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An Experimental Study Of Uncertainty In Coordination Games

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Abstract

Global games and Poisson games have been proposed to address equilibrium indeterminacy in Coordination games. The former assume that agents face idiosyncratic uncertainty about economic fundamentals, whereas the latter model the number of actual players as a Poisson random variable to capture population uncertainty in large games. Given that their predictions differ, it is imperative to understand first which type of uncertainty drives empirical behavior in environments with strategic complementarities, and second whether such behavior is consistent with the theoretical predictions of the corresponding Coordination games. We thus design an experiment to study the behavior of subjects in Poisson, Global and Common Knowledge Coordination games. We find that *only* uncertainty about the number of actual players in large games influences subjects' behavior. Crucially, such behavior is consistent with the theoretical prediction of Poisson Coordination games.

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1 Introduction

In many situations in macroeconomics, strategic complementarities arise: individual gains from taking a certain action are non-decreasing in the number of agents who chose the same action. Common Knowledge Coordination games, where "economic fundamentals" (i.e. profitability determinants) and number of agents are assumed to be common knowledge, emphasize that in such environments equilibrium cannot be pinned down uniquely because beliefs are indeterminate. This lack of predictability poses a serious problem for many academics and practitioners when it comes to predicting, for instance, the onset of speculative attacks.

Global Coordination games constitute the most popular approach to escape the prediction of equilibrium indeterminacy. They assume that agents face idiosyncratic uncertainty about economic fundamentals (see Morris and Shin (1998), Heinemann (2000), and Heinemann and Illing (2002)). A more recent approach, Poisson Coordination games, is motivated instead by the fact that the number of potential speculators is by definition very large in macroeconomic environments hence the standard assumption that every player takes every other player's behavior as given and known when contemplating his/her best response may be violated. In large societies, for instance, it may be prohibitively expensive to collect the necessary information for who all the stakeholders are. Following the suggestion of Myerson (2000), this approach models the number of actual players as a Poisson random variable.[1] Importantly, Global and Poisson Coordination games lead to drastically different predictions. The Global Coordination game prediction about, say, the onset of speculative attacks manifests a threshold level of fundamentals that defines two areas in the region where Common Knowledge Coordination games predict multiplicity of equilibria: one in which a successful attack takes place, and another, where a successful attack does not materialize. In sharp contrast, the Poisson Coordination game prediction is that no speculative attack will take place as long as the reward from a successful attack, net of the short-selling cost, is sufficiently small (see Section 3 for more details). Therefore, it is imperative to understand first the nature of uncertainty that predominantly drives empirical behavior in environments

[1] This modelling choice is driven, in part, by certain convenient properties associated with the Poisson distribution (see Myerson (1998)). As a complementary justification for the latter modelling choice, suppose that the identity of every stakeholder is indeed common knowledge, but also that binding individual orders for short sales of a currency must arrive with the central bank by a given time. Standard theory suggests that each agent will decide on his/her action by taking the number of orders at the collector's disposal as given. However, the probability that a phone call to a busy switchboard goes through or the webpage of an online site is uploaded successfully at times of high traffic decreases with the number of stakeholders. As a result, and under the assumption that the average number of successful phone calls or online visits is known, in a large environment, stakeholders should actually view the number of actual players in the Coordination game as a Poisson random variable.

with strategic complementarities, and second whether such behavior is consistent with the theoretical predictions of the corresponding Coordination games. Investigating these questions is the focus of this paper. In particular, we design an experiment to study the behavior of subjects in Poisson, Global and Common Knowledge Coordination games (henceforth, for brevity, referred to as *Poisson*, *Global* and *Common Knowledge games*, respectively, unless there is a risk of confusion).[2] In the context of macroeconomic situations, our setup captures games between currency or debt speculators, start-up investors and technology adopters under network externalities.

The experimental design is formulated around asking subjects to state their intent to buy a cash amount.[3] Registering to buy the cash amount entails paying a fee, which is less than the cash amount. The fee is non-refundable; that is, once a subject registers to buy the cash amount, the fee is subtracted from the subject's initial endowment. Additionally, registering to buy the cash amount does not imply that the cash amount is awarded. In order to get the cash amount, a threshold number of registrations has to be met. If fewer subjects than the number dictated by the threshold register then the cash amount is not awarded. The experimental sessions are conducted over the Internet. Internet is ideal for Poisson experiments as subjects cannot infer the number of participants, which is typically the case in a laboratory experiment. Crucially, in order to circumvent the difficulties that would arise given the (assumed) unfamiliarity of many subjects with Poisson probabilities, we applied the specific probabilities onto a roulette wheel while noting that the latter is not a standard wheel. In order to maintain consistency with the Poisson experimental sessions, the Global and Common Knowledge sessions were also conducted over the internet in an analogous setup to the Poisson sessions while accommodating the underlying assumptions of each theory. Once all the relevant information was disclosed, subjects were asked to make a decision whether to buy the cash amount. Our approach resembles how managers and investors commit to their decisions nowadays: after contemplating the pros and cons of various alternatives, managers and investors will often place their (short-selling, purchase or investment) orders online.

We find that *only* uncertainty about the number of actual players in large games influ-

[2]To the best of our knowledge, we are the first to provide an experimental investigation of Poisson *Coordination* games. The only other experimental study of Poisson games we know of is that of Ostling, Wang, Chou, and Camerer (2011) who assume Poisson-distributed uncertainty about the number of players participating in the Swedish *Lowest Unique Positive Integer* (LUPI) game. The behavioral patterns of the field and laboratory data are consistent with the theoretical predictions.

[3]In the lingo of the speculative attack model of Morris and Shin (1998), registering to buy the cash amount reward is analogous to attacking the currency peg. Alternatively, in the context of investors and technology adopters under network externalities, registering to buy the cash amount is analogous to undertaking the investment opportunity and adopting the new technology, respectively.

ences subjects' behavior. Specifically, when contrasting behavior in single shot Common Knowledge and Poisson games, we find that subjects' behavior across the two games is statistically different. This result implies that, for the chosen parameters, experienced players are also very likely not to register to buy the cash amount. Note that in a repeated setup, at the end of each period, subjects receive feedback on the total number of registrations. The percentage of subjects in the single shot Poisson experiments that do not register is around 95%. We hypothesize that such high percentage is likely to deter subjects from registering in the next period, and so on and so forth. In light of Heinemann, Nagel, and Ockenfels (2004) and Cabrales, Nagel, and Armenter (2007), we expect that the behavior of experienced subjects in the Common Knowledge games will be different from the above. Indeed, our robustness controls confirm that uncertainty about the number of actual players is an important determinant of experienced subjects' behavior as well. Moreover, subjects in Poisson games forego to register to buy the cash amount in accordance with the theoretical prediction for the chosen parameters. In the model's interpretation this means that, in the case of speculative attacks, creating bigger markets (for instance, by removing trading restrictions and market entry fees and/or improving cooperation between national financial networks) and thereby introducing uncertainty about the number of participants, coupled with a sufficiently high Tobin tax, decreases the prior probability of an attack by debt or currency speculators.

Finally, motivated by the results in Cabrales, Nagel, and Armenter (2007), we also contrast the empirical findings of Global to those in Common Knowledge in single shot games. In line with existing results, we find that in Global and Common Knowledge games subjects' behavior is statistically similar. Therefore, uncertainty about economic fundamentals does not have an impact on inexperienced subjects' behavior. In particular, subjects in both games split almost evenly between foregoing registering to buy the cash amount and registering to buy the cash amount. This result is not theoretically predicted in either informational protocol.

The paper adheres to the following plan. We present next the literature review. In Section 3, we review the theoretical predictions of Global, Poisson and Common Knowledge games. In Section 4, the experimental design is presented. In Section 5, we report the results. In Section 6, we conduct robustness analysis on subjects' behavior with smaller and larger sample sizes as well as report results on experienced subjects' behavior. In Section 7, we discuss the important findings and offer suggestions for future research.

2 Literature Review

An important issue that arises in environments with strategic complementarities is whether beliefs about equilibrium outcomes can be pinned down uniquely. Most of the received theoretical literature has focused on the interaction of heterogeneity in beliefs or preferences/technologies and uncertainty about economic fundamentals to study uniqueness of equilibrium. The ensuing common view is that in order to escape a prediction of indeterminacy of equilibria a model needs to have a sufficiently large degree of heterogeneity and/or of asymmetric information.[4] In particular, Global games, probably the most influential of all these approaches, postulate that agents face idiosyncratic uncertainty about economic fundamentals. This equilibrium is in threshold strategies that prescribe the "safe" action (e.g. do not speculate) if and only if the idiosyncratic signal about the unknown state of the economy is a sufficiently strong indication that profitability is low.

Heinemann, Nagel, and Ockenfels (2004) (henceforth referred to as HNO) study an experiment that resembles the speculative attack model of Morris and Shin (1998) with repeated play. In comparing sessions between Common Knowledge and Global games, they find that subjects use threshold strategies in both informational protocols. In Common Knowledge games, the authors find that observed behavior lies between the payoff dominant equilibrium and the Global game solution. In Global games, they find that observed behavior is closer to the Global game solution. In their setup, the relevant economic fundamental is the profit from short selling the currency. The payoff dominant solution prescribes that all subjects choose the "risky" action (e.g. speculate) as long as the level of economic fundamentals exceeds the fee, whereas the Global game solution specifies a level of economic fundamentals above which enough registrations take place for the cash amount to be awarded. HNO interpret these findings as evidence to suggest that "a commitment by the central bank to provide public information increases the prior probability of a speculative attack" (p. 1584).

Our study differs in two distinct ways from that of HNO. First, in our experiment, subjects are required to make only one decision based on the information provided, whereas in the study of HNO, each subject had to make a series of decisions (160 decisions in total) based on a different informational draw each time. Second, the context of a subject's decision differs in this setup compared to the one in HNO. In our setup, a subject has to sacrifice an amount of money from the initial endowment (pay a non-refundable fee) to buy the cash amount. Otherwise, a subject gets to keep the endowed amount. In the study of HNO, subjects are required to decide between the safe and the risky action; however, the risky

[4] Morris and Shin (2003) provide an overview of Global games. Herrendorf, Valentinyi, and Waldman (2000), Burdzy, Frankel, and Pauzner (2001), and Frankel and Pauzner (2000) exploit heterogeneity of agents to the same effect.

action does not take away any money from their total earnings.

