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Coordination failure caused by sunspots

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Abstract

In a coordination game with Pareto-ranked equilibria, we study whether a sunspot can lead to either coordination on an inferior equilibrium (mis-coordination) or to out-of equilibrium behavior (dis-coordination). While much of the literature searches for mechanisms to attain coordination on the efficient equilibrium, we consider sunspots as a potential reason for coordination failure. We conduct an experiment with a three player 2x2x2 game in which coordination on the efficient equilibrium is easy and should normally occur. In the control session, we find almost perfect coordination on the payoff-dominant equilibrium, but in the sunspot treatment, dis-coordination is frequent. Sunspots lead to significant inefficiency, and we conclude that sunspots can indeed cause coordination failure.

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1. Introduction

The purpose of this paper is to study experimentally whether a sunspot can lead to coordination failure, i.e. either coordination on an inferior equilibrium (mis-coordination) or to out-of equilibrium behavior (dis-coordination) in a coordination game with Pareto-ranked equilibria. A sunspot is an extrinsic random variable that does not directly affect economic fundamentals. While much of the relevant literature searches for mechanisms to attain coordination on the efficient equilibrium (e.g. Bornstein et al. 2002; Weber 2006; Brandts and Cooper 2006; Brandts et al. 2007), we focus on potential reasons for coordination failure. Is it possible that in a game in which coordination on the efficient equilibrium is easy and should normally occur, a sunspot could prevent subjects from coordinating on any equilibrium or even make them coordinate on an inferior equilibrium? If so, sunspots can explain coordination failures or collective choices of dominated equilibria observed in the real world such bank runs, stock market crashes or other financial turmoil (see Diamond and Dybvig 1983; Allen and Gale 2004; Harrison and Weder 2006). In addition to these macroeconomic coordination problems, coordination is also important for large organizations, in which it is necessary to synchronize the efforts of individual workers in order to avoid production bottlenecks (see Van Huyck et al. 1990; Knez and Camerer 1994). In both cases, rumors or some external news could affect the behavior of agents and lead to coordination failure.

Previous work has shown that it is not easy to generate sunspots in the laboratory that affect subjects' behavior (Marimon et al. 1993). Duffy and Fisher (2005) were the first to experimentally establish that sunspots may influence economic choices. We modify their approach in two ways. First, we consider Pareto-ranked equilibria whereas their model has equilibria which are not Pareto-ranked. Second, we simplify the game and its presentation. The reason for this simplification and the use of Pareto-ranked equilibria is to create an environment where coordination is very likely, in fact almost sure, and investigate if a certain type of noise can lead to substantial inefficiencies. While Duffy and Fisher (2005) generate sunspots in a market setting, we use a simple three-player 2x2x2 game, in which coordination on the obvious Pareto-superior equilibrium is very easy. Similar to Duffy and Fisher (2005), our sunspot is an announcement determined by the roll of a die. We find that sunspots influence choices and cause coordination failure even though the conditions of the experiment are such that we theoretically should not expect any effects of the sunspot. We thus show that sunspots can affect economic behavior, but also that they can do it in a significant and welfare-decreasing way.

In the experiment, a sunspot consists of two payoff-irrelevant announcements which correspond with the strategies available to subjects. Due to the very suggestive character of our sunspot, our work can be related to the literature on recommendation in games and correlated equilibria (e.g. Brandts and MacLeod 1995; Cason and Sharma 2007; Kuang et al. 2007; Duffy and Feltovich 2010). However, our sunspot differs from a recommendation not only because of its obvious random nature but also because of its public one. In their paper on correlated equilibria, Duffy and Feltovich (2010) run experiments in which players receive a private recommendation drawn from publicly announced distribution, while in our framework the random announcement which is publicly made is the same for all. As a consequence, correlated equilibria[1] may emerge in the Duffy and Feltovich's framework, whereas only pure and mixed-strategy equilibria exist in ours.

