

Reducing overreaction to central banks' disclosures: theory and experiment*

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Abstract

Financial markets are known for overreacting to public information. Central banks can reduce this overreaction either by disclosing information to a fraction of market participants only (partial publicity) or by disclosing information to all participants but with ambiguity (partial transparency). We show that, in theory, both communication strategies are strictly equivalent in the sense that overreaction can be indifferently mitigated by reducing the degree of publicity or by reducing the degree of transparency. We run a laboratory experiment to test whether theoretical predictions hold in a game played by human beings. In line with theory, the experiment does not allow the formulation of a clear preference in favor of either communication strategy. This paper then discusses the opportunity for central banks to choose between partial transparency and partial publicity to control market reaction to their disclosures.

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1 Introduction

Financial markets are known for overreacting to public information: press releases or public speeches disclosed by influential economic actors, such as central banks, commonly provoke large swings in market mood. Whereas the general presumption is that more information improves the efficiency of the market outcome, recent literature argues that disclosing public information can reduce its efficiency. Public disclosures are indeed detrimental to welfare if the market overreacts to inaccurate public information, as documented by Morris and Shin (2002), or if public disclosures contain information that exacerbates economic inefficiencies, as highlighted by Gai and Shin (2003), Angeletos and Pavan (2007) or Baeriswyl and Cornand (2010).

Since central banks orchestrate the development of the financial system in present-day economies, their disclosures usually attract the attention of the major market participants. In an environment characterized by strategic complementarities, market participants react to the disclosure of the central bank not solely because it contains valuable information about economic fundamentals, but also because they know that other market participants will react to the same disclosure as well. In the words of Morris and Shin (2002), public information is a “double-edge instrument” as it is common knowledge¹: the desire to coordinate leads agents to condition their actions to a stronger degree on public disclosures than is optimal from a social perspective. In this context, the communication strategy of the central bank directly influences economic efficiency as its public disclosures strongly shape market outcomes. Because of the focal role of central banks’ disclosures, the issue of the communication strategy of the central bank goes beyond the question of whether disclosing information is desirable or not: it also deals with the question of how to disclose information in such a way that the market does not excessively overreact to it. Controlling the degree of market participants’ overreaction to its disclosures is an important and challenging task for a central bank.

How can the central bank potentially reduce the overreaction to its disclosures? The theoretical literature envisages two disclosure strategies for reducing the overreaction of market participants to public information. The first – partial publicity – consists of disclosing transparent public information to a fraction of market participants only (see Cornand and Heinemann (2008)). The degree of publicity is determined by the fraction of market participants who receive the public signal. Choosing a communication channel which does not reach all market participants reduces overreaction to the disclosure as the uninformed participants cannot react to it, whereas the informed participants react less strongly as they know that some of their peers are uninformed. The second strategy – partial transparency – consists of disclosing ambiguous public information to all market participants (see Heinemann and Illing (2002)²). The degree of transparency is determined

¹Common knowledge is knowledge that is known by everyone; everyone knows that everyone shares this knowledge until an infinite degree of specularity.

²Note however that Heinemann and Illing (2002) apply this concept to speculative attacks, while Baeriswyl and Cornand (2010) and Baeriswyl (2011) to monetary policy issues.

by the idiosyncratic inaccuracy of the public signal disclosed to all market participants. Communicating with ambiguity reduces overreaction since ambiguity entails uncertainty about how other market participants interpret the disclosure, which mitigates its focal role. Of the two communication strategies, which one should the central bank prefer? More precisely, should the central bank disclose clear information to a subgroup of market participants or should it disclose ambiguous information to all participants?

The main purpose of this paper is to answer this question. First, it theoretically analyses the effectiveness of partial publicity and partial transparency at reducing the overreaction of market participants to public information. Second, it empirically tests these theoretical predictions with a laboratory experiment. And third, it draws up policy recommendations about strategies to disclose information to the public.

This paper is the first to provide an analysis of both communication strategies within the same general setting and to compare their effectiveness. The theoretical contribution of the paper is to show that partial publicity and partial transparency are equivalent in reducing overreaction to public information and in improving welfare. Both strategies are equivalent in the sense that overreaction can be indifferently mitigated either by reducing the degree of publicity or by reducing the degree of transparency: there is an equivalence relationship between the fraction of informed market participants capturing the degree of partial publicity and the variance of idiosyncratic noise capturing the degree of partial transparency. Moreover, the optimal degree of publicity entails the same average weight assigned to public disclosures (relative to private information) and the same welfare as the optimal degree of transparency. Observing that both disclosure strategies are theoretically equivalent, we run a laboratory experiment in order to check whether theoretical predictions hold in a game involving human beings, and whether the experiment indicates a preference for one or the other strategy.