Cabrales, Nagel, and Armenter (2007) (henceforth referred to as CNA) study an experiment that resembles the 2X2 setup of Carlsson and van Damme (1993). Analogous to HNO, CNA also investigate behavior in Common Knowledge and Global games, but distinguish between short-term and long-term play. The authors utilize a discrete state space with five possible states and signals to make the theoretic reasoning simpler. CNA find that in Global games with long-term play, subjects' behavior converges towards the Global game solution, which coincides on average with the risk dominant equilibrium. However, the authors point out that the theoretical results of Carlsson and van Damme (1993)[5] do not hold in situations with players that are inexperienced and, in some cases, may even not hold after a relatively lengthy interaction (p. 232). CNA also find that in Common Knowledge games, observed behavior of inexperienced subjects can be anywhere (weakly) between the payoff dominant equilibrium and the Global game solution, and that behavior across Common Knowledge and Global games for such subjects is similar. Similar to CNA we also do not find a statistically significant difference in inexperienced subjects' behavior across Common Knowledge and Global games. This is a departure from the findings of HNO. Yet echoing the discussion in CNA (p. 232), the difference in results may be driven by the absence of learning effects given that our subjects interact only once.

Crucially, the aforementioned literature has not paid particular attention to the implications of the fact that in the above strategic environments, the number of economic agents is often very large. As Myerson (2000) points out, in games with a very large number of players, "it is unrealistic to assume that every player knows all the other players in the game; instead, a more realistic model should admit some uncertainty about the number of players in the game" (p. 7). Following this suggestion, Makris (2008) models the coordination problem as a Poisson game, where it is common knowledge that the number of actual players is a Poisson random variable, and shows that the equilibrium is unique if the transaction cost (fees) relative to the gain from coordination to the risky action is above a well-defined threshold − the unique equilibrium prescribes that all players take the safe action.

[5] Morris, Rob, and Shin (1995) and Kajii and Morris (1997) elucidate the logic behind the theoretical results of Carlsson and van Damme (1993).

3 Theoretical Predictions

We deploy the canonical Coordination game used in Morris and Shin (1998) (with different notation). Denote by $N > 1$ the number of players, who decide whether to register to buy a cash award (i.e. attack a currency). Denote by T the registration fee (opportunity cost), Y the state of the economy/economic fundamentals, and $Y/2$ the cash award gross of the fee with $Y \in [Y_{min}, Y_{max}]$.[6]

The cash amount is awarded if the number of registered players is at least as high as $\alpha(Y)$. Therefore, after letting ν be the number of other players who register, the payoff of each player is

$$\begin{array}{cc} 0 & \text{if he does not register,} \\ -T & \text{if he registers and } \nu < \alpha(Y) - 1, \\ Y/2 - T & \text{if he registers and } \nu \geq \alpha(Y) - 1. \end{array}$$

The function $\alpha(.)$ and the registration fee are common knowledge. The minimum number of registrations required for the cash amount to be awarded is set as

$$\alpha(Y) = C - \frac{Y}{D}$$

with

$$C > 0, D > 0 \text{ and}$$

$$C - \frac{Y_{max}}{D} \leq 1.$$

The last condition states that in the worst economic fundamentals ($Y = Y_{max}$), the cash amount is awarded even if only one player registers.[7]

Note that for $Y \geq \overline{Y} \equiv \alpha^{-1}(1)$, a single registration is enough for the cash amount to be awarded, while for $Y < \overline{Y}$ more than one registrations will typically be needed. We assume that

$$2T < \overline{Y}$$

to ensure that it is not weakly dominant to abstain from registering for any cash amount

[6] To map the notation here to that in Morris and Shin (1998) and Heinemann (2000), the interested reader should just use $Y = Y_{max} - (Y_{max} - Y_{min})\theta$, where $\theta \in [0, 1]$ is the state of the economy in these papers. Moreover, $Y_{max}/2$ is the capital gain from short selling in the worst state of the economy ($\theta = 0$), while $Y_{min}/2$ is the short-selling reward in the best state of the economy ($\theta = 1$).

[7] Here, to fix ideas, a higher cash award corresponds to worse economic fundamentals. This relationship pertains to the example of a speculative attack. For the case of innovation, the converse relationship should be used; that is, a higher cash award would correspond to better economic fundamentals.

when $Y < \overline{Y}$. Let $\underline{\text{Y}}$ denote the supremum of all levels of economic fundamentals for which it is not (weakly) profitable to register given that all other $N-1$ players register. That is, $\underline{\text{Y}}$ is the largest of the economic fundamentals $2T$ and $\alpha^{-1}(N)$. The significance of this state of economic fundamentals is that it is dominant to abstain from registering for any state $Y < \underline{Y}$. This range of fundamentals is non-empty if the best state of economic fundamentals ($Y = Y_{min}$) is smaller than $\underline{\text{Y}}$. This is ensured by our next assumption. In the best state of economic fundamentals, the cash amount awarded is smaller than the fee; that is,

$$2T > Y_{min}.$$

In what follows, we distinguish between three cases regarding agents' information about economic fundamentals and number of players. Under common knowledge of economic fundamentals and number of players (i.e. in the Common Knowledge game), zero registrations (the maximin outcome) is the unique equilibrium outcome for $Y < \underline{Y}$. Furthermore,[8] N registrations (the payoff dominant outcome) is the unique equilibrium for $Y \geq \overline{Y}$. However, in the "grey area" (i.e. in the remaining area of economic fundamentals) there is multiplicity of equilibria. Depending on self-fulfilling beliefs both the maximin and payoff dominant outcomes (zero and N registrations, respectively) are equilibria.

In the Global game, the cash amount is uncertain and subjects receive idiosyncratic signals/hints on the state of the economy denoted by x. The unknown state Y is uniformly distributed and conditional on realized Y, x is uniformly distributed over $[Y - \varepsilon_Y, Y + \varepsilon_Y]$ with

$$2\varepsilon_Y < min\{Y_{max} - (C-1)D, max\{(C-N)D, 2T\} - Y_{min}\}.$$ [9]

These distributions are common knowledge. In this case, there is a unique Bayesian Nash Equilibrium (BNE), where all players register if and only if their signal is higher than x^*, where x^* is defined (see also HNO) by

$$\frac{1}{2\varepsilon_Y} \int_{x^*-\varepsilon_Y}^{x^*+\varepsilon_Y} \frac{Y}{2}[1 - \sum_{j=0}^{\lceil a(Y)-2 \rceil} Bin(j, N-1, p(Y, x^*))]dY = T. \tag{1}$$

The symbolic function $\lceil \cdot \rceil$ rounds-up the fraction to the nearest integer from above, and

[8] If $\underline{\text{Y}} = 2T$, then contributing when $Y = \underline{Y}$ is never profitable because even if enough contributions are made so that the cash amount is awarded, the latter just covers the registration fee. Therefore, it is weakly dominant to not contribute when $Y = \underline{Y} = 2T$.

[9] This is (in terms of our notation) the assumption found in Morris and Shin (1998) in footnote 4 (i.e. $2\varepsilon_Y < min\{Y_{max} - \overline{Y}, \underline{Y} - Y_{min}\}$.

$Bin(\cdot)$ is the binomial distribution where

$$p(Y, x^*) = \frac{Y + \varepsilon_Y - x^*}{2\varepsilon_Y}.$$

To understand this condition, note first that receiving a signal x leads to the posterior that the state Y is uniformly distributed over $[x - \varepsilon_Y, x + \varepsilon_Y]$. Second, conditional on contributing, the cash award will be awarded if at least $a(Y) - 1$ other agents also contribute. Third, conditional on state being Y all signals lie in $[Y - \varepsilon_Y, Y + \varepsilon Y]$. The term in the square brackets is therefore the probability that the cash amount is awarded given that each and every of the other agents is expected to register if and only if their signal is higher than x^*, and the left hand side of the condition above is the associated expected benefit from contributing when the received signal is x^*. The condition above simply says that an agent who has received the marginal signal x^* should be indifferent between contributing or not when all other agents are expected to register if and only if their signal is higher than x^*.

However, the above result relies heavily on the assumption that the state and signal are continuous random variables. If, on the other hand, these are discrete random variables, then there may not be a unique BNE. In fact, there may not even be a unique symmetric BNE in threshold strategies, where all agents register if and only if their signal is higher than a given threshold signal. If, as it will be the case with the Global game played by our subjects, $Y \in \{Y_{min}, Y_{min} + 1, Y_{min} + 2, ..., Y_{max} - 1, Y_{max}\}$ and $x_Y \in \{Y - \varepsilon_Y, Y - \varepsilon_Y + 1, Y - \varepsilon_Y + 2, ..., Y + \varepsilon_Y - 1, Y + \varepsilon_Y\}$ where Y_{min}, Y_{max} and ε_Y are positive integers, then a symmetric BNE equilibrium in a threshold strategy with threshold x^* is given by the solution to the fixed-point problem

$$x^* \in \{k | Y_{min} - \varepsilon_Y \leq k \leq Y_{max} + \varepsilon_Y \text{ and } U(x, k) \leq 0 \; \forall \; x \leq k \text{ and } U(x, k) \geq 0 \; \forall \; x > k\}, \quad (2)$$

where $U(x, k)$ is the expected payoff of a contributing agent with signal x when all other payers are expected to register if and only if their signal is higher than k.

