Experimental Evidence on the Use of Information in Beauty-Contest Game

Zahra Gambarova

University of Leicester

March 13, 2018

Abstract. This paper tests the predictions of the Keynesian beauty contest game with private information. Players have two objectives in K-beauty contest game, to be as close as possible to the fundamental and, at the same time, to coordinate (anti-coordinate) with other players. We test in laboratory how subjects divide attention between public and private information when choosing an action under different strategic environments. We find that, when subjects want to coordinate they reduce weight put on private information, which is consistent with the results of previous experiments. We also test the theory in the anti-coordination domain, and fail to find increase of the weights on private information. Even though, subjects do not learn to play best-response strategy in anti-coordination game, under both environments they react to the correlation in private signals according to theoretical predictions.

1. Introduction

This paper tests the social value of information in the economic environment requiring its participants to coordinate on some objective. We ask subjects to play Keynesian beauty contest game where they are provided with a common prior over the underlying state and additionally, a completely private of correlated private signal. After the signals realised, subjects are asked to choose an action based on the information available to them. The aim of the experiment is to understand how subjects in the lab use information under different strategic environments, and how they internalize correlation in their signals.

We find that, subjects in the lab assign equal weight on the common and private information with similar precisions when the task is to guess the fundamental state. When the task is to be closer to their partner at the same time, they reduce the weight on the private information in consistent with theory. However, subjects in the lab do not increase the weight on private information when the task is to avoid the partner. The reaction to the correlation in their signals is consistent with the theory, the weights are increased in coordination, and decreased in anti-coordination domain, relative to the independent signals.

Most of the daily life activities require people to coordinate on some common objective. In some situations subjects get utility not only from hitting the objective, but also being able to coordinate with others. These situations are represented in beauty-contest games. The terminology ”Beauty contest” comes from the parable introduced by Keynes (1936). The reader of the newspaper should choose the prettiest faces among the introduced photos, but at the same time they need to guess the most popular answer given by others. In our design the game is captured by a linear quadratic pay-off function. Players need to guess the unobserved state of the world, at the same time to be as close as possible (or as far as possible) to other participants.

There are two forms of uncertainty in this game: to guess the state correctly (fundamental motive) and to predict the behaviour of others (coordination motive). When they face uncertainty about the objective and others’ belief about it, the success of their action depends on the use of information they receive. In Morris and Shin (2002) players are given information about state in the form of noisy signals. Signal observed by each player alone is private and used to guess the state. Signal observed by everyone is public and used to make believes about the state and what others know about it at the same time.

When the objective is to predict the fundamental both private and public information play the same role, therefore they attract the same weight at this stage. To guess the average action, or for coordination motive, players put more weight on public signal than private. When players want to be close to other players they want to know what others know, hence, they value public signal over private. The importance of each motive depends upon the application or the preferences.

This is one of the recently evolving topics in microeconomic theory and has found broad application in fields, such as, oligopolistic competition, frictions in financial markets, central bank communication, and many others. The model is applied to illustrate the effect of available information in financial crises, political economy, competition in the market affects outcomes of each participant and overall welfare of the society. Morris and Shin (2002) shows in the model of beauty contest with endogenously given private and public signal that in equilibrium players overuse the public signal. It causes concerns about the social value of public signal, as, noisy public signal can harm social welfare when overused.

As existing theories on the topic have a potential of being applied in a variety of economic situations it is useful to test their predictions in the controlled lab environment. This experiment design allows to find weakness and strength, and suggest the areas where the theory can be applied with success in policy decisions. Our goal is to test the value of public signal in the controlled lab environment in the beauty-contest game. Subjects are given common and private information and asked to assign importance on each when their actions are not related, strategic complements or substitutes. Another goal is to test how subjects in the lab internalize the correlation in their private signals under different strategic situations.

Our experiment is based on the model of beauty contest game with private and public information as in Morris and Shin (2002); Myatt and Wallace (2014). Myatt and Wallace (2014) is a model with correlated signals which contains Morris and Shin (2002) as a special case. Subjects in this model decide how much they value each information. They can choose an action which is the linear combination of two piece of information they have. The weight put on signals depends on the relative importance of fundamental and coordination (anti-coordination) motives. As it turns out, in the Morris and Shin (2002) environment, subjects tend to ignore independent private information as the coordination motive increases, and hence weight on public information increases. Once the private information become correlated in Myatt and Wallace (2014), this result weakens. Hence, the correlation in the private signals can reduce the overuse of public signals. With anti-coordination motive, weights on independent private information increases, but correlated private information attracts less weight in comparison.

Related literature. This paper is related to several strands of literature on lab experiments. In the first place, its a contribution to the previous tests of beauty contest game with exogenously given information. Second, we test how subjects react to the correlation in their signals. And the last, we contribute to the discussion of the difference in ability of learning to play equilibrium between the games of strategic substitutes and complements.

Cornand and Heinemann (2014) test the hypothesis that, subjects attach larger weight to public than to private information if they have incentive to coordinate their actions in the lab. They find that, indeed, subjects assign larger weight to public information as coordination motive increases, but the effect is smaller than equilibrium predictions. They lean towards coordinating on the public signal, but do not achieve full coordination during the course of the session. Similar results obtained by Dale and Morgan (2012), low quality public signal decreases social welfare, but less than predicted by theory.

After confirming that the weight on public information increases with coordination motive, next Baeriswyl and Cornand (2016) test how response to public disclosure depends on the the signal precisions. Consistent with the first experiment, the weight assigned to the public information tends to increase in coordination motive as predicted by theory. Regarding to the precision of the signals, when subjects form expectations, they assign more weight on more precise signal.

My, Cornand, and dos Santos Ferreira (2017) proposes the theory of endogenous coordination motive and tests the reverse hypothesis that, the higher the precision of the public signal, the higher the weight on the coordination motive will be. The results are consistent with the theory when fundamental uncertainty is larger than coordination uncertainty, players tend to put more weight on coordination motive. However, the reverse does not hold, as players again put more weight on coordination motive even when coordination uncertainty is bigger. In line with predictions of theory, higher average weight on the coordination motive implies a larger weight on the public signal.