The literature on recommendations shows that in some cases subjects follow a recommendation to play a strategy that leads to an inferior equilibrium. In other cases, recommendations create uncertainty about whether the other players will follow the

[1] Correlated equilibria are a superset of Nash equilibria. They correspond to distributions of equilibrium possibilities resulting from correlation in players' strategies (see Duffy and Feltovich, 2010).

recommendation which results in dis-coordination. Brandts and MacLeod (1995) show that if incentives are strong enough, subjects follow reasonable recommendations, but ignore unreasonable ones. In particular, recommendations to play an equilibrium that is not subgame-perfect are usually not followed. This is in contrast to our finding that subjects follow a sunspot, although it is in their interest not to do so.

Duffy and Fisher (2005) provide evidence that the semantics of the sunspot matter. Subjects are more inclined to coordinate on a sunspot, if the sunspot can be interpreted as being related to the economic problem. If the sunspot is abstract or difficult to relate to the economic problem, subjects seem to ignore it. For this reason we choose to frame our experiment as a real-work economic problem rather than using an abstract game. We consider workers' decisions to go on a strike. A strike can be seen as a coordination game, because a worker wants to join the others either striking or not striking. If a worker does not join his coworkers, he either foregoes benefits of a successful strike or he bears the costs of an unsuccessful one. It can be argued that our sunspot is very evocative in nature; however, one should note that this paper aims to study whether subjects follow random signals although it is clearly not in there interest to do so. According to Franzosi (1989), it is difficult to explain why strikes occur. Perfectly rational and informed workers and managers would generally prefer to negotiate and avoid strikes. Hence striking might be a dominated equilibrium in a coordination game and workers' decision to go on strike might be influenced by exogenous signals that either make coordination on not striking more difficult or even ease the coordination on striking. Kaufman (1982) presents empirical evidence that non-economic attitudinal or psychological factors such as the militancy of workers, the charisma of union leaders or public opinion towards organized labor have explanatory power for the annual number of strikes and the number of workers involved in strikes in the US. Therefore, we believe that such psychological motivations for strikes could be influenced by aforementioned random events.

2. Experimental design and procedure

We use a coordination game in which subjects in groups of 3 people are put in the role of workers and choose between the two actions *work* (W) and *strike* (S). The effect of sunspots is studied in a within-subject design, in which subjects play two different phases of 20 periods (a total of 40 periods) – one phase without sunspot and one with. The payment depends on performance in all the periods. The sunspot corresponds to an announcement which is made aloud at the beginning of each period in the phase with sunspots. There are two possible announcements – "work" and "strike" – which correspond to the subjects' action space. In this way it is very clear how the sunspot could be used as a coordination device. The realized announcement is determined randomly by the roll of a (6-sided) die. In order to make the random determination of the announcement very salient to subjects, one of them (chosen randomly) rolls the die herself and the experimenter makes aloud the announcement about the number on the die to the whole group.

Given the results in Duffy and Fisher (2005) on the significance of the sunspots' semantics, we do not expect abstract announcements such as "green" and "red" to have an effect. That's why we choose intentionally announcements directly related to the subjects' action space. Furthermore, given its random determination, the announcement/sunspot is not a recommendation, although it could appear to be so[2]. Therefore, it should be obvious that choosing the action according to the announcement generally cannot be expected to lead to higher payoffs.

[2] According to the participants' answers to the questionnaire, the random feature of the announcement was well understood by all of them.