In the Poisson game, the cash amount is common knowledge. In addition, the number of actual players is a Poisson random variable with the mean n being common knowledge. In this case, as shown in Makris (2008), the predictions for economic fundamentals such that $Y < 2T$ or $Y \geq \overline{Y}$ coincide with the corresponding predictions of Common Knowledge games. However, for economic fundamentals within the remaining area, the unique equilibrium is the maximin outcome (where no player registers) if and only if

$$1 - F(\lceil \alpha(Y) \rceil - 2 \mid n) < 2T/Y, \quad (3)$$

where $F(\cdot \mid n)$ is the cumulative distribution function with parameter n, and the symbolic function $\lceil \cdot \rceil$ rounds-up the fraction to the nearest integer from above. To understand this condition note that an expected utility maximizer will not take a bet if the ratio of the price to the payoff under a win is higher than the probability of winning the bet. Condition (3) is such a condition after identifying the price with the fee, the payoff under a win with the cash amount reward, and the probability of winning the bet with the left-hand side of the condition. Using the "environmental property" of Poisson games (Myerson (1998)), the probability in the left-hand side of the above condition is simply the probability of a successful attack from the point of view of an attacking player in the game conditional on expecting the other players in the game to attack.[10] The above condition does not seem to be very cognitive demanding and we should thus expect subjects' behavior to be largely consistent with it. Yet when the above inequality does not hold then multiplicity of equilibria is predicted instead. Importantly, the prediction of the Poisson game is the same whether the state Y is a continuous or a discrete variable.

In the experiments, we will choose parameters such that the theoretical prediction prescribes that there is equilibrium indeterminacy in the Common Knowledge games, whereas in both the Poisson games and (all symmetric BNE in threshold strategies of) the Global games, the theoretical prediction prescribes that all players do not register. To justify the latter choice notice first that our aim in this paper is to investigate environments where Poisson games predict uniqueness of equilibrium. Second, to ensure uniqueness of equilibrium in Global games we would need to restrict attention to continuous variables for states and signals. However, continuous random variables cannot be implemented perfectly in the lab as the designer always needs to restrict values within some decimals. The finer the grid the more complications might arise as a result of that. What we chose to do instead was to simplify the cognitive environment faced by subjects by focusing on integer-based treatments. The discrete grid could always give rise to multiplicity of equilibria as we discussed earlier. Therefore, to give the best chance to Global games in the lab we aimed at choosing parameters such that *all* symmetric BNE in threshold strategies imply the same behavior regardless of the realized signals. Third, choosing parameters such that all players *do* register under

[10]Consider a potential player who is told he is an actual player in the game. Being an actual player is a new piece of information that might affect the player's beliefs about the actual size of the game. On one hand, he might then believe that the number of other players is Poisson-distributed with a mean of $n-1$ (since him being in the game has lowered the mean of the number of remaining players). On the other hand, the fact that he is an actual player is a clue that the number of players is large − not small. Under the Poisson distribution, the two effects exactly cancel out. According to this "environmental equivalence" property, under the Poisson distribution, the mean number of players in the game from the point of view of an outsider (or a potential player) is equal to the mean number of other players in the game from the point of view of a player who has found himself in the game.

all symmetric BNE in threshold strategies of the Global games would imply multiplicity of equilibria in the corresponding Poisson games.[11]

Lastly, we emphasize two more important features of our experimental design. Trying to give the worst chance to Poisson games in the lab, we chose parameters to barely satisfy condition (3). Moreover, for the parameters we chose, the prediction of the Global games with state and signal being continuous random variables (and hence having a unique BNE) prescribes *also* that all players would not contribute.

4 Experimental Design

Our experimental setup features a coordination problem that is examined under three informational protocols: Poisson games, Global games and Common Knowledge games. The experiments were conducted over the Internet. Internet is ideal for Poisson experiments as subjects cannot infer the number of participants, which is typically the case in a laboratory experiment. To maintain consistency with the Poisson treatments, the treatments based on Global and Common Knowledge games were also conducted over the Internet. A disadvantage of running experiments over the Internet is that it becomes very hard to monitor participants' engagement with the game. In particular, there is no control over what participants are doing. For instance, participants could take a break to call someone, to browse the web, to eat pizza, to have a coffee etc. To safeguard against such distractions and to maintain subjects' focus to the game, the screens included timers that allowed a limited, but sufficient amount of time to read comfortably the instructions. In addition, the inclusion of timers minimized the possibility of wired or wireless communication. Once the time lapsed, the subjects would concurrently move to the next screen.[12] Next, we provide a detailed description of the experimental design. We then formulate our general hypotheses.

[11]The way we have checked this is as follows. We asked, for given Y_{max} and Y_{min}, what are the values for N, C, D, T and ε_Y that satisfy the various constraints of the model and maximised the difference $Y^P - (x^G + \varepsilon_Y)$, where Y^P is the solution to condition (3) as an equality, and x^G is the highest symmetric BNE threshold signal. We have solved this optimization problem numerically by deploying the genetic algorithm in MATLAB (R2014b), with 'initial population' size of 2900 admissible profiles of control variables (N, C, D, T, ε_Y), and requiring that N and ε_Y are integers. We found that the value function of this problem is negative. This implies that the only states Y that would generate signals that are higher than any symmetric BNE threshold signal (i.e. $Y > x^G + \varepsilon_Y$) are higher than Y^P and thereby violate condition (3).

[12]In the questionnaire that followed the game play stage, none of the subjects reported running out of time while reading the instructions on any of the screens.

4.1 Treatments

Upon logging in, subjects were endowed with £12 in lieu of a show-up fee. Subjects were then provided with the instructions. The instructions accommodated the underlying assumptions of the corresponding theories. Right after the delivery of the instructions, subjects were asked to make a decision whether to buy the cash amount. A value added of this approach is that it mimics how managers and investors commit to their decisions nowadays: after contemplating the pros and cons of various alternatives, managers and investors will often place their (short-selling, purchase or investment) orders online. Finally, subjects were asked to complete a short questionnaire consisting of demographic questions. With the conclusion of the experimental session, subjects claimed their earnings from the school office of Social Sciences at the University of Southampton.

First, we describe the Poisson treatments. In the first stage of the experiment, subjects were instructed that there would be a computer draw and that the number drawn would correspond to the number of subjects participating in the second stage of the experiment.[13] Subjects were explicitly told that the number drawn would not be revealed to them. The Poisson process was based on $n = 17$. To circumvent the difficulties that would arise given the (assumed) unfamiliarity of many subjects with Poisson probabilities, we applied the specific probabilities onto a roulette wheel (see Figure 1). We showed the roulette wheel pictorially and noted the following.

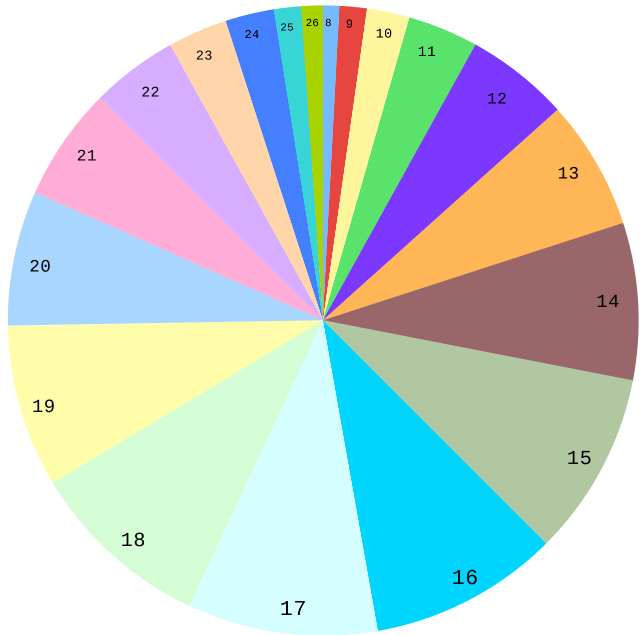
> You can see that the roulette is not a standard roulette; the number drawn can be any number between 8 and 26, but not all numbers are equally likely to be drawn. Numbers closer to 17 (the mean) are more likely to be drawn.

The instructions specified that subjects not selected to participate in the second stage of the experiment would be dismissed, but would keep their initial endowment.

In the second stage, subjects had the option to buy a cash amount of £12.50 at a fee of £9 (£10). Subjects were informed that the cash amount of £12.50 would be issued only if a minimum of $\alpha(Y)$ subjects registered to buy it, and that the fee of £9 (£10) required for the purchase of the cash amount was non-refundable and collected immediately. That is, if a subject registered to buy the cash amount of £12.50, the £9 (£10) would be subtracted automatically from the initial endowment regardless of the number of subjects registering. The threshold $\alpha(Y)$ was 16 when the fee was £9, and 15 when the fee was £10. The subjects were then asked to indicate whether they would like to register to buy the £12.50 cash amount.

[13]In each of the Poisson sessions, we sent log in information to 26 subjects. The total number of participants in each Poisson treatment is shown in Table 1.

Figure 1: Roulette Wheel in the Poisson Treatments for $n = 17$



Notes: We circumvented the difficulties that would arise given the (assumed) unfamiliarity of many subjects with Poisson probabilities by applying the specific probabilities onto a roulette wheel.

Analogous to the Poisson treatments, Global treatments also included a computer draw in the first stage. The drawn integer (between 5 and 95 inclusive) was referred to as "Y" in the instructions. We forewent indicating the actual Y drawn, yet we provided subjects with a *hint* about the drawn Y. The hint was an integer within a range of $+5$ and -5 from the Y drawn.[14] For example, for $Y = 45$, subjects would receive a hint integer in the set of $\{40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50\}$, where each integer had a probability of $\frac{1}{11}$ of being drawn. The hint integer was indicated in bold. Additionally, the number of subjects participating in the experiment was set at $N = 17$ and was indicated on the screens.

In the second stage of the experiment, subjects had the option to buy a cash amount of £$\frac{Y}{2}$ at a non-refundable fee of £9 (£10). The cash amount would be awarded conditional on at least $\alpha(Y) = C - \frac{Y}{4}$ registering to buy it, where C was replaced in the experimental instructions by 22 (21) when the fee was £9 (£10). In order to circumvent calculation errors, we indicated on the screen the number of subjects that needed to register to win the cash amount for every possible value of Y. The subjects had to indicate next whether they would

[14] To map the values here to the notation in Section 3, let $Y_{max} = 95$, $Y_{min} = 5$, $\varepsilon_Y = 5$ and thereby $x \in [0, 100]$.

like to register to buy the cash amount.