This paper is an attempt to take the test further with better controlled environment. Existing theory provides unique predictions given the normality of the distribution and the linearity of the strategies used by players. The previous experiments on beauty-contest game used signals from uniform distribution. In our design all signals are taken from normal distribution. Furthermore, instead of estimation, we induce the linear strategies which gives another control to have precise estimation of the weights assigned to each signal. Additionally, we test the behaviour in Keynesian beauty contest game when actions are strategic complements, as well as, substitutes.

An important application of the beauty contest game is a firm choosing actions when his profit depends on the unobserved demand, his price and price set by other firms competing in the industry. The action of firms competing on price as in Bertrand competition are strategic complements, as firms are willing to to set high price, but also they want to do it together (Myatt and Wallace, 2015). Cournout competition is the game of strategic substitutes, as firms competing on quantities are willing to produce more given the other firm produces less (Myatt and Wallace, 2016). Previous experiments on the value of information concentrates on the game of complements only. According to Fehr and Tyran (2008) and others agents learn to play equilibrium faster in the game of strategic substitutability, than in complementarity. Taking into account the striking difference between the two games and the importance of substitutes games on its own, we think it is important to analyse the predictions of the model in the anti-coordination dimension as well.

This paper also contributes to the literature on bidding with private and common value uncertainty. Our information environment is closer to the Goeree and Offerman (2003) and Vives, Bayona, and Brandts (2016), who show that subjects fail to internalise the correlation in their values while bidding. Our structure is different, as in our model the state is always common, but private signals are either independent or correlated. At the same time our strategic environment is more simple, unlike in the previous models, the number of participants and risk attitude do not affect the strategies. These allow us to test the internalization of the correlation in a better controlled environment.

The paper is organized as follows. The theoretical background for the model followed by the predictions to test are described in the section two. Section three describes the experiment and parameters chosen for the model to be tested. The results from the experiment are introduces in section four and summarised in the conclusion section.

2. THEORETICAL BACKGROUND

The model of interest is a quadratic pay-off ”beauty contest” game, where players' objective is to be close to some unobserved underlying state variable and to the average action taken by all other players (Myatt and Wallace, 2014). It is an L players simultaneous move game consisting of the three steps.

(1) Nature draws unobservable state $\theta \in R$ from uniform distribution over the range $(-\infty, +\infty)$.
(2) A player faces a vector of information choice $x_l \in R_+^n$ consisting of n different information sources. Given each source $j \in \{1, ..., n\}$ the observations of different players are correlated. After the signals are observed, players use signals to form beliefs about some state θ, and the average action taken by others.
(3) Finally, players take an action $a_l \in R$ and receives a payoff u_l.

The payoff for a player l depends on the proximity of his action a_l to the state variable θ, and to the average action taken by others $\bar{a}$. The following utility function combines these preferences adopting quadratic-loss specification

$$u_l = \bar{u} - (1-\gamma)(a_l - \theta)^2 + \gamma(a_l - \bar{a})^2. \tag{1}$$

The parameter $\gamma \in (-1;1)$ determines the preference for matching with others relative to being closer to the true state. If $\gamma = 0$, the only objective is to guess the true state θ. If $\gamma = 1$, it becomes pure coordination game, where the only motive is to match with other players, and θ becomes irrelevant. For other values of γ both fundamental and coordination motives are present. The sign of γ also effects the nature of the game. For $\gamma \in (0;1)$ it is the game of strategic complementaries, where matching others is payoff increasing. For the $\gamma \in (-1;0)$ incentive is to take the action different from others, which is the game of strategic substitutes.

All agents share the common value over the state θ. θ is assumed to be from improper prior. The assumption of improper prior simplifies the results and can be avoided by making one of n signals perfectly correlated for everyone. The information source i, observed by player l has the following structure

$$x_{il} = \theta + \eta_i + \varepsilon_{il}, \quad \text{where} \quad \eta_i \sim N(0, \kappa_i^2) \quad \text{and} \quad \varepsilon_{il} \sim N(0, \xi_i^2). \tag{2}$$

Each signal $\bar{x}_i = \theta + \eta_i$ comes with some "sender" noise η_i, which defines the quality or accuracy of the information source, and indexed by $\frac{1}{\kappa_i^2}$. On the top of the sender noise, players add some "receiver" noise ε_{il} when accepting the signal $x_i = \bar{x} + \varepsilon_{il}$. The receiver noise reflects the clarity of observation and indexed by $\frac{1}{\xi_i^2}$. Each signal is distributed normally $x_{il} \sim N(\theta, \sigma_{il}^2)$, where $\sigma_{il}^2 = \kappa_i^2 + \xi_i^2$. Conditional on θ signals are independent across n information sources. But observation of each source is correlated across players; $cov[x_{il}, x_{il'}|\theta] = \rho_{ill'}\sigma_{il}\sigma il'$, for two players l and $l' \neq l$, and the correlation coefficient ρ_{il} . The nature of publicity of the signal sources is determined by ρ_{il}

$$\rho_{il} = \kappa_i^2 \Big[(\kappa_i^2 + \xi_i^2)(\kappa_i^2 + \xi_i^2) \Big]^{-\frac{1}{2}}. \tag{3}$$

The case $\rho_i = 0$, means signals are not correlated, or purely private, and obtained by setting $\kappa_i^2 = 0$. When $\rho_i = 1$ signals are common , or perfectly public, and this case is obtained by setting $\xi_i^2 = 0$.

The player's strategy is the choice of action $A_l(\cdot)$ taken in response to the realized signal x_l. The best-reply action of player l is found from the differentiation of the quadratic objective function is

$$A_l(x_l) = (1-\gamma)E[\theta|x_l] + \gamma E[A_l(x_l')|x_l]. \quad (4)$$

Best-reply action is a linear combination of two expectations. Given normality assumption, $E[\theta|x_l]$ is linear as well, which means the $E[A_l(x_l')|x_l]$ is also a linear function, hence, there is a unique linear equilibrium. Taking into account the complexity of the problem, at first the linear strategy is guessed and expected utility is calculated. The strategy $A_l(x_l) = \sum_{i=1}^{n} \omega_{il} x_{il}$ is linear in signals received, if there are weights $\omega_l \in R^n$ such that $\sum_{i=1}^{n} \omega_{il} = 1$. The expected utility of player l depends on the proximity to the unobservable state variable θ, and to the action chosen by another players $\bar{a} = \frac{\sum_{l' \neq l} a_l}{L-1}$.