The payoffs are shown in the following table:

Table 1: Payoff table

Other Players' Decisions in Your Group

Your Decision		If **BOTH of the other** participants choose **WORK**	If **ONE of the other** participants chooses **WORK** and the other chooses **STRIKE**	If **BOTH of the other** participants choose **STRIKE**
	WORK	**40**	**10**	**10**
	STRIKE	**0**	**20**	**20**

The game has the two pure strategy Nash equilibria (S,S,S) and (W,W,W) which are Pareto-ranked[3]. Notice that the payoff-dominant equilibrium (W,W,W) is also risk-dominant[4], which distinguishes our game from a typical stag-hunt game where the inefficient equilibrium is risk-dominant. Even though there is still strategic uncertainty, the aforementioned characteristic of the equilibrium ensures that there is no conflict between risk- and payoff dominance in our game. Moreover, expected payoff from playing W is higher than the expected payoff from playing S, as long as subjects expect that others will choose "work" with probabilities equal or greater than $1/\sqrt{5}$.[5]

Under these circumstances, we expect subjects to coordinate easily on (W,W,W) in the absence of a contradictory signal as well as in the presence of one. Indeed, even with the randomly determined announcement "strike", conventional theory predicts that rational subjects (with common knowledge of rationality) should ignore the signal and coordinate on (W,W,W). However, a "strike" announcement might create strategic uncertainty if some subjects believe that other subjects will follow the announcement. In that case, we will observe that at least some subjects choose S instead of W. Potentially, strategic uncertainty could be so strong that all subjects coordinate on (S,S,S), whenever they receive the strike announcement. This would be a sunspot equilibrium, in which every subject believes the other subjects will follow the announcement. By playing the best response to this belief, the belief would be self-confirming.

In order to avoid reputation effects, the game is played as a repeated one-shot game with random matching. Another reason for random matching is to relate this experiment to a macroeconomic context where agents do not normally know each other and frequently there are new entrants into a group. Moreover, we vary the order of the sunspot phase to check for order effects. To do this, we run control/sunspot sessions (C/S sessions hereafter), where subjects start by playing a coordination game without announcements in the first 20 periods and play a coordination game with the sunspot in the last 20 periods, and sunspot/control sessions (S/C sessions hereafter), where, they start with the sunspot phase and play the pure coordination game without announcements after period 20.

We use two devices in order to avoid that the sunspot destroys the expected coordination on the superior equilibrium making our experiment a hard test of the relevance of sunspots.

[3] Indeed, there is a symmetric mixed-strategy equilibrium in which players choose "work" and "strike" with probabilities $1/\sqrt{5}$ and $1-\left(1/\sqrt{5}\right)$, respectively. The expected payoff in the mixed strategy equilibrium is 16 resulting in an efficiency of 40 per cent (relative to equilibrium payoffs in (W,W,W)).

[4] As the product of the deviation losses for W,W,W is the highest (Harsanyi and Selten 1988).

[5] This can be also observed from the probabilities of the mixed-strategy equilibrium.

The first one consists of choosing a low probability for the “work” announcement. Actually, if the “strike” announcement occurs frequently enough, subjects have many opportunities to observe the behavior of the other players and to learn that coordination failure is costly. Hence, we announce “work” only if the die shows 1 and “strike” otherwise. With the same rationale, the second device consists of providing the subjects with the complete history of the game. After each period subjects are informed about their own decision, the decisions of the other players in the group, the earned points and the announcement, if there was one. Displaying this information for all past periods should also facilitate learning and coordination on the superior equilibrium.

The sessions for this experiment were conducted in LEEX at Universitat Pompeu Fabra (UPF) and in LEE at University of Copenhagen (CPH), using z-Tree (Fischbacher 2007). 36 undergraduate students from various departments of UPF and 48 students from various departments of CPH participated in this experiment. After receiving the instructions, and prior to the start of the game, participants answered control questions to check their understanding of the game at hand. They were also asked to fill in a questionnaire, at the end of each session, to collect their comments. As mentioned above, each session consisted of two different treatments, one with an announcement (the sunspot treatment) and another without an announcement (the control treatment). In the sunspot treatments, the throw of a die was used in order to determine which announcement was realized. At the beginning of each period subjects were randomly matched with others. One of the participants (randomly chosen) threw the die in front of all the participants and the experimenter announced aloud the number on the die and the corresponding announcement (“work” or “strike”) for the period. Finally, subjects received a reminder of this announcement on their computer screen.