Finally, in the Common Knowledge treatments subjects were told: the number of participants (i.e. 17), the cash amount (i.e. £12.50), the fee (i.e. £9 or £10) and the threshold number of registrations (i.e. 16 or 15) that needed to be met to earn the cash amount. The subjects were then asked to make a decision, analogous to Poisson and Global treatments.

Table 1: CHARACTERISTICS OF THE EXPERIMENTAL SESSIONS

Common Knowledge Games						
# of Subj.	# of Ses.	Mean	Threshold	Fee (£)	Amount (£)	Acronym
34	2	-	16	9	12.50	CK169
34	2	-	15	10	12.50	CK1510
Poisson Games						
# of Subj.	# of Ses.	Mean	Threshold	Fee (£)	Amount (£)	Acronym
40	2	17	16	9	12.50	P169
44	2	17	15	10	12.50	P1510
Global Games						
# of Subj.	# of Ses.	Mean	Threshold	Fee (£)	Amount (£)	Acronym
34	2	-	$22 - \lceil \frac{Y}{4} \rceil = 16$	9	$\frac{Y}{2} = 12.50$	G169
34	2	-	$21 - \lceil \frac{Y}{4} \rceil = 15$	10	$\frac{Y}{2} = 12.50$	G1510

Notes: In the first column, we provide the total number of participants in each treatment. We conducted two sessions per treatment. The number of participants in the Global and Common Knowledge sessions was common knowledge. Notice that the number of participants in *each* session in the Global and Common Knowledge treatments coincides with the mean n of the Poisson treatments. Moreover, the cash amount is the same in the three game types. Also, in the calculation of the threshold in Global games, the symbolic function $\lceil \cdot \rceil$ rounds-up the fraction to the nearest integer from above. The acronyms in the last column consist of the game type (*CK* for Common Knowledge games, *P* for Poisson games and *G* for Global games), the threshold (15 or 16) and the fee (9 or 10).

The experimental sessions took place in October of 2012 and May of 2013. We conducted two sessions per treatment. The 220 subjects were recruited from the undergraduate student population of the University of Southampton. We announced our experiments via class presentations. In order to participate, students replied by e-mail. We then indicated to the respondents the date and time of the experiment, and asked them to confirm their attendance. Those who confirmed were subsequently sent log in information (username and password) and the url of the website. Most of the participants majored in business, economics, finance, and mathematics. Participants were allowed to participate in *only* one session. Each session lasted approximately 20 minutes. Average earnings per participant were £9.40. Specifically, in the Common Knowledge games, subjects made on average £7.51, in the Poisson games, subjects made on average £11.51, whereas in the Global games, the average earnings were £7.79. The experimental instructions for all treatments are reported in the Appendix. Some general characteristics of the sessions are shown in Table 1. Note that each treatment is denoted by an acronym. In particular, the acronym $(type, threshold, fee)$ consists of the *type* of game (*CK* for Common Knowledge games, *P* for Poisson games and *G* for Global games), the *threshold* (15 or 16) and the *fee* (9 or 10).

At this point and before proceeding to the general hypotheses, we feel compelled to justify our choices with respect to the cash amount (£12.50), (expected) number of players (17), the threshold number of players (15 or 16), the fee (£9 or £10) and the initial endowment (£12). For design reasons, the draw of Y was conducted first. The drawn Y was 25. In HNO, there is a one-to-one map between the Y and the cash amount. However, a cash amount of £25 seems unreasonably high for an experiment lasting approximately 20 minutes. Instead, we decided to offer a cash amount of £$\frac{Y}{2}$ (i.e. £12.50). To ensure comparability across game types, the cash amount used in Common Knowledge and Poisson games was also set to £12.50. Moreover, the number of players in Global and Common Knowledge games had to be large enough to capture the "largeness" of the games *while* being cost effective. This motivates our choice of the number of players. To ensure comparability across game types, the population mean of the Poisson distribution used in Poisson games had to also be equal to the number of players in Global and Common Knowledge games.

The threshold and the fee were chosen next. Presumably, a lower fee and a lower threshold would make subjects more willing to register to buy the cash amount. However, ensuring equilibrium uniqueness in the Poison games implies that we cannot choose low values for *both* the fee and the threshold number (recall condition (3)). In addition, the threshold number of registrations should not exceed the number of players in Global and Common Knowledge games (otherwise, subjects would have a dominant strategy to not register). Our chosen parameters struck a balance when faced with a tradeoff between low fees and high threshold numbers at the design stage. To see this, observe the Poisson Cumulative Distribution Table (included in the Appendix) for $n = 17$. Consider first, the lowest fee required for the threshold number of registrations to be equal to the mean number of the Poisson distribution while satisfying condition (3). Looking at the table and applying condition (3) this fee is £7.86. Consider next decreasing the threshold number of registrations by 1 and 2 subjects. The corresponding lowest fee such that condition (3) is satisfied is £9 and £10, respectively. Having a threshold level which is (at least) equal to the mean number of the Poisson distribution could make subjects perceive it as less likely that the cash amount will be awarded. This in turn could make subjects unwilling to register. To make it harder for the theoretical prediction of Poisson games to be confirmed by subjects' behavior, we showed preference towards increasing the fee by merely £1.14 and £2.14 in order to decrease the threshold number of registrations by 1 and 2 subjects, respectively. Similarly, lower threshold numbers, such as 11 would imply a fee significantly close to the cash amount. For example, the fee required for a threshold number of registrations of 11 is £12.18. It is therefore highly doubtful that a subject would risk losing the fee of £12.18 to earn the cash amount of £12.50. Instead, we chose to set the fee at £9 and £10 and thereby to set a threshold number of registrations of 16 and 15, respectively to ensure condition (3), while also ensuring that (a) the fee is not very close to the awarded cash amount, and (b) the threshold number of registrations is less than the mean number of the Poisson distribution. Finally, considering the duration of the experiment (approximately 20 minutes) and the minimum wage in UK ($\approx$ £6 per hour), we stipulated that no subject should get a compensation below £2. Therefore, the difference between the highest fee (i.e. £10) and the endowment should not be less than £2, which led us to provide subjects with an initial endowment of £12.

4.2 General Hypotheses

We formulate next six hypotheses. The first, second and third hypotheses examine the behavioral differences across the three informational conditions. This is important in order to understand the nature of uncertainty that influences strategic behavior in macroeconomic environments with strategic complementarities. Thus, we test for differences in subjects' behavior across Common Knowledge and Poisson games, Poisson and Global games, Global and Common Knowledge games.

HYPOTHESIS 1: Subjects' behavior is statistically similar across Common Knowledge and Poisson games when controlling for the parameter choices of each pairwise comparison.

HYPOTHESIS 2: Subjects' behavior is statistically similar across Poisson and Global games when controlling for the parameter choices of each pairwise comparison.

HYPOTHESIS 3: Subjects' behavior is statistically similar across Global and Common Knowledge games when controlling for the parameter choices of each pairwise comparison.

Finally, the last three hypotheses serve as a direct test of the predictions of Poisson, Global and Common Knowledge games, respectively. Recall that on one hand, Poisson and Global games for the parameters specified, predict that subjects will forego the opportunity to register to buy the cash amount and will keep their endowment. Furthermore, in Global games, the theoretical prediction holds regardless of the private signals that subjects receive on the state of the economy. On the other hand, Common Knowledge games establish that based on our parameter choices, subjects will either all coordinate on registering to buy the cash amount or all coordinate on foregoing to resister to buy the cash amount. The last three hypotheses are formulated as follows.

HYPOTHESIS 4: Subjects in Poisson games will choose to forego registering to buy the cash amount in accordance with the prediction of Poisson games for the parameters specified.

HYPOTHESIS 5: Subjects in Global games will choose to forego registering to buy the cash amount in accordance with the prediction of Global games for the parameters specified.[15]

HYPOTHESIS 6: Subjects in Common Knowledge games will either all coordinate on registering to buy the cash amount or all coordinate on foregoing to resister to buy the cash amount in accordance with the prediction of Common Knowledge games for the parameters specified.

5 Results

All hypotheses are formally tested through pairwise χ^2-tests, where the H_0 states that behavior across treatments is not statistically different. Each hypothesis is matched with the corresponding result; that is, result i is a report on the test of hypothesis i. Note that the decision of a subject in the game is a binary variable. The subjects who chose not to register to buy the cash amount were assigned a value of 1. The subjects who chose to register were assigned a value of 0. Next, we provide summary statistics on the experimental data.

5.1 Summary Statistics

Table 2 reports descriptive statistics on the raw data. Recall that subjects had to decide whether to register to buy a cash amount at a fee or forego this option and keep the endowment of £12. In the table, we display the frequency and percentage of subjects who registered to buy the cash amount, and the frequency and percentage of subjects who chose to keep their endowment. The summary statistics are classified by treatment. With the

[15] In both Global treatments, the equilibrium threshold signals are 41, 42, 43 and 44, which are all higher than $Y + \varepsilon_Y = 25 + 5 = 30$.

exception of Treatment CK1510, in all other treatments, the subjects who chose not to register outnumbered the ones that chose to register. In the Common Knowledge and Global treatments, the percentages of those who kept the endowment of £12 range from 47.1% to 58.8%. In sharp contrast, the percentages in the Poisson treatments are substantially higher (95.0% in P169 and 95.5% in P1510). Overall, out of 220 subjects, 68 chose to register to buy the cash amount and 152 subjects chose to keep the endowment of £12. The threshold was not met in any of the treatments; consequently, the cash amount was not awarded.