Maximizing (1) is the same problem as minimizing the losses:

$$min(1-\gamma)(a_l - \theta)^2 + \gamma(a_l - \bar{a})^2 \quad (5)$$

Taking expectation of (5), and denoting $\widehat{\psi}_i = \frac{1}{(1-\gamma)\kappa_i^2 + \xi_i^2}$, the influence of signals is found from the first order condition with respect to $\omega_i > 0$, the problem becomes:

$$\min \sum_{i=1}^{n} \frac{\omega_{il}^2}{\widehat{\psi}_i} + \gamma \sum_{i=1}^{n} \kappa_i^2 \left[\omega_{il} - \frac{\sum_{l' \neq l} \omega_{il'}}{L-1} \right]^2) \text{ subject to } \sum_{i=1}^{n} \omega_i = 1 \quad (6)$$

Optimal weights which solve the problem (6) are:

$$\omega_i = \frac{\widehat{\psi}_i}{\sum_{j=1}^{n} \widehat{\psi}_j}, \text{ where } \widehat{\psi}_i = \frac{1}{(1-\gamma)\kappa_i^2 + \xi_i^2} \quad (7)$$

From (7) influence of the signals is increasing in their accuracy and clarity. The reason behind this result is clear, when signals become noisy they attract lower weight in equilibrium. The effect of γ on w depends on the nature of the signal. γ influences w through common noise κ_i^2 in signals. When γ increases influence the signal attract increases whenever $\kappa_i^2 \neq 0$. Hence, as coordination motive increases weight on private information decreases compared to the public information.

As we have clear predictions under the assumption of rationality and ex-ante symmetry of players, the comparative statics can be tested in an experiment. With two

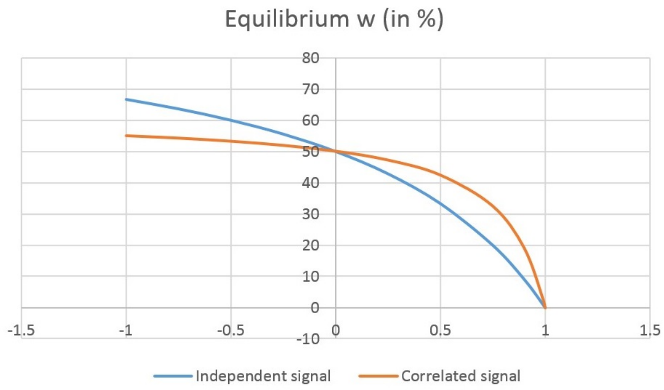

FIGURE 1. Equilibrium weights (in $\%$)

type of information, let's assign weight w to private and $1 - w$ to public information. Figure 1 shows how w changes in γ, given the precisions of public and private information is similar. We are going to test the following hypotheses:

H1**:** The first hypothesis is, given precisions are similar, when the strategic motive is absent, subjects put equal weight on public and private information.

H0: When $\gamma = 0 \implies \omega = 0.5$;
Ha: $\omega \neq 0.5$.

This hypothesis could not been rejected by the previous experiments on k-beauty contest game with a different design (Cornand and Heinemann, 2014). We will use this hypothesis as a benchmark to compare our results with the previous work. This is also benchmark for the next hypotheses testing.

H2**:** The second hypothesis is, weight on private information changes with strategic motives. According to the theory, as coordination motive increases, players assign lower on private information. In contrast, the weight on private information increases when anti-coordination motive increases.

H0: As γ increases, w decreases.
Ha: As γ increases, w does not decrease.

According to Fehr and Tyran (2008) players are better in playing equilibrium in the game of strategic substitutes, than complements. The possible reasons are the difficulty of optimization in coordination games, and the cost of mistakes. They divide players into the high types, who are rational, and low types, who can not optimize their strategies. In the game of complements rational players want to mimic low types, therefore, there is a deviation from equilibrium. However, in the games of substitutes it is optimal to respond to the low types taking optimal actions. Cornand and Heinemann (2014) find an evidence supporting this hypothesis in the domain of coordination. They showed that the weight on private information decreases with coordination motive, but less than predicted by theory. The previous experiments ignored the game of substitutes, concentrating in the game complements only. We are going to test if subjects manage to play equilibrium in both domains.

H3**:** The last hypothesis is, players can internalize the correlation in their signals. According to theory, in the coordination domain the weights on correlated private signals decreases less, and in the anti-coordination domain increases less than the weights on independent private signals.

H0: As γ increases, the rate by which w decreases is lower with $\rho > 0$, than $\rho = 0$.
Ha: the rate by which w decreases is not lower with $\rho > 0$, than $\rho = 0$.

This hypothesis was tested mainly by the literature on bidding in auctions, and recently, by Vives, Bayona, and Brandts (2016) testing how sellers submit supply function in the oligopoly competition when their cost is correlated. The previous literature fails to find support for this hypothesis due to the complex nature of their environment. We aim to test the reaction to the correlation in signals under simple and better controlled environment.

3. Experimental Design

To test the theory we assign specific values to the parameters of the model. Subjects are paired in groups of two players, $L \in \{1, 2\}$, and play beauty-contest game. This simplification do not affect the qualitative predictions of the model with l players, instead helps to simplify the environment to achieve better controlled results.

At each period fundamental is chosen randomly from $N(100, 10)$. This prior is a common information, everybody knows the distribution, but no one knows the exact value of the fundamental. Each player also receives a private information with some error drawn from $N(0, 10)$. Each period, subjects observe the value of public and private information and decide how much weight to assign to each of them (w is the weight on private, $1 - w$ on the public information), depending on the strategic motive they face.