Hence, the subjects had common information about the announcement, which was determined according to the roll of the die. In order to get more independent observations from each treatment, we divided participants in each treatment into subgroups of 6 people, and the subjects from each subgroup were randomly matched with each other for the remaining periods. All participants were paid a show-up fee of 3 € (20 Danish kroner (DKK)) and moreover, received 1 € per 150 points (15 DKK per 150 points) at the end of the experiment. All the subjects were paid in cash at the end of each session and the average earnings were €15 in Barcelona and €16 in Copenhagen.

3. Results and Discussion

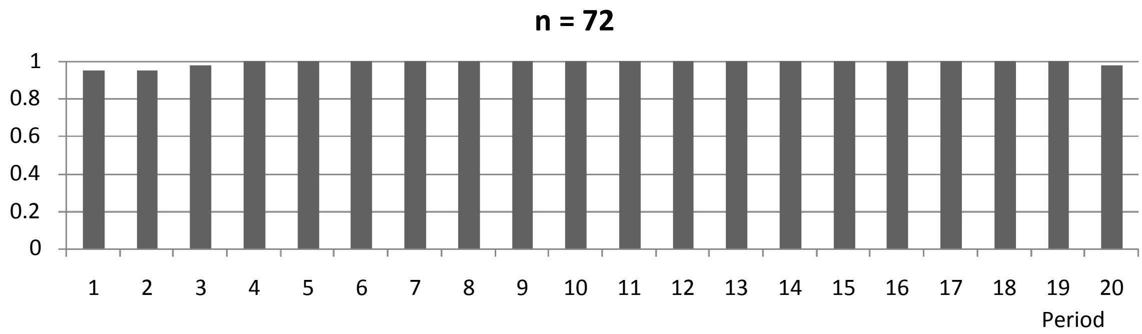
We begin this section with an analysis of the control treatments from both sessions. Firstly, we will see that without sunspots subjects coordinate easily on the Pareto efficient equilibrium. Afterwards, we return to the sunspot treatments and find that sunspots create coordination failure.

3.1 Control Treatment

Figure 1 summarizes the share of W decisions from all treatments and sessions without announcements (both C/S sessions and S/C sessions in both places, i.e. Universitat Pompeu Fabra and University of Copenhagen).

We clearly see that without announcements coordination was almost perfect. Indeed, 98.6% of all 1680 decisions were W and even in the first periods W was chosen in 95.2% of all cases. In brief, the subjects almost always managed to coordinate on the payoff-dominant equilibrium.