Table 2: Descriptive Statistics

Common Knowledge Games					
	Registered		Not Registered		Amount
Acronym	Freq.	%	Freq.	%	Awarded?
CK169	16	47.1	18	52.9	No
CK1510	18	52.9	16	47.1	No
Poisson Games					
	Registered		Not Registered		Amount
Acronym	Freq.	%	Freq.	%	Awarded?
P169	2	5.0	38	95.0	No
P1510	2	4.6	42	95.5	No
Global Games					
	Registered		Not Registered		Amount
Acronym	Freq.	%	Freq.	%	Awarded?
G169	14	41.2	20	58.8	No
G1510	16	47.1	18	52.9	No
Total	68		152		

Notes: The table indicates the number of subjects who registered, and the number of those who did not register to buy the cash amount in each treatment. In addition, we provide the corresponding percentages. The total number of participants in each treatment is indicated in Table 1. The threshold was not met in any of the treatments. The acronyms consist of the game type (*CK* for Common Knowledge games, *P* for Poisson games, and *G* for Global games), the threshold (15 or 16), and the fee (9 or 10).

5.2 Subjects' Behavior Across Game Types

Next, we investigate whether subjects' decisions varied significantly across game types when controlling for the parameter choices. In particular, we test for differences in subjects' behavior across Common Knowledge and Poisson games, Poisson and Global games, Global and Common Knowledge games. The results are displayed in Table 3.

Table 3: Differences in Subjects' Behavior Across Game Types

Alternative hypothesis:	$decision_i \neq decision_j$
	p-values
Common Knowledge games vs Poisson games	
CK169 & P169	0.000
CK1510 & P1510	0.000
Poisson games vs Global games	
P169 & G169	0.000
P1510 & G1510	0.000
Global games vs Common Knowledge games	
G169 & CK169	0.625
G1510 & CK1510	0.628

Notes: We utilize the χ^2-test to determine whether subjects' decisions differ across game types ($i \neq j$) conditional on the same parameters. The acronyms consist of the type of treatment (*CK* for Common Knowledge games, *P* for Poisson games and *G* for Global games), the threshold (15 or 16) and the fee (9 or 10).

The first hypothesis aims to investigate any behavioral differences across Common Knowledge and Poisson games. The findings based on the statistical analysis are formalized in our first result.

RESULT 1: Subjects' behavior differs significantly between Common Knowledge and Poisson games when controlling for the parameter choices of each pairwise comparison.

Support. All the p-values in the pairwise comparisons are below the 1% level of statistical significance.

The second hypothesis compares subjects' behavior in Poisson and Global games. The second result indicates that subjects' behavior differs significantly.

RESULT 2: Subjects' behavior differs significantly between Poisson and Global games when controlling for the parameter choices of each pairwise comparison.

Support. All the p-values in the pairwise comparisons are below the 1% level of statistical significance.

The third hypothesis investigates any behavioral differences across Global and Common Knowledge games. We find that there are no differences in subjects' behavior across the two game types when controlling for the parameter choices. This finding is formalized in our third result.

RESULT 3: Subjects' behavior does not differ significantly between Global and Common Knowledge games when controlling for the parameter choices of each pairwise comparison.

Support. All p-values are large enough to infer that the observed distributions are statistically similar; H_0 cannot be rejected.

5.3 Theory and Subjects' Behavior

To investigate the consistency of subjects' behavior with the theoretical predictions, the distribution of each treatment is compared to the predicted distribution of the corresponding theory. Panel A, in Table 4, indicates the p-values of the treatments under the H_0 that the observed distribution and the distribution where all subjects choose to not register are statistically similar. The p-values in Panel B are based on the assumption that the observed distribution and the distribution where all subjects register to buy the cash amount are statistically similar.

The fourth hypothesis was formulated to test the consistency of subjects' behavior with the prediction of Poisson games. The results in Panel A present serious evidence of such consistency for the parameters specified. Given that our sample size is large enough, we also run a probit regression where the dependent variable is a subject's decision and the six treatments are the covariates with Treatment CK169 set as the base. Acknowledging that coefficients in probit models are estimated up to scale and cannot be directly interpreted, we only present marginal effects in Table 5. The standard errors are reported in parentheses. Crucially, the coefficients are statistically significant only in Poisson games. The marginal effects imply an increase in probability of 42.1% (P169) and 42.5% (P1510) in not registering to buy the cash amount in the Poisson treatments, which is consistent with the findings in Panel A of Table 4. We formalize next our fourth result.

RESULT 4: Subjects' behavior in Poisson games is consistent with the prediction of Poisson games for the parameters specified.

Support. The marginal effects of the two Poisson regressor coefficients highlight that there is an increase in probability of 42.1% (P169) and 42.5% (P1510) in not registering to buy the cash amount, which is also statistically significant at the 1% level.

The fifth hypothesis tests the consistency of subjects' behavior with the prediction of Global games. Our fifth result states that such consistency is not verified for the parameters

Table 4: Theory and Subjects' Behavior

Panel A		*Panel B*	
Alternative hypothesis:	$decision_i \neq 1$	Alternative hypothesis:	$decision_i \neq 0$
	p-values		p-values
Common Knowledge games		*Common Knowledge games*	
CK169	0.000	CK169	0.000
CK1510	0.000	CK1510	0.000
Poisson games		*Poisson games*	
P169	0.152	P169	-
P1510	0.153	P1510	-
Global games		*Global games*	
G169	0.000	G169	-
G1510	0.000	G1510	-

Notes: The decision of a subject in the game is a binary variable. The subjects who chose not to register to buy the cash amount were assigned a value of 1; otherwise, were assigned a value of 0. We utilize the χ^2-test to determine whether subjects' decisions in Common Knowledge, Poisson and Global games differ from the theoretical predictions for the parameters specified. Panel A indicates the p-values in the assumption that the observed distribution and the distribution where all subjects choose to not register are statistically similar. The p-values in Panel B are based on the assumption that the observed distribution and the distribution where all subjects register to buy the cash amount are statistically similar. The acronyms consist of the type of treatment (*CK* for Common Knowledge games, *P* for Poisson games and *G* for Global games), the threshold (15 or 16) and the fee (9 or 10).

specified. The finding is formalized next.

RESULT 5: Subjects' behavior in Global games differs from the prediction of Global games for the parameters specified.

Support. All the p-values in the Global game treatments in Panel A of Table 4 are below the 1% level of statistical significance.

Hypothesis 6 aims to examine whether all subjects coordinate on foregoing registering to buy the cash amount or all coordinate on registering to buy the cash amount in the Common Knowledge treatments. On one hand, the p-values of the Common Knowledge treatments in Panel A of Table 4 serve to determine whether subjects coordinate on foregoing registering to buy the cash amount. On the other hand, the p-values of the corresponding Common Knowledge treatments in Panel B serve to determine whether subjects coordinate on registering to buy the cash amount. Our sixth result formalizes our findings.

Table 5: Marginal Effects

Dependent variable:	decision
Regressor	dy/dx
CK1510	-0.059
	(0.121)
P169	0.421***
	(0.092)
P1510	0.425***
	(0.091)
G169	0.059
	(0.120)
G1510	0.000
	(0.121)
Number of obs	220

Notes: We report marginal effects after a probit regression on decision. Treatment CK169 is set as the base against which the estimated parameters are compared. dy/dx for factor levels is the discrete change from the base level. All standard errors are reported in parentheses. The acronyms consist of the game type (*CK* for Common Knowledge games, *P* for Poisson games and *G* for Global games), the threshold (15 or 16) and the fee (9 or 10). *** Significant at the 1% level.

RESULT 6: Subjects' behavior in Common Knowledge games differs from the predictions of Common Knowledge games for the parameters specified.

Support. All the p-values in the Common Knowledge treatments are below the 1% level of statistical significance.

5.4 Consistency in Subjects' Behavior Within Game Types

The last three results suggest that only the theoretical prediction of Poisson games is supported. The theoretical predictions of Common Knowledge and Global games are not supported for the parameters chosen. Even though the corresponding theoretical predictions for the parameters chosen do not change, it is plausible that subjects' decisions are in fact influenced by the specific parameter choices. If this is so, our findings will be compromised by confounding effects caused by parameter sensitivity. It is thus imperative to test whether subjects' behavior within Common Knowledge and Global games is consistent for the specific parameter choices. Table 6 indicates the p-values under the H_0 that there exists a non-random association within the two treatments of Common Knowledge games and within the two treatments of Global games. The test does not reject the H_0 in any pairwise treatment comparison in the two game types; that is, subjects' behavior is consistent within game types for the parameters explored.

Table 6: Differences in Subjects' Behavior Within Game Types

Alternative hypothesis:	$decision_i \neq decision_j$
	p-values
Common Knowledge games	
CK169 & CK1510	0.628
Global games	
G169 & G1510	0.625

Notes: We utilize the χ^2-test to determine if the frequencies of subjects' decisions across treatments ($i \neq j$) within Common Knowledge and Global games are statistically different. The acronyms consist of the game type (*CK* for Common Knowledge games and *G* for Global games), the threshold (15 or 16) and the fee (9 or 10).

5.5 Comparative Statics

Population uncertainty seems to be a main driving force of behavior in these setups. Furthermore, our statistical analysis confirms that subjects forego to register to buy the cash amount in accordance with the prescription of Poisson games. However, a number of natural questions still remain unanswered. How does subjects' behavior change as we increase (or decrease) the threshold level? Is population uncertainty such a big deterrent that subjects will always forego registering? How does subjects' behavior change in the region where Poisson games predict multiplicity? We conduct next a comparative statics exercise to try to shed some light to all these important questions. Specifically, we vary the threshold in order to observe its impact on the empirical distribution of contributions in a Poisson treatment when the fee is £9, the cash amount is £12.50 and the mean number of the Poisson distribution is 17.[16] Some general characteristics of the comparative statics sessions are shown in Panel A of Table 7. In Panel B, we report descriptive statistics on the raw data.

In Figure 2, we plot the proportion of subjects who did not register to buy the cash amount over different thresholds. Note that for the threshold levels of $13-15$, the theoretical

[16] In principle, we could have varied instead the mean of the Poisson distribution, or the fee, or even the cash amount. We showed preference towards changing the threshold simply because it led to the least number of changes in the experimental instructions. For one, changing the mean of the distribution would lead to different roulette wheels and for another, changing the fee or the cash amount would lead to further changes in the final payoffs provided.