There are two variables which changes across all treatments: $\{\gamma, \rho\}$ (See Table 1). In the baseline treatment $(T0)$, there does not exist any strategic motive $\gamma = 0$ and subjects receive independent private information $\rho = 0$ about the fundamental. Keeping $\rho = 0$, coordination with independent information is introduced $(T1)$ by setting $\gamma = 0.9$, and anti-coordination $(T2)$ by $\gamma = -1$. For each motive we introduce treatment with correlated private information by setting $\rho = 0.6$ We choose correlation level same as Vives, Bayona, and Brandts (2016) to make predictions comparable.

TABLE 1. Treatments

	$\gamma = 0$	$\gamma = 0.9$	$\gamma = -1$
$\rho = 0$	$T0$	$T1$	$T2$
$\rho = 0.6$	$T3$	$T4$	$T5$

To test if subjects can form Bayesian beliefs in the simple environment $(H1)$, at first, we compare w from $T0$ and $T3$ to the equilibrium predictions. Given parameter values, in both treatments, subjects should assign $w = 50$ to the private information. This comparison also will serve as a benchmark for the next hypotheses testing.

For $H2$, to test the behaviour in coordination domain, we compare w from $T0$ and $T3$ to $T1$ and $T4$, and in anti-coordination domain we compare w from $T0$ and $T3$ to $T2$ and $T5$. Given there is no significant difference between $T0$ and $T3$, we expect weights to decrease from $T0$ and $T3$ to $T1$ to $T4$ and to increase from $T0$ and $T3$ to $T2$ and $T5$.

$H3$ is checked by comparing values of w from $T1$ and $T2$ to $T4$ and $T5$. Given there is no significant difference between $T0$ and $T3$, we expect weights to increase from $T1$ to $T4$ and to decrease from $T2$ to $T5$.

Theoretical predictions for the unique equilibrium values of w, in percentage, for each treatment, given parameter values assigned, are shown in the Table 2.

TABLE 2. Equilibrium weights

w	$\gamma = 0$	$\gamma = 0.9$	$\gamma = -1$
$\rho = 0$	50	9	67
$\rho = 0.6$	50	19	55

There are 4 sessions in total. Each session consist of three stages, each running for 10 rounds. In all sessions, subjects are asked to guess the fundamental in the stage 1. Tasks for the stages 2 and 3 are similar for each session, but changes across different sessions. The treatments in each session are described in the Table 3.

TABLE 3. Overview of the sessions

Sessions	Stage 1	Stage 2	Stage 3
1	$T0$	$T1$	$T1$
2	$T3$	$T4$	$T4$
3	$T0$	$T2$	$T2$
4	$T3$	$T5$	$T5$
Rounds	10	10	10

In stages 1 and 2 participants are paired with a computer always playing the optional strategy and asked to make a decision. This decision was made to observe the learning effect. Subjects in previous experiments (Cornand and Heinemann, 2014; Vives, Bayona, and Brandts, 2016), fail to play optimal strategies and moreover, they do not show nay pattern of learning. It is assumed that subjects best-response to the heterogeneous beliefs they hold about their partners. We assume, the explanation to their finding is the challenge of learning best-respond to the changing environment. In their environment subjects are facing a new partner each round and each partner is learning at the same time. We decided to control for beliefs by assigning the computer as a partner and check if subjects can learn to play best-response strategies. In stage 3 they are paired with another participant anonymously, and play the next 10 rounds as a team. Again, we wanted to avoid changing the environment by facing different players each round. The aim of this stage was to check if there is a change in best-responses and if teams can learn to play optimal strategies.

After each round participants are given information about the true state, other players action and their own payoffs. Feedback is introduced to induce the learning effect. After the experiment participants are asked to fill in the questionnaire about personal information and were paid in private.

4. EXPERIMENTAL RESULTS

The experiment was run at the EXEC laboratory at University of York. The participants were students from all various disciplines across the university. In the start of the session instructions were read aloud. Students were asked to answer comprehension questions before proceeding to the choice stage. Overall, 60 students participated in 4 sessions. Each session lasts for 90 minutes and subjects earned 11 pounds on average as a result of their choice. All sessions were run using experimental software z-tree (Fischbacher, 2007).

At first, we analyse the overall data, to test the hypotheses stated previously. In the next subsection, we look at the dynamics of the sessions to observe any learning patterns.

4.1. **Analysis of behaviour.** In this subsection we compare observed w across treatments to test the hyphoteses $1-3$. We also compare the average w from experiment to equilibrium prediction to find directions of deviations from theoretical predictions.

Result 1.1: For $\gamma = 0$, subjects put equal weights on private information and prior consistent with Bayesian equilibrium.

For the overall data, this hypothesis cannot be rejected using two-tailed Wilcoxon signed-rank test at a p-level of 46.6% and signtest at a p-level of 51.2% (See Table 4).

Result 1.2: For $\gamma = 0$, there is no significant difference among the weights attached to the private signals among all sessions.

Kruskal-Wallis test cannot reject the equality on weights among four sessions at a p-level of 0.32.

Result 1: when $\gamma = 0$ the weights assigned on private information is consistent with theory. There is no difference in weights among all treatments.

Overall, the results for $H1$ is consistent with the predictions of Cornand and Heinemann (2014). Subjects can form Bayesian beliefs under simple environment.

Result 2.1: For $\gamma = 0$, the weights attached to the private information between coordination and anti-coordination treatments are significantly different.

This result shows that strategic motives effected the process of belief formation when they were not present (See Table 5). Two-sided MW test rejects the equality of weights on private signals between coordination and anti-coordination treatments at a p-level of 7%. Sign test rejects the equality in favour of the alternative that weights in coordination treatment are smaller than anti-coordination weights at a p-level of 1.8%.

To check the reason behind the non equality, weights for each treatment were compared to the equilibrium predictions separately. Two-sided MW test rejects the equality of weights from anti-coordination treatment to equilibrium predictions at a p-level of 3.4%, whereas for coordination treatments the hypothesis cannot be rejected at a p-level of 37.6%. Hence, the reason of difference is the failure to play equilibrium in anti-coordination domain.