Figure 1: Share of “W” decisions in the control treatments

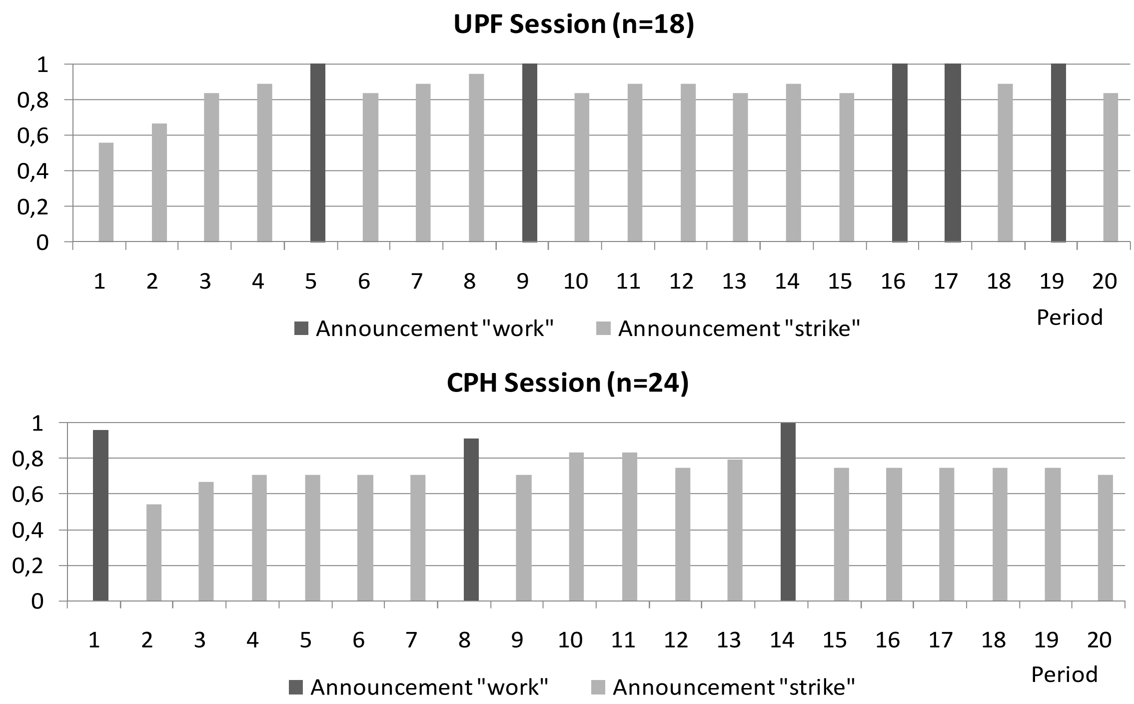


We take this finding as a confirmation that the subjects understood the game and that our game is easy enough so that coordination on the superior equilibrium (W,W,W) occurs right from the start if subjects are not influenced by sunspot announcements.

3.2 Sunspot Treatment

Figure 2 shows only the share of W decisions in the treatments with sunspots in which announcements were made in the first 20 periods (S/C sessions). It doesn’t give any information about the equilibrium reached by each subgroup.

Figure 2: Share of W decisions in the sunspot treatments of the S/C sessions



The difference from the control treatment is striking. In both places, a large percentage of subjects chooses S in each period with a “strike” announcement. At the UPF session, full coordination on (W,W,W) was only achieved in the cases in which there was a “work” announcement and never with a “strike” announcement. In the CPH sessions W was chosen by all subjects in only one period where there was a “work” announcement and failed to coordinate perfectly in all other periods.

Taking both places together, the total share of W decisions was 98.1% if the announcement was “work” and 77.1% if the announcement was “strike”. As visible in Figure 2, the share of W choices was significantly lower in Copenhagen (73.0%) than in Barcelona (83.3%) if there was a “strike” announcement (Wilcoxon signed-rank test, z=-3.262, p=0.0011).

Averaging over periods and subjects within subgroups gives us five clearly independent observations in both the sunspot and the control treatment[6] for the S/C sessions. The Wilcoxon signed-rank test applied to these average shares of work decisions confirms that there is a significant difference between the two treatments (z=-2.03, p=0.04).

While the sunspot appears to change the behavior of some subjects, it is not strong enough to generate a sunspot equilibrium, i.e. an equilibrium determined following the random announcement (Cass and Shell 1983)[7]. Indeed, we never observe mis-coordination on the inferior (S,S,S) Nash equilibrium in any subgroup with a “strike” announcement, but rather dis-coordination on equilibria such as (S,W,W) or (S,S,W). Thus, in our experiment the sunspot does not appear as a coordination device but rather as a source of uncertainty. This is not surprising, because strategic uncertainty appears to be very low in the control treatment, in which subjects coordinate almost perfectly on the payoff-dominant equilibrium right from the start. Furthermore, given that 63% of the subjects in CPH S/C session and 67% of the subjects in UPF S/C session are responsible for this dis-coordination for at least 1 and up to 17 periods, we can conclude that the dis-coordination observed in this experiment is not due to the decisions of a few subjects but rather a general phenomenon.

