table below, simply circle X or Y as appropriate, while the information is still on your screen at the end of that round, before clicking Continue.

Round	My Reco.	Choice	Counterpart's Reco.	Choice	My Point
1	X Y	X Y	X Y	X Y	
2	X Y	X Y	X Y	X Y	
3	X Y	X Y	X Y	X Y	
4	X Y	X Y	X Y	X Y	
5	X Y	X Y	X Y	X Y	
6	X Y	X Y	X Y	X Y	
7	X Y	X Y	X Y	X Y	
8	X Y	X Y	X Y	X Y	
9	X Y	X Y	X Y	X Y	
10	X Y	X Y	X Y	X Y	
11	X Y	X Y	X Y	X Y	
12	X Y	X Y	X Y	X Y	
13	X Y	X Y	X Y	X Y	
14	X Y	X Y	X Y	X Y	
15	X Y	X Y	X Y	X Y	
16	X Y	X Y	X Y	X Y	
17	X Y	X Y	X Y	X Y	
18	X Y	X Y	X Y	X Y	
19	X Y	X Y	X Y	X Y	
20	X Y	X Y	X Y	X Y	

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