Result 2.2: In the coordination domain the weight on private information decreases. Still, it decreases less than predicted by equilibrium strategy.

To test if the weights adjust when coordination motive is introduced weights from coordination treatment are compared to the baseline. One-sided signtest rejects the equality of weights in favour of the alternative hypothesis that the weight on private information decreases in the coordination treatment relative to the baseline for both independent (at a p-level of 0%) and correlated information (at a p-level of 5.6%) sessions (See Table 7).

Even though subjects decrease weights in coordination domain, one-sided sign-test rejects the equality of weights to the equilibrium predictions in favour of the alternative that the weight on private information are higher than equilibrium at a p-level of 0% (See Table 4).

Result 2.3 In contrast with theory, the weight on private information does not increase with anti-coordination motive. Moreover, the weight assigned to private information is significantly different from the weight predicted by equilibrium strategy.

Two-sided signtest cannot reject the equality of weights between baseline and anti-coordination treatments at a p-level of 12.1% for independent, and 33.1% for correlated signal treatments (See Table 7). Hence subjects do not adjust the weight in anti-coordination domain accordingly. This is also related to the previous finding that, they do not play equilibrium strategy in the baseline treatment.

One-sided signtest rejects the equality of weights to the equilibrium predictions in favour of the alternative hypothesis that subjects assign lower weights than predicted at a p-level of 1.1% for independent and 9% for correlated information treatments (See Table 4)).

From the results, subjects assign higher weights on signals in baseline treatment, and lower weights in anti-coordination treatment, than predicted by theory. Hence, we could not identify difference in the weights between two treatments.

Result 2: Equilibrium behaviour is violated when strategic are motives present. Subjects decreased the weight in the domain of coordination, but fail to increase in the domain of anti-coordination.

Overall, the behaviour in the coordination domain is consistent with the results of Cornand and Heinemann (2014). Subjects decreased weight on private information, but do not play equilibrium. The behaviour in the anti-coordination treatment has never been tested before, hence we cannot compare the results directly to any previous test.

Result 3.1: For $\gamma = 0$, there is no significant difference between the weights attached to the independent and correlated private signals.

To be able to compare the effect of correlation in information, as a control test, the equality of weights between independent and correlated information, for the baseline treatments could not be rejected using two-sided MW test at a p-level of 71.1%. Moreover, the equality is not rejected for both coordination and anti-coordination domains separately as well (See Table 6).

Result 3.2: For $\gamma = 0.9$, the weight attached on independent signals is higher than weight on correlated signals as predicted by theory.

Two-sided Mann-Whitney rank-sum test rejects the equality of weights between independent and correlated information in coordination treatment at a p-level of 1%. Kolmogorov-Smirnov test also rejects the equality in favour of the alternative hypothesis that the weights are higher in correlated treatment at a p-level of 2.7% (See Table 6).

Result 3.3: For $\gamma = -1$, the weights attached on independent signals are smaller than weights on correlated signals as predicted by theory.

Two-sided Mann-Whitney rank-sum test rejects the equality on weights between independent and correlated information in anti-coordination treatment at a p-level of 2%. Kolmogorov-Smirnov test also rejects the equality in favour of the alternative hypothesis that weights are lower in correlated treatment at a p-level of 0.9% (See Table 6).

Result 3: Subjects react to correlation in their signals as predicted by theory. On coordination domain the correlated signals get the higher, on anti-coordination domain the lower weight than independent signals.

Result 3 contradicts to the findings of Vives, Bayona, and Brandts (2016) and other literature failing to find adjustments in actions when signals are correlated. Even though, subjects fail to adjust weight in anti-coordination game, they always manage to internalize the correlation in private information. We assume the reason for the different result is the environment the hypothesis was tested. In Vives, Bayona, and Brandts (2016) subjects need to response to the correlation in their signals, as well as, to the strategic motive of their game (competing in the oligopolistic market). In our case the number of people in the team do not affect their decision, as it do not change the strategic environment. Hence, we manage to observe clear effect of correlation.

4.2. **Learning.** To further test if subjects learn to play optimal strategy we look at time trends of their choice data. We took the average of weights per 5 rounds for each person. By comparing first and second half of the treatment we try to find if there is any change in the responses. For this purposes, the data is aggregated to coordination and anti-coordination games and each tested separately.

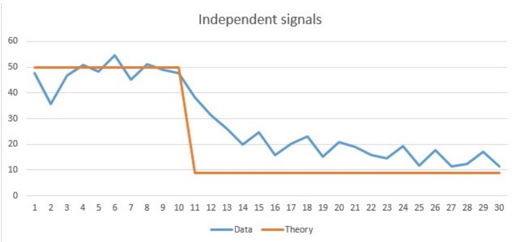

FIGURE 2. w from $T0$ and $T1$

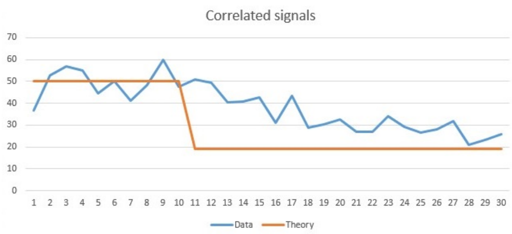

FIGURE 3. w from $T3$ and $T4$

Result 4.1: On the coordination domain, subjects internalize the correlation in the their information by adjusting the weights downwards. However, it takes time to adjust their choice to the optimal predictions, which happens only by the end of the session.

The dynamics of w in coordination treatment are shown in Figure 2 and 3. In baseline treatment of coordination game two-sided ranksum test cannot reject the equality of weights. It also cannot reject equality of weights to the equilibrium strategy. In the first part of the second treatment their weight is significantly adjusted downwards in comparison to the previous treatment. In the second half of the treatment, weights decreases further, which shows that subject learn to play optimal strategy in coordination game. Even though weights are still higher than equilibrium prediction, in the second half of the third treatment two-sided signrank test cannot reject the equality of weights to equilibrium prediction. According to results, it looks like when the game played repeatedly subjects learn to play optimal strategy. Furthermore, they learn faster when the opponent is computer which plays the optimal strategy all the time. In the treatment with a partner learning slows down, but it still does not stop. (See Tables 8 and 9)

Result 4.2: On the anti-coordination domain, subjects cannot internalize the correlation in their information. They manage to adjust their choice to the optimal predictions by the end of the session, however there is no clear sign of learning.