By running different sessions with different order of treatments, a significant order effect is found. Comparing the averages of the independent observations from the C/S session, in which subjects played the control treatment first and the sunspot one next, to those of the S/C session, where subjects played the sunspot treatment first and consequently the control, there are significant differences (Wilcoxon rank sum test, 7 observations, z=-3.169, p=0.0015). Thus, the order matters and subjects learn enough from the control treatment to avoid mis or dis-coordination when the sunspot is introduced, whereas when announcements are made in first periods it leads to dis-coordination and, therefore, to inefficiencies.

Another way to assess the importance of the sunspot is to estimate the following random effects panel probit model for each period *t* and each subject *i* (840 observations):

$$P(W_{it}) = \beta_0 + \beta_1 STRIKE_{it} + \beta_2\, PERIOD_t + \boldsymbol{\gamma} GD_{\boldsymbol{i}}$$

W_{it} indicates the choice of WORK, *STRIKE* equals 1 if the announcement is “strike” and 0 otherwise, *PERIOD* is a time variable, and *GD* is a collection of dummy variables indicating the subgroups with one subgroup at UPF omitted. The time variable serves to check for learning effects and the subgroup dummies control for any group-specific effects.

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[6] Unfortunately, due to an allocation problem of subjects to subgroups in the control group of the Copenhagen session we are left with 5 instead of 7 independent observations for the control group of the Copenhagen session and thus two subgroups are not used and we are left with 5 independent observations in total for the control groups.

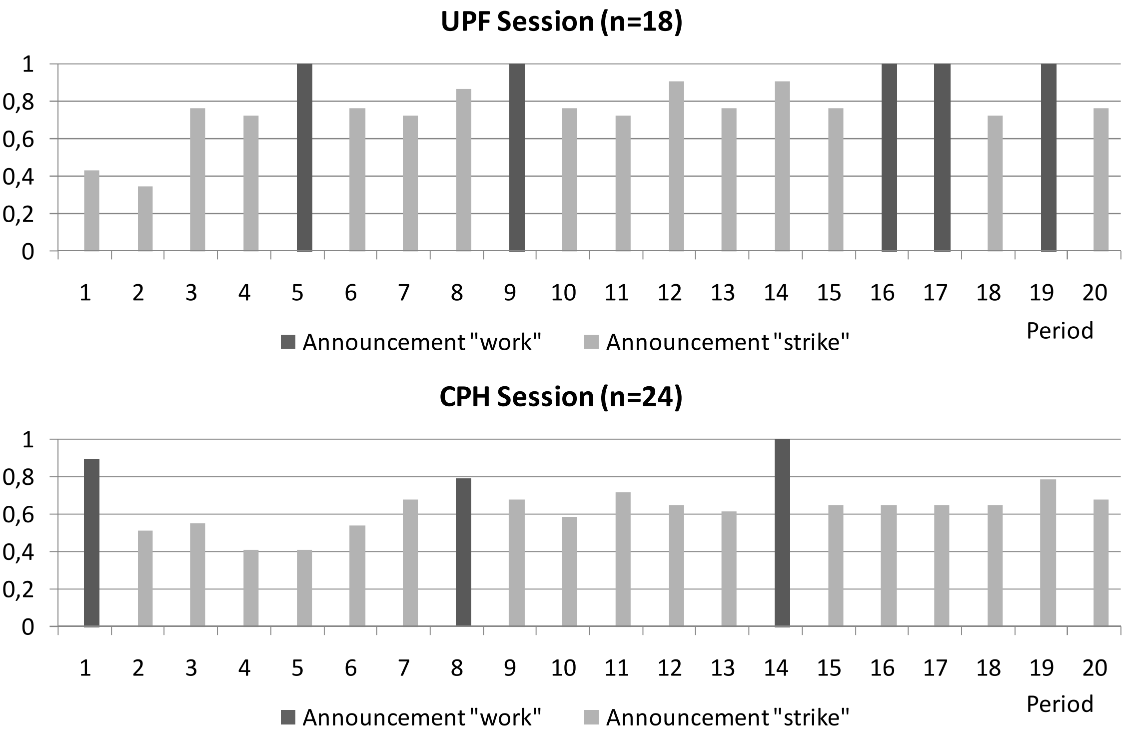
[7] In our framework, the outcome of the game which occurs when all agents follow the announcement is defined as a sunspot equilibrium and not a correlated equilibrium. This comes from the fact that the uncertainty device is inside the rules of the game here. Indeed, all players know exactly what announcement the others are received (public signal), whereas they know only distributions of announcement in case of correlated equilibrium (private signal).