Table 7: CHARACTERISTICS OF THE COMPARATIVE STATICS SESSIONS

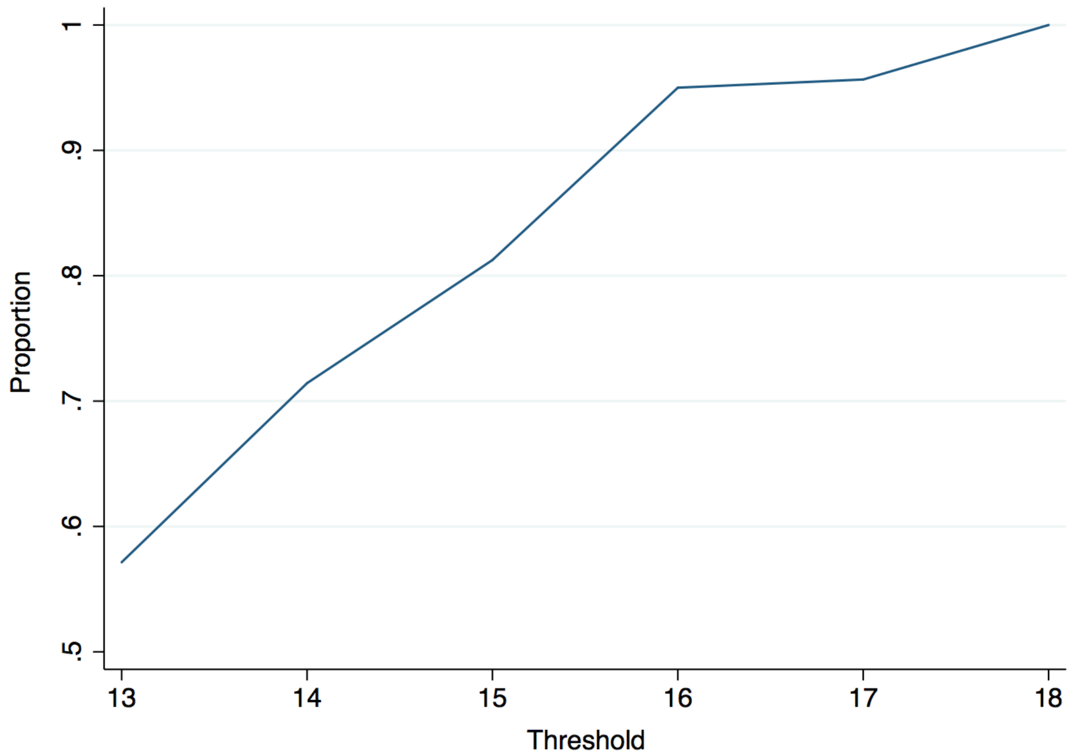
Panel A						
# of Subj.	# of Ses.	Mean	Threshold	Fee (£)	Amount (£)	Acronym
21	1	17	13	9	12.50	P139
14	1	17	14	9	12.50	P149
16	1	17	15	9	12.50	P159
40	2	17	16	9	12.50	P169
23	1	17	17	9	12.50	P179
15	1	17	18	9	12.50	P189

Panel B					
	Registered		Not Registered		Amount
Acronym	Freq.	%	Freq.	%	Awarded?
P139	9	42.9	12	57.1	No
P149	4	28.6	10	71.4	No
P159	3	18.8	13	81.2	No
P169	2	5.0	38	95.0	No
P179	1	4.3	22	95.7	No
P189	0	0.0	15	100.0	No

Notes: In Panel A, we provide some general characteristics of the comparative statics sessions. In the first column, we provide the total number of participants in each treatment. The acronyms in the last column consist of the game type (P for Poisson games), the threshold (13, 14, 15, 16, 17, 18) and the fee (9). In Panel B, we report the number of subjects who registered, and the number of those who did not register to buy the cash amount in each treatment. In addition, we provide the corresponding percentages. P169 is reproduced from Tables 1 and 2.

prediction is that either all subjects will register to buy the cash amount or none of the subjects will register to buy the cash amount (i.e. condition (3) does not hold, which results in equilibrium indeterminacy). In contrast, for the threshold levels of $16 - 18$, condition (3) is satisfied, hence the theoretical prediction is that no subject will register to buy the cash amount. The line is increasing for the thresholds investigated. Consequently, the number of subjects that do not register seems to be increasing in the threshold level. Furthermore, in the Poisson treatments where multiplicity of equilibria is predicted, we still observe a large proportion of subjects not registering, but these proportions are well below the proportion of P169 (i.e. 0.95). We benchmark our statistical analysis on P169 and compare the empirical distribution of that treatment to those of the other treatments. Comparing P169 and P159,

Figure 2: Comparative Statics Over Different Thresholds



Notes: The figure displays the proportion of subjects who did not register to buy the cash amount over different thresholds. Specifically, we vary the threshold in order to observe its impact on the empirical distribution of a Poisson treatment when the fee is £9, the cash amount is £12.50 and the mean number of the Poisson distribution is 17. For the threshold levels of $13 - 15$, the theoretical prediction is that either all subjects will register to buy the cash amount or none of the subjects will register to buy the cash amount, whereas for the threshold levels of $16 - 18$, the theoretical prediction is that no subject will register to buy the cash amount.

we find that the distributions are marginally statistically similar (the p-value is 0.103). However, when comparing P169 and P149, and P169 and P139, we find that the distributions are statistically different (the p-values are 0.016 and 0.000, respectively). Thus, the further you move below the threshold the more pronounced the difference in subjects' behavior becomes. Furthermore, the empirical distribution of P169 is neither statistically different from that of P179 nor from that of P189 (the p-values are 0.907 and 0.378, respectively). These results are consistent with the theoretical prediction of Poisson Coordination games.

6 Robustness Analysis

Contrasting the behavior in Common Knowledge and Poisson games, we found that subjects' behavior across the two game types is statistically different (RESULT 1). This result implies that uncertainty regarding the number of actual players is an important determinant of inexperienced subjects' behavior. More specifically, in Common Knowledge games, we found that subjects split almost evenly between foregoing registering to buy the cash amount and registering to buy the cash amount. However, in Poisson games, subjects forewent to register to buy the cash amount. Crucially, such behavior is in fact consistent with the theoretical prediction of Poisson games (RESULT 4). Both results are important findings that deserve further scrutiny. We thus sought additional experimentation with smaller and larger sample sizes. Furthermore, we investigated the stability of the results with respect to the behavior of experienced subjects. The characteristics of the robustness sessions are displayed in Table 8. The experimental instructions of the robustness controls are also included in the Appendix.

Table 8: Characteristics of Robustness Sessions

Common Knowledge Games						
# of Subj.	# of Ses.	Mean	Threshold	Fee (£)	Amount (£)	Acronym
16	4	-	4	10	12.50	CK410
38	2	-	18	9	12.50	CK189
38	2	-	17	10	12.50	CK1710
34	2	-	16	9	12.50	CK169L
Poisson Games						
# of Subj.	# of Ses.	Mean	Threshold	Fee (£)	Amount (£)	Acronym
16	4	4	4	10	12.50	P410
48	2	19	18	9	12.50	P189
46	2	19	17	10	12.50	P1710
45	2	17	16	9	12.50	P169L

Notes: In the first column, we provide the total number of participants in each treatment. We conducted four sessions in the small sample treatments and two sessions in the large sample treatments in each game. We also conducted two sessions with experienced participants in each game type. The number of participants in the Common Knowledge sessions was common knowledge. Note that the number of participants in *each* session in the Common Knowledge treatments coincides with the mean n of the Poisson treatments. This was done to ensure comparability across the two game types. The acronyms consist of the game type (*CK* for Common Knowledge games and *P* for Poisson games), the threshold (4, 17, 18), the fee (9 or 10) and letter "L" for long-term play.

6.1 Small and Large Sample Sizes

First, we investigate subjects' behavior with a smaller sample size. We ran four sessions in Common Knowledge games and four sessions in Poisson games. In the Common Knowledge games, four subjects participated in each session. The choice of a setup with four subjects was motivated by the extensive literature in the Turnaround games (Brandts and Cooper (2006), Brandts, Cooper, and Fatas (2007), Brandts and Cooper (2007), Cooper, Ioannou, and Qi (2014)). Consequently, given the choice of $N = 4$, to ensure comparability between Common Knowledge and Poisson games, we set the mean of the Poisson distribution to $n = 4$. Moreover, in both game types, the threshold was set to $\alpha(Y) = 4$. This choice was made for two reasons. First, having a setup where the threshold exceeds the (expected) number of players is problematic because (a) such setup would invite experimenter effects, and (b) it would be dominant for subjects to not register in Common Knowledge games. Second, the only value for the threshold level that does not exceed the mean population and ensures equilibrium uniqueness in the Poisson games is in fact $\alpha(Y) = 4$ for the parameters specified (i.e. $n = 4, \frac{Y}{2} = £12.50,\ T \in \{9, 10\}$). Next, we experimented with a larger sample size. Our choice was to set $N = 19$ in the Common Knowledge games and $n = 19$ as the mean of the Poisson distribution in the Poisson games. For the larger group size, we decided to run two treatments in an analogous manner to the earlier treatments. The fee was set at either $T = £9$ or $T = £10$, which corresponds to a threshold number of registrations of 18 and 17, respectively. These choices ensured equilibrium uniqueness in Poisson games in a similar manner to our corresponding parameter choices under the smaller sample sizes.

Table 9 reports descriptive statistics on the raw experimental data of smaller and larger sample sizes. Similar to the earlier findings, the threshold was not met in any of the treatments; consequently, the cash amount was not awarded. Furthermore, in Common Knowledge games, the number of subjects is split between those choosing to register and those choosing not to register. Finally, in Poisson games, only 6 subjects out of the 110 that participated registered to buy the cash amount. The other 104 subjects forewent registering.