The dynamics of w in coordination treatment are shown in Figure 4 and 5. In anti coordination sessions, the first half of the baseline treatment weights are significantly higher than optimal. In the second half, weights adjusted downwards, and the equality to optimal strategy cannot be rejected by two-sided signrank test. Once the anti coordination motive is introduced, subjects do not exert any statistically significant sign of learning. The weights on private information are significantly different from equilibrium predictions in the computer treatment. In the third treatment, two-sided ranksum test cannot the reject the equality to equilibrium. (See Tables 10 and 11)

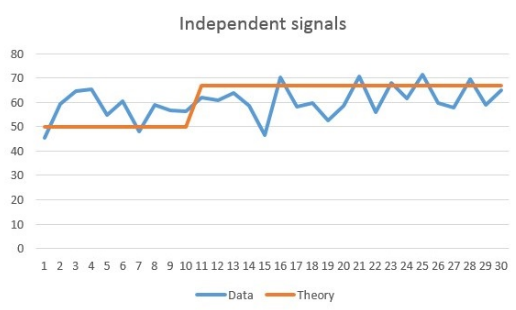

FIGURE 4. w from $T0$ and $T2$

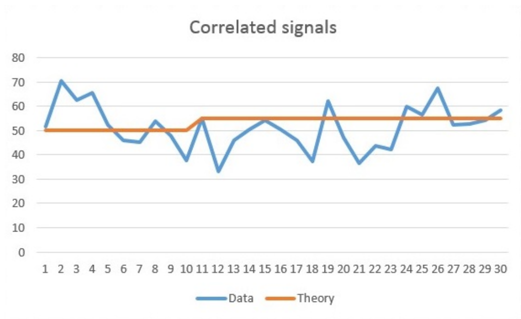

FIGURE 5. w from $T3$ and $T5$

Result 4: Subject learn to play equilibrium in the coordination games, however, they fail to demonstrate clear sign of learning in anti-coordination games.

The data shows that subjects demonstrate clear patterns of learning in coordination game, but fail to do so in anti-coordination game. This result contradicts to the previous similar experiments, where subjects did not learn to play best-response. We believe, leaving the partner stable across the rounds creates better environment for learning. Even when faced with real partners, subjects continue to learn and play the optimal strategy in the last rounds.

Our findings also contradict to Fehr and Tyran (2008) who observed better learning in the games of strategic substitutes. The results are directly comparably, as the underlying games are different. However, this means, their results were specific to the game chosen. Another possible reason for our results is the choice of parameters. In the coordination game, difference in optimal weights between baseline and coordination treatments is relatively larger, than anti-coordination treatment. It is possible that the subjects fail to internalize anti-coordination motive. In the last question of questionnaire, most of them state that, private information do not help them to understand what their partner is doing, hence they assign more importance in public information.

5. Conclusion

According to theory, to form beliefs about the fundamental, it is optimal to put more importance to the precise information. However, when decision makers also interested in the actions of others, they overreact to public information. Because of its dual nature, it conveys information about the fundamental, and at the same time, about the beliefs of others. Overreaction to low quality public information can reduce the welfare of society by causing bubbles and financial crises. Central bank and other government bodies disclosing important information related to public policy should optimize their announcements. Hence, it is essential to understand how individuals perceive the difference in the nature and publicity of information they hold and how they react to those differences.

We find that, even though, overall subjects manage to assign the optimal weight on signals in baseline treatment, equilibrium behaviour is violated when strategic are motives present. Subjects decreased the weight in the domain of coordination, but fail to increase in the domain of anti-coordination. However, the difference in weights assigned to independent and correlated signals consistent with theoretical predictions. Unlike previous experiments, we also find that subject can learn to play best response strategies if the environment is suitable for learning.

6. APPENDICES

APPENDIX A. DERIVATION OF THE MODEL

To find optimal weights the following minimization problem is solved.

$$min \quad (1-\gamma)E[(a_l-\theta)^2] + \gamma E[(a_l-\bar{a})^2]$$

The strategy for player l is assumed to be $a_l = \sum_{i=1}^{n} \omega_{il}\big(\theta + \eta_i + \varepsilon_{il}\big)$. Using the condition $\sum_{i=1}^{n} \omega_{il} = 1$ implies $a_l - \theta = \sum_{i=1}^{n} \omega_{il}\big(\eta_i + \varepsilon_{il}\big)$. Hence, the first expectation is

$$E\big[(a_l-\theta)^2\big] = \sum_{i=1}^{n} \omega_{il}^2 \bigg(\kappa_i^2 + \xi_i^2\bigg).$$

The mean of action taken by other players is $\bar{a} = \frac{\sum_{i=n}^{n} \sum_{l' \neq l} \omega_{il'}\big(\theta+\eta_i+\varepsilon_{il'}\big)}{L-1}$. since players are symmetric, and

$$a_l - \bar{a} = a_l - \frac{\sum_{l' \neq l} a_l}{L-1} = \sum_{i=n}^{n} \omega_{il}\big(\theta + \eta_i + \varepsilon_{il}\big) - \frac{\sum_{i=n}^{n} \sum_{l' \neq l} \omega_{il'}\big(\theta + \eta_i + \varepsilon_{il'}\big)}{L-1} =$$

$$= \theta - \frac{(L-1)}{L-1}\theta + \sum_{i=1}^{n} \eta_i \left[\omega_{il} - \frac{1}{L-1} \sum_{l' \neq l} \omega_{il'}\right] + \sum_{i=1}^{n} \omega_{il}\varepsilon_{il} - \frac{1}{L-1} \sum_{i=n}^{n} \sum_{l' \neq l} \omega_{il'}\varepsilon_{il'} =$$

$$= \sum_{i=1}^{n} \eta_i \frac{(L-1)\omega_{il} - \sum_{l' \neq l} \omega_{il'}}{L-1} + \sum_{i=1}^{n} \left[\frac{(L-1)\omega_{il}\varepsilon_{il} - \sum_{l' \neq l} \omega_{il'}\varepsilon_{il'}}{L-1}\right]$$