We find that the announcement of "strike" reduces the probability of W by 0.098 (p=0.001) and that each additional period increases the probability of W by 0.004 (p=0.008)[8]. This means that the strike announcement has a significant effect at the individual level, but also that individuals learn to ignore it over time (even if only slowly).

3.3 Efficiency

The dis-coordination caused by the sunspot is quite costly. We measure efficiency by the actual payoff per period divided by 40, which is the obtained payoff in the Pareto-dominant equilibrium (W,W,W). Figure 3 shows us the average levels of efficiency in the treatments in which the sunspot matters.

Figure 3: Average level of efficiency in the sunspot treatments of the S/C session



At the UPF session (upper panel), the average level of efficiency is always 1 if the announcement is "work", but only three times above 0.8 if the announcement is "strike". The mean of the level of efficiency at the UPF session with a "strike" announcement is equal to 0.728, which is significantly smaller than 1 (Wilcoxon signed-rank test, z=-3.936, p=0.0001).

At the Copenhagen session (lower panel), the average level of efficiency[9] is always below 0.8 if the announcement is "strike" and the mean of the average level of efficiency in the 17 periods with "strike" announcements is equal to 0.61, which is significantly smaller than the average efficiency of 0.896 in the three "work" periods (Wilcoxon signed-rank test, z=-3.390, p=0.0007).

Overall, efficiency is significantly reduced when the sunspot is introduced in the first periods compared to periods where it is absent (0.714 vs. 0.901, Wilcoxon rank sum test, z=

[8] A likelihood ratio test rejects the null hypothesis of no random effects at p<0.001. Of the six subgroup dummy variables, two for CPH and one for UPF are significantly negative.

[9] Due to an exchange effect, average earnings in CPH are greater than those in UPF even if the average level of efficiency is lower in the former. Indeed, the show-up fee is lower in CPH than in UPF (20DKK equals to 2.70 €), but subjects receive more money for 150 points in CPH than in UPF (15 DKK equals to 2€).

3.372, p=0.0007). We conclude that the sunspot is relevant, as it can produce significant economic losses through dis-coordination when subjects have not learned enough about the game.

4. Conclusion

We have demonstrated that a purely random signal unrelated to the fundamentals of the game – a sunspot – produces coordination failure (and efficiency losses) among individuals who almost perfectly coordinate among themselves otherwise. This is especially remarkable because our coordination game is so simple. With only two Nash equilibria in pure strategies and with the payoff-dominant equilibrium also being risk-dominant, coordination on this superior equilibrium is made very easy, as confirmed by our control treatments. Yet the introduction of a – in terms of fundamentals – irrelevant signal has a strong impact on behavior.

Our study is the second paper that shows the relevance of sunspots in a laboratory experiment. In contrast to the results in Duffy and Fisher (2005), the sunspots in our experiment do not facilitate coordination, but lead to dis-coordination in a setting with Pareto ranked equilibria. This is a new potential impact of sunspots which has not been extensively discussed in the theoretical literature before. Thus, this study is consistent with the view that real life coordination failures can be caused by random, exogenous signals.

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