In Table 10, we present the robustness analysis for the smaller sample size. For the analysis, we utilize Fisher's exact test. Panel A calculates the p-value to determine whether subjects' decisions differ across Common Knowledge and Poisson games conditional on the same parameters. The H_0 states that behavior between the two game types is not statistically different. The p-value in the pairwise comparison is below the 2% level of statistical significance. Therefore, the H_0 is rejected. Furthermore, Panel B displays the p-value under the H_0 that the observed distribution in Poisson games and the distribution where all subjects choose to not register are statistically similar. The H_0 cannot be rejected (the p-value is 0.500).

Table 9: Descriptive Statistics of Smaller & Larger Sample Sizes

Common Knowledge Games					
	Registered		Not Registered		Amount
Acronym	Freq.	%	Freq.	%	Awarded?
CK410	7	43.8	9	56.3	No
CK189	16	42.1	22	57.9	No
CK1710	18	47.4	20	52.6	No
Poisson Games					
	Registered		Not Registered		Amount
Acronym	Freq.	%	Freq.	%	Awarded?
P410	1	6.3	15	93.8	No
P189	3	6.3	45	93.8	No
P1710	2	4.4	44	95.7	No

Notes: The table indicates the number of subjects who registered, and the number of those who did not register to buy the cash amount in each treatment. In addition, we provide the corresponding percentages. The total number of participants in each treatment is indicated in Table 8. The threshold was not met in any of the treatments. The acronyms consist of the game type (*CK* for Common Knowledge games and *P* for Poisson games), the threshold (4, 17, 18) and the fee (9 or 10).

Table 11 presents the robustness analysis for the larger sample size. In particular, Panel A tests whether subjects' decisions varied significantly across Common Knowledge and Poisson games when controlling for the parameter choices. We find that subjects' behavior differs significantly between the two game types. All the p-values in the pairwise comparisons are below the 1% level of statistical significance. To investigate the consistency of subjects' behavior in Poisson games with the respective theoretical prediction, the distribution of each Poisson treatment is compared to the predicted distribution. Panel B indicates the p-values of the treatments under the H_0 that the observed distribution in Poisson games and the distribution where all subjects choose to not register are statistically similar. The results present further evidence of such consistency. Finally, in Panel C, we take advantage of the large sample size to present the marginal effects. Treatment CK189 is set as the base. The standard errors are reported in parentheses. The coefficients are statistically significant in Poisson games. More specifically, the marginal effects imply an increase in probability of 35.9% in P189 and 37.8% in P1710 in not registering to buy the cash amount in the Poisson treatments, which is consistent with the previous findings.[17] Overall, the robustness analysis

[17] We also ran marginal effects with Treatment CK1710 set as the base. With the latter base, the marginal

Table 10: Robustness Analysis for Small Samples

Panel A	
Alternative hypothesis:	$decision_i \neq decision_j$
	p-value
Common Knowledge games vs Poisson games	
CK410 & P410	0.019
Panel B	
Alternative hypothesis:	$decision_i \neq 1$
	p-value
Poisson games	
P410	0.500

Notes: The decision of a subject in the game is a binary variable. The subjects who chose not to register to buy the cash amount were assigned a value of 1; otherwise, were assigned a value of 0. For the analysis, we utilize Fisher's exact test. Panel A calculates the p-value under the H_0 that behavior across Common Knowledge and Poisson games ($i \neq j$) is not statistically different conditional on the same parameters. Panel B indicates the p-value under the H_0 that the observed distribution in Poisson games and the distribution where all subjects choose to not register are statistically similar. The acronyms consist of the game type (*CK* for Common Knowledge games and *P* for Poisson games), the threshold (4) and the fee (10).

confirms that RESULT 1 and RESULT 4 are insensitive to smaller or larger sample sizes in Common Knowledge and Poisson games.

6.2 Experienced Subjects' Behavior

In real life, for many applications of Coordination games, there are ample (personal or social) learning opportunities. We know from the received literature (e.g. HNO and CNA) that experience can have a profound impact on behavior in Global games. Therefore, we study next the impact of experience on subjects' behavior in Common Knowledge and Poisson games. We ran two sessions in the Common Knowledge game with $N = 17$, and two sessions in the Poisson game with $n = 17$ as the mean of the Poisson distribution. The other two parameters were identical across the two informational protocols (i.e. $a(Y) = 16$ and $T = 9$). Crucially, in these sessions, we allowed for repeated play (denoted as CK169L and P169L in Table 8). Specifically, subjects were informed that the play would be repeated for 20 periods

effects imply an increase in probability in the Poisson treatments of 41.1% in P189 and 43.0% in P1710 in not registering to buy the cash amount. Both results are statistically significant at the 1% level.

Table 11: Robustness Analysis for Large Samples

Panel A	
Alternative hypothesis:	$decision_i \neq decision_j$
	p-values
Common Knowledge games vs Poisson games	
CK189 & P189	0.000
CK1710 & P1710	0.000
Panel B	
Alternative hypothesis:	$decision_i \neq 1$
	p-values
Poisson games	
P189	0.128
P1710	0.153
Panel C	
Dependent variable:	decision
Regressor	dy/dx
P189	0.359***
	(0.087)
P1710	0.378***
	(0.086)
Number of obs	132

Notes: The decision of a subject in the game is a binary variable. The subjects who chose not to register to buy the cash amount were assigned a value of 1; otherwise, were assigned a value of 0. In Panel A, we utilize the χ^2-test to determine whether subjects' decisions differ across Common Knowledge and Poisson games ($i \neq j$) conditional on the same parameters. In addition, Panel B indicates the p-values in the assumption that the observed distribution in Poisson games and the distribution where all subjects choose to not register are statistically similar. In Panel C, we report marginal effects after a probit regression on decision. Treatment CK189 is set as the base against which the estimated parameters are compared. dy/dx for factor levels is the discrete change from the base level. All standard errors are reported in parentheses. The acronyms consist of the game type (*CK* for Common Knowledge games and *P* for Poisson games, the threshold (17 or 18) and the fee (9 or 10). *** Significant at the 1% level.

and in each period there would be a new draw of the number of active players.[18] In addition, at the end of each period, subjects were provided feedback on the period's game play. The feedback consisted of (i) the active player's decision in the period, (ii) the number of active players in the period, (iii) the number of active players who chose to register to buy the

[18]This parallels the design of HNO in Global games where in every period there is a new draw of the economic fundamentals over which there is uncertainty.

cash amount, and (iv) the number of active players who chose not to register to buy the cash amount. To maintain consistency with the payments in the single shot experiments, we informed subjects that at the end of the experimental session, there would be a computer draw where one period (common to all participants in the session) would be selected for payment. Thus, a participant's payoff would be determined based on his/her decision in the drawn period.[19] [20] Considering the duration of the experiment (approximately 60 minutes) and the minimum wage in UK, we stipulated that no subject should get a compensation below £6. Therefore, we changed the initial endowment made to the subjects from £12 to £15. Otherwise, the design was analogous to the ones in the corresponding single shot experiments.

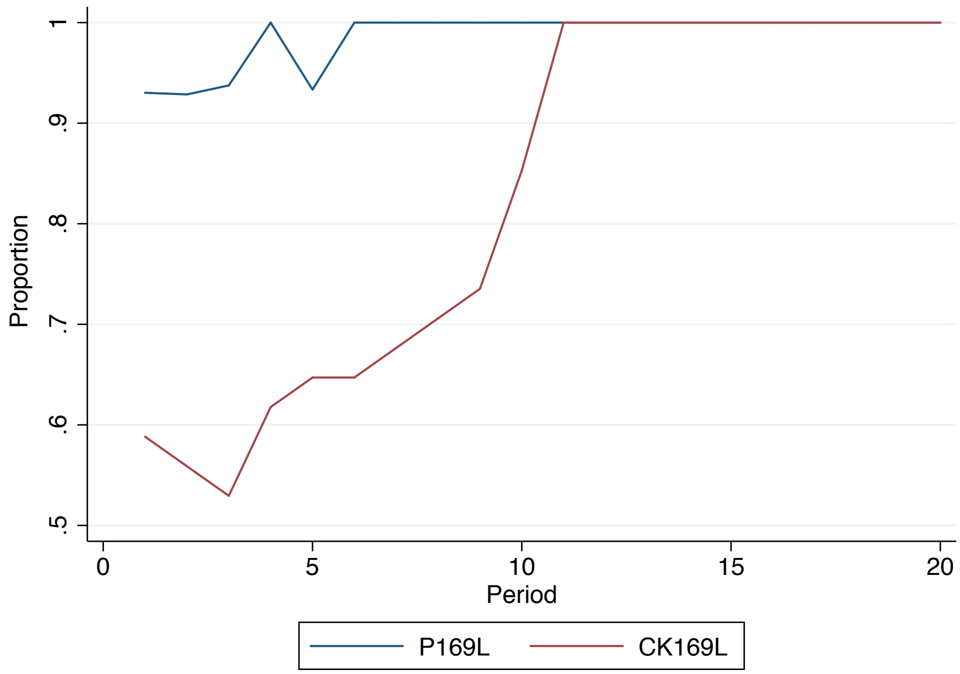
In Figure 3, we display the proportion of subjects who did not register to buy the cash amount over the 20-period span in the treatments with long-term play. Based on the earlier results in the single shot Poisson games (recall that 95% of the subjects chose not to register to buy the cash amount), we hypothesized that a very high percentage in the first period would be a significant deterrent to register in the next period (recall feedback is provided in each period) and so on and so forth. A proportion quite close to 1 is thus expected throughout the 20-period play. As shown in Figure 3, this prediction is confirmed. Through the first five periods in the Poisson games the proportion of active subjects that chose not to register is over 90%. From the sixth period onwards, all active players chose not to register to buy the cash amount. It is important to reiterate that such behavior is also consistent with the theoretical prediction of Poisson games. In Common Knowledge games, convergence to a proportion of 1 is slower. More specifically, only from the eleventh period onwards the proportion of subjects who chose not to register equals 1.[21] Before convergence, the proportion fluctuates between 0.53 and 0.85.

[19]Subjects in the Poisson experiments that were not selected to participate in the second stage of the experiment in the drawn period were paid their initial endowment.