So, the second expectation is

$$E\big(a_l - \bar{a}\big)^2 = E\left[\sum_{i=1}^{n} \eta_i \frac{(L-1)\omega_{il} - \sum_{l' \neq l} \omega_{il'}}{L-1}\right]^2 + E\left[\sum_{i=1}^{n} \frac{(L-1)\omega_{il}\varepsilon_{il} - \sum_{l' \neq l} \omega_{il'}\varepsilon_{il'}}{L-1}\right]^2 =$$

$$= \sum_{i=1}^{n} \kappa_i^2 \left[\frac{(L-1)\omega_{il} - \sum_{l' \neq l} \omega_{il'}}{L-1}\right]^2 + \frac{(L-1)^2 \sum_{i=1}^{n} \omega_{il}^2 \xi_i^2}{(L-1)^2} + \frac{\sum_{i=n}^{n} \sum_{l' \neq l} \omega_{il'}^2 \xi_i^2}{(L-1)^2}$$

Substituting these expectations back into the $E(u_l)$, yields,

$$\min(1-\gamma) \sum_{i=1}^{n} \omega_{il}^2 \bigg(\kappa_i^2 + \xi_i^2\bigg) + \gamma \sum_{i=1}^{n} \kappa_i^2 \left[\frac{(L-1)\omega_{il} - \sum_{l' \neq l} \omega_{il'}}{L-1}\right]^2 + \gamma \sum_{i=1}^{n} \omega_{il}^2 \xi_i^2 +$$

$$+ \gamma \frac{\sum_{i=n}^{n} \sum_{l' \neq l} \omega_{il'}^2 \xi_i^2}{(L-1)^2} \text{ subject to } \sum_{i=1}^{n} \omega_i = 1$$

The $\{\omega\}$ is a symmetric solution of this maximization problem if and only if

$$\{\omega\} \in \underset{\omega_l \in R^n}{\arg\min} L = (1-\gamma)\sum_{i=1}^{n}\omega_{il}^2\left(\kappa_i^2+\xi_i^2\right)+\gamma\sum_{i=1}^{n}\kappa_i^2\left[\frac{(L-1)\omega_{il}-\sum_{l'\neq l}\omega_{il'}}{L-1}\right]^2+$$
$$+\gamma\sum_{i=1}^{n}\omega_{il}^2\xi_i^2 \text{ subject to } \sum_{i=1}^{n}\omega_i = 1$$

The influence of signals is found from the first order condition with respect to $\omega_i > 0$. Denote $\widehat{\psi}_i = \frac{1}{(1-\gamma)\kappa_i^2+\xi_i^2}$, and substitute back,

$$\min\sum_{i=1}^{n}\frac{\omega_{il}^2}{\widehat{\psi}_i}+\gamma\sum_{i=1}^{n}\kappa_i^2\left[\omega_{il}-\frac{\sum_{l'\neq l}\omega_{il'}}{L-1}\right]^2) \text{ subject to } \sum_{i=1}^{n}\omega_i = 1$$

F.O.C. wrt ω_{il}: $\Longrightarrow 2\frac{\omega_{il}}{\widehat{\psi}_i}+2\gamma\kappa_i^2\left[\omega_{il}-\frac{\sum_{l'\neq l}\omega_{il'}}{L-1}\right]=\lambda$

$\omega_{il}[\frac{1}{\widehat{\psi}_i}+\gamma\kappa_i^2]-\gamma\kappa_i^2\frac{\sum_{l'\neq l}\omega_{il'}}{L-1}=\frac{\lambda}{2}$

$\omega_{il'}[\frac{1}{\widehat{\psi}_i}+\gamma\kappa_i^2]-\gamma\kappa_i^2\frac{\sum_{l'\neq l}\omega_{il'}}{L-1}=\frac{\lambda}{2}$

By symmetry of players $\omega_{il}=\omega_{il'}=\omega_i$,

$\min\sum_{i=1}^{n}\frac{\omega_i^2}{\widehat{\psi}_i})$ subject to $\sum_{i=1}^{n}\omega_i = 1$

A solution must satisfy $\frac{\partial L}{\partial\omega_{il}}=\frac{\partial L}{\partial\omega_{j1}}$, for all $i\neq j$.

$$\omega_i=\frac{\widehat{\psi}_i}{\sum_{j=1}^{n}\widehat{\psi}_j}.$$

The weight signals attract in equilibrium depends on its relative precision.

Appendix B. Tables for hypotheses testing

Tables with p-values of the hypothesis testing mentioned in the text are presented below.

Table 4 presents p-values from the comparison of average weights to the equilibrium predictions for different treatments.

TABLE 4. p-values for $H0 : w = eq$

$H0 : w = eq$	$\gamma = 0$		$T1$	$T4$		$T2$	$T5$
Signrank							
$H1 : w \neq eq$	0.466		0.002	0.005		0.049	0.022
Signtest							
$H1 : w \neq eq$	0.512		0.021	0.002		0.021	0.180
$H1 : w > eq$	0.256		0.011	0.001		0.998	0.971
$H1 : w < eq$	0.821		0.998	0.999		0.011	0.090

Table 5 shows p-values for the the comparison of average weights between $T0$ for coordination and anti-coordination sessions, and $T3$ for both sessions separately. Then the average of total weights $T0$ and $T3$ from both sessions are compared to each other.

TABLE 5. p-values for $H0 : w = w$ between coordination and anti-coordination treatments when $\gamma = 0$

	$T0 = T0$	$T3 = T3$	$T0 = T3$
MW			
$H1 : w \neq w$	0.105	0.312	0.070
KS			
$H1 : w \neq w$	0.415	0.153	0.035
$H1 : A < C$	0.939	0.526	0.875
$H1 : C < A$	0.210	0.076	0.018

Table 6 shows p-values from the comparison of the average weights of independent signals to the correlated signals for all coordination motives.

TABLE 6. p-values for $H0 : w = w$ between between independent and correlated information.

	$T0 = T3$	$T1 = T4$	$T2 = T5$
MW			
$H1 : w \neq w$	0.711	0.010	0.002
KS			
$H1 : w \neq w$	0.882	0.055	0.018
$H1 : cor < ind$	0.503	1.000	0.009
$H1 : ind < cor$	0.825	0.027	1.000

Table 7 shows p-values for testing hypothesis 2. The average weights from treatments 0 and 1 compared to the average weights from treatments 1 and 4 to test if the weights decrease in coordination environment. The average weights from treatments 0 and 1 compared to the average weights from treatments 2 and 5 to test if the weights increase in anti-coordination environment.

TABLE 7. p-values for testing $H0 : w = w$ between $\gamma = 0$ vs $\gamma = 0.9$ and $\gamma = 0$ vs $\gamma = -1$

$w = w$	Coor		Anti Coor	
$H0:$	$T0 = T1$	$T3 = T4$	$T0 = T2$	$T1 = T4$
Signrank				
$H1 : w \neq w$	0.000	0.056	0.121	0.331
Signtest				
$H1 : w \neq w$	0.000	0.180	0.455	0.791
$H1 : w > w$	0.000	0.089	0.895	0.395
$H1 : w < w$	1.000	0.971	0.227	0.788

Table 8 shows p-values from the comparison of average weight across different time intervals for the sessions with coordination. The data is averaged for each five periods and compared to the average from the next five periods.

TABLE 8. P-values for trend in coordination treatment

$H0 : w = w$	$5 - 10$	$10 - 15$	$15 - 20$	$20 - 25$	$25 - 30$
Signrank					
$H1 : w \neq w$	0.453	0.001	0.001	0.434	0.168
Signtest					
$H1 : w \neq w$	0.572	0.005	0.002	0.851	0.442
$H1 : w > w$	0.828	0.003	0.001	0.425	0.221
$H1 : w < w$	0.286	0.999	0.999	0.714	0.876

Table 9 shows p-values from comparisons of average weights from each five periods to the equilibrium predictions for the same stage in coordination sessions.

TABLE 9. P-values for learning in coordination treatment

$H0: w = eq$	5	10	15	20	25	30
Signrank						
$H1: w \neq eq$	0.258	0.766	0.000	0.000	0.034	0.191
Signtest						
$H1: w \neq eq$	0.265	1.000	0.000	0.001	0.201	0.585
$H1: w > eq$	0.932	0.645	0.000	0.001	0.100	0.292
$H1: w < eq$	0.133	0.500	1.000	0.999	0.951	0.820

Table 10 shows p-values from the comparison of average weight across different time intervals for the sessions with anti-coordination. The data is averaged for each five periods and compared to the average from the next five periods.

TABLE 10. P-values for trend in anti-coordination treatment

$H0: w = w$	$5-10$	$10-15$	$15-20$	$20-25$	$25-30$
Signrank					
$H1: w \neq w$	0.028	0.629	0.805	0.453	0.249
Signtest					
$H1: w \neq w$	0.136	0.851	1.000	0.362	0.362
$H1: w > w$	0.068	0.425	0.645	0.900	0.900
$H1: w < w$	0.969	0.714	0.500	0.181	0.181

Table 11 shows p-values from comparisons of average weights from each five periods to the equilibrium predictions for the same stage in coordination sessions.

TABLE 11. P-values for learning in anti-coordination treatment

$H0: w = eq$	5	10	15	20	25	30
Signrank						
$H1: w \neq eq$	0.003	0.766	0.011	0.005	0.039	0.658
Signtest						
$H1: w \neq eq$	0.013	1.000	0.099	0.002	0.201	0.856
$H1: w > eq$	0.006	0.645	0.979	1.000	0.951	0.708
$H1: w < eq$	0.998	0.500	0.049	0.001	0.100	0.428

REFERENCES

BAERISWYL, R., AND C. CORNAND (2016): "The Predominant Role of Signal Precision in Experimental Beauty Contests.," *The BE Journal of Theoretical Economics*, 16(1), 267–301.

CORNAND, C., AND F. HEINEMANN (2014): "Measuring agents reaction to private and public information in games with strategic complementarities.," *Experimental Economics*, 17(1), 61–77.

DALE, D. J., AND J. MORGAN (2012): "Experiments on the social value of public information.," *Mimeo*.

FEHR, E., AND J.-R. TYRAN (2008): "Limited Rationality and Strategic Interaction: The Impact of the Strategic Environment on Nominal Inertia," *Econometrica*, 76(2), 353–394.

FISCHBACHER, U. (2007): "z-Tree: Zurich toolbox for ready-made economic experiments," *Experimental Economics*, 10(2), 171–178.

GOEREE, J. K., AND T. OFFERMAN (2003): "Winner's curse without overbidding," *European Economic Review*, 47(4), 625–644.

KEYNES, J. M. (1936): *General theory of employment, interest and money*. London: Macmillan.

MORRIS, S., AND H. S. SHIN (2002): "Social Value of Public Information," *The American Economic Review*, 92(5), 1521–1534.

MY, K. B., C. CORNAND, AND R. DOS SANTOS FERREIRA (2017): "Speculation rather than enterprise? Keynes beauty contest revisited in theory and experiment.," *Working paper*.

MYATT, D. P., AND C. WALLACE (2014): "Central bank communication design in a Lucas-Phelps economy," *Journal of Monetary Economics*, 63, 64–79.

MYATT, D. P., AND C. WALLACE (2015): "Cournot competition and the social value of information," *Journal of Economic Theory*, 158, 466–506.

——— (2016): "Information Use and Acquisition in Price-Setting Oligopolies," *The Economic Journal*.

VIVES, X., A. BAYONA, AND J. BRANDTS (2016): "Supply Function Competition, Private Information, and Market Power: A Laboratory Study.," Discussion paper.