[20]The underlying idea of the random lottery incentive scheme is that subjects make a number of decisions knowing that at the end of the experimental session one of these decisions will be selected for payment. There is a vast literature testing the validity of this payment scheme. Laury (2012) finds that subjects do not scale down decisions when they are only being paid for a subset of these decisions. In addition, Cubitt, Starmer, and Sugden (1998) find no evidence that such design contaminates elicited preferences. Hey and Lee (2005) show that subjects separate the various questions and respond to each question individually and in isolation from the rest; thus, incentives are retained. A value added of this approach is that it neutralizes the income effect that would otherwise be experienced as subjects progress through the periods.

[21]This finding is in line with earlier results documented in Brandts and Cooper (2006), Brandts, Cooper, and Fatas (2007), Brandts and Cooper (2007), and Cooper, Ioannou, and Qi (2014)) where subjects converge to the safe action after sufficiently many periods of repeated interaction.

Figure 3: Experienced Subjects' Behavior



Notes: The figure displays the proportion of subjects who did not register to buy the cash amount over the 20-period span in the treatments with long-term play. The acronyms consist of the game type (*CK* for Common Knowledge games, and *P* for Poisson games), the threshold (16), the fee (9), and letter "L" for long-term play.

7 Concluding Remarks

We study experimentally uncertainty in Coordination games while focusing on the behavior of players in single shot games. Specifically, we design an experiment to study the behavior of subjects in Poisson, Common Knowledge and Global Coordination games. Our study is the first to investigate experimentally Poisson Coordination games. Contrasting the behavior in Common Knowledge and Poisson Coordination games, we find that subjects' behavior across the games is statistically different (RESULT 1). More specifically, in Poisson games, subjects forego to register to buy the cash amount, whereas in Common Knowledge games, subjects split almost evenly between foregoing registering to buy the cash amount and registering to buy the cash amount. This result implies that uncertainty regarding the number of actual players is an important determinant of inexperienced subjects' behavior. Similar to Common Knowledge games, in Global games, subjects also split almost evenly between foregoing registering to buy the cash amount and registering to buy the cash amount. Statistical analysis confirms that subjects' behavior differs significantly between Poisson and Global games (RESULT 2). A possible explanation for the difference in subjects' behavior between Poisson and Global games could be the particular informational structure inherent in the Poisson games, which may have led subjects to fear that 'not enough' subjects are active to make it worthwhile to register to buy the cash amount. Furthermore, our third result, corroborates existing experimental results, which suggest that idiosyncratic uncertainty about economic fundamentals does not drive inexperienced subjects' behavior. More specifically, subjects' behavior does not differ significantly when comparing Global and Common Knowledge games (RESULT 3). A potential explanation could be that subjects have "homemade priors" about the other players' payoff type, which induce similar behavior in Global and Common Knowledge games.[22] However, testing the hypothesis of "homemade priors" in a systematic way is out of the scope of the current study, and is thus deferred for future research.

Crucially, we find that subjects' behavior in Poisson Coordination games is indeed consistent with the theoretical prediction (RESULT 4). In particular, if potential players perceive that the number of actual players is a Poisson random variable, theory predicts behavior well in online experiments that attempt to capture "large" games between players. In terms of policy implications, our findings encourage, in the case of speculative attacks, the imposition of a Tobin tax along with increasing the size of the markets as a means to reduce the prior probability of an attack by debt or currency speculators. Furthermore, we find that subjects' behavior differs from the prediction of Global games (RESULT 5). We highlight the difference in the results of this study with the results of HNO. A plausible explanation for the difference can be attributed to learning effects. Learning and/or repeated game effects are absent from the single shot experiments conducted here. However, our results confirm the findings of CNA, who point out that the theoretical results of Carlsson and van Damme (1993) do not hold in situations where players are inexperienced, and in some cases may even not hold after a relatively lengthy interaction (p. 232). Finally, subjects' behavior in Common Knowledge games differs from the theoretical equilibrium prediction of multiplicity (RESULT 6).

The two major results (RESULT 1 and RESULT 4) drove us to conduct further experiments in Common Knowledge and Poisson games with smaller and larger sample sizes to investigate whether these results hold under such sample sizes as well. Additionally, we con-

[22]Homemade priors refer to subjects' personal beliefs on other players' payoff type(s) that are not induced by the experimenter. The notion of "homemade priors" was introduced by Camerer and Weigelt (1988) to explain deviations from sequential equilibrium predictions in a reputation formation game. We thank David K. Levine for bringing to our attention the literature on homemade priors.

ducted experiments to investigate their stability with respect to the behavior of experienced subjects. Strikingly, all robustness checks confirm that the two results are insensitive to smaller and larger sample sizes and also hold in setups with long-term play.

An important avenue for future research could be the provision of a unified theory of explaining behavior across various treatments. Such fruitful attempts have been undertaken by Heinemann, Nagel, and Ockenfels (2009), and Kneeland (2012). The former study estimates various parameters of a Global game and shows that the estimated model performs well on that front. The latter study utilizes the experimental dataset of HNO to calibrate a model that rests on the limited-depth-of-reasoning solution concept. However, neither study incorporates Poisson treatments. Finally, an engaging future direction could be the investigation of whether our results on Poisson Coordination games carry over to other important contexts, such as Voting games (Bouton and Castanheira (2012)) and Discrete Public Goods games (Makris (2009)).

References

Bouton, Laurent, and Micael Castanheira. "One Person, Many Votes: Divided Majority and Information Aggregation." *Econometrica* 80: (2012) 43–87.

Brandts, Jordi, and David J. Cooper. "A Change Would Do You Good: An Experimental Study on How to Overcome Coordination Failure in Organizations." *American Economic Review* 96: (2006) 669–93.

———. "It's What You Say, Not What You Pay: An Experimental Study of Manager-Employee Relationships in Overcoming Coordination Failure." *Journal of the European Economic Association* 5, 6: (2007) 1223–68.

Brandts, Jordi, David J. Cooper, and Enrique Fatas. "Leadership and Overcoming Coordination Failure with Asymmetric Costs." *Experimental Economics* 10, 3: (2007) 269–84.

Burdzy, Krzysztof, David M. Frankel, and Ady Pauzner. "Fast Equilibrium Selection by Rational Players Living in a Changing World." *Econometrica* 69: (2001) 163–89.

Cabrales, Antonio, Rosemarie Nagel, and Roc Armenter. "Equilibrium Selection Through Incomplete Information in Coordination Games: An Experimental Study." *Experimental Economics* 10: (2007) 221–34.

Camerer, Colin F., and Keith Weigelt. "Experimental Tests of a Sequential Equilibrium Reputation Model." *Econometrica* 56, 1: (1988) 1–36.

Carlsson, Hans, and Eric van Damme. "Global Games and Equilibrium Selection." *Econometrica* 61, 5: (1993) 989–1031.

Cooper, David J., Christos A. Ioannou, and Shi Qi. "Coordination with Endogenous Contracts: Incentives, Selection, and Strategic Anticipation.", 2014. Mimeo.

Cubitt, Robin P., Chris Starmer, and Robert Sugden. "On the Validity of the Random Lottery Incentive System." *Experimental Economics* 1, 2: (1998) 115–31.

Frankel, David M., and Ady Pauzner. "Resolving Indeterminacy in Dynamic Settings: The Role of Shocks." *Quarterly Journal of Economics* 115: (2000) 285–304.

Heinemann, Frank. "Unique Equilibrium in a Model of Self-Fulfilling Currency Attacks: Comment." *American Economic Review* 90, 1: (2000) 316–8.

Heinemann, Frank, and Gerhard Illing. "Speculative Attacks: Unique Sunspot Equilibrium and Transparency." *Journal of International Economics* 58: (2002) 429–50.

Heinemann, Frank, Rosemarie Nagel, and Peter Ockenfels. "The Theory of Global Games on Test: Experimental Analysis of Coordination Games with Public and Private Information." *Econometrica* 72, 5: (2004) 1583–99.

———. "Measuring Strategic Uncertainty in Coordination Games." *Review of Economic Studies* 76: (2009) 181–221.

Herrendorf, Berthold, Akos Valentinyi, and Robert Waldman. "Ruling Out Multiplicity and Indeterminacy." *Review of Economic Studies* 67: (2000) 295–308.

Hey, John D., and Jinkwon Lee. "Do Subjects Separate (or Are They Sophisticated)?" *Experimental Economics* 8, 3: (2005) 233–65.

Kajii, Atsushi, and Stephen Morris. "The Robustness of Equilibria to Incomplete Information." *Econometrica* 65: (1997) 1283–309.

Kneeland, Terri. "Coordination Under Limited Depth of Reasoning.", 2012. Mimeo.

Laury, Susan K. "Pay One or Pay All: Random Selection of One Choice for Payment.", 2012. Mimeo.

Makris, Miltiadis. "Complementarities and Macroeconomics: Poisson Games." *Games and Economic Behavior* 62: (2008) 180–9.

———. "Private Provision of Discrete Public Goods." *Games and Economic Behavior* 67: (2009) 292–9.

Morris, Stephen, Rafael Rob, and Hyun Song Shin. "p-Dominance and Belief Potential." *Econometrica* 63: (1995) 145–57.

Morris, Stephen, and Hyun Song Shin. "Unique Equilibrium in a Model of Self-Fulfilling Currency Attacks." *American Economic Review* 88, 3: (1998) 587–97.

———. "Global Games: Theory and Applications." In *Proceedings of the 8th World Congress of the Econometric Society*, edited by M. Dewatripont, L. Hansen, and S. Turnovsky. Cambridge University Press, 2003.

Myerson, Roger. "Population Uncertainty and Poisson Games." *Journal of International Game Theory* 27: (1998) 375–92.

———. "Large Poisson Games." *Journal of Economic Theory* 94: (2000) 7–45.

Ostling, Robert, Joseph Taoyi Wang, Eileen Chou, and Colin F. Camerer. "Field and Lab Convergence in Poisson LUPI Games." *American Economic Journal: Microeconomics* 3, 3: (2011) 1–33.