The experiment is run with three informational treatments, each corresponding to a disclosure strategy. The first treatment corresponds to the canonical model of Morris and Shin (2002), where each subject receives a private and a public signal. The second treatment implements the strategy of partial publicity, where only a subgroup of subjects receives the public signal. The third treatment implements the strategy of partial transparency, where each subject receives the public signal with an idiosyncratic noise. As predicted by the model of Morris and Shin, the experiment exhibits subjects' overreaction to public information. The overreaction, however, is weaker than theoretically predicted, as in Cornand and Heinemann (2010), whose aim is to measure overreaction to public information when subjects face the information structure of the game of Morris and Shin and analyze the welfare detrimental effects of public information.³ The present experi-

³In a speculative attack game close to Morris and Shin (2004), Cornand (2006) – relying on the design of Heinemann et al. (2004) and Cabrales et al. (2007) who consider pure and perfect public signal versus private signal in different treatments – experimentally emphasizes the focal potential of public signals. Her framework, however, does not allow measuring subjects' over-reaction to public information. In a paper based on Allen et al. (2006), Gao (2008) finds that public information has a positive market efficiency effect due to the endogenous link between the informational content role and the coordination role of public information and finds that transparency is welfare improving.

ment also confirms theoretical predictions which maintain that partial transparency and partial publicity are equally effective at reducing the overreaction to public information: both strategies significantly limit overreaction, and to the extent that theory predicts, by limiting the degree of common knowledge in the lab. In line with theory, these findings suggest that human beings react equally to a limited degree of publicity as to a limited degree of transparency. The reason is however different. While partial publicity succeeds in reducing overreaction because uninformed subjects are deprived of public signal, it is the ambiguity surrounding the public signal which reduces overreaction under partial transparency.

Although neither the theory nor the experiment gives a clear preference in favor of either disclosure strategy, this paper makes a case for partial transparency rather than partial publicity for two reasons. First, partial transparency seems easier to implement than partial publicity in our information age, where media quickly relay important information on a large scale. Second, partial publicity infringes upon equity and fairness principles; a central bank may indeed find it politically untenable to intentionally withhold important information from a subgroup of market participants. These findings suggest that institutions, such as central banks, should control the overreaction to their public disclosures by carefully formulating their content rather than by selecting their audience. Such a statement rationalizes the mystic of central banks' speeches.

The paper is organized as follows. Section 2 presents the model and derives the equivalence relationship between partial publicity and partial transparency. Section 3 develops the experimental set-up. Sections 4 and 5 give the results of the experiment and explain the behavior of participants. Section 6 discusses the policy recommendations we can draw from our study, and Section 7 concludes.

2 The theoretical model

This section adapts the theoretical Keynesian 'beauty contest' formalized by Morris and Shin (2002) (henceforth MS) to the derivation of the optimal communication strategy for three informational frameworks. First, the standard case of MS where each agent receives a private and a public signal is discussed. Second, following Cornand and Heinemann (2008), we consider the case of partial publicity (PP) where only a subgroup of agents receives a public signal. And third, we analyze the case of partial transparency (PT) where each agent receives a public signal with an idiosyncratic noise.

The economy is populated by a *continuum* of agents indexed by the unit interval $[0, 1]$ and by a central bank. The spirit of the Keynesian 'beauty contest' is characterized by strategic complementarities in agents' decision rule: each agent takes his decision not only according to its expectation of economic fundamentals but also according to his expectation of other agents' decision. Generally, the optimal action of agent i under

strategic complementarities can be expressed as:

$$a_i = (1 - r)\mathbb{E}_i(\theta) + r\mathbb{E}_i(\bar{a}),$$

where $\theta \in \mathbb{R}$ is the fundamental, a_i is the action taken by the agent i , \bar{a} is the average action over all agents, and r is a constant. The parameter r is the weight assigned to the strategic component which drives the strength of the coordination motive in the decision rule. Assuming $0 \leq r \leq 1$ implies that decisions are strategic complements: agents tend to align their decision with those of others.

Such an optimal decision rule can be derived from various economic contexts. For example, Amato et al. (2002), Hellwig and Veldkamp (2009), and Baeriswyl and Cornand (2010) interpret the ‘beauty contest’ as the price-setting rule of monopolistically competitive firms; Angeletos and Pavan (2004) as the investment decision rule of competing firms.

For the sake of generality, social welfare is assumed to decrease in both the dispersion of actions across agents $\int_i (a_i - \bar{a})^2 di$ and the distortion of the average action from the fundamental $(\theta - \bar{a})^2$. The social loss function is given by:

$$L(a, \theta) \equiv \int_i (a_i - \bar{a})^2 di + \lambda(\theta - \bar{a})^2, \quad (1)$$

where a is the action profile over all agents and λ the weight assigned to the economic distortion from the fundamental. The welfare function used in the transparency debate of MS is a controversial matter because the detrimental effect of transparency is driven by the relative weight of dispersion (coordination) and distortion (stabilization) at the social level. The social loss function in the form of (1) includes many welfare specifications. This social loss is reminiscent of the loss of the representative household derived from a micro-founded monopolistic competitive economy. The parameter λ can then take a value consistent with the micro-foundation of the model. However, the welfare in MS given by $-\int_i (a_i - \theta)^2 di$ corresponds also to the loss (1) with $\lambda = 1$, as shown in Baeriswyl (2011).

2.1 Pure public signal (MS)

The first considered informational framework corresponds to that of MS where each agent i receives a private signal x_i and a pure public signal y . These signals deviate from the fundamental θ by some error terms which are normally distributed. Whereas the private signal $x_i = \theta + \epsilon_i$ with $\epsilon_i \sim N(0, \sigma_\epsilon^2)$ is different for each agent i , the public signal $y = \theta + \eta$ with $\eta \sim N(0, \sigma_\eta^2)$ is the same for all agents. Noise terms ϵ_i of distinct agents and the noise η of the public signal are independent and their distribution is treated as exogenously given.

2.1.1 Equilibrium

To derive the perfect Bayesian equilibrium action of agents, we express the first-order expectation of agent i about the fundamental θ conditional on his private and public information:

$$\mathbb{E}(\theta|x_i, y) = \frac{\sigma_\eta^2}{\sigma_\epsilon^2 + \sigma_\eta^2}x_i + \frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + \sigma_\eta^2}y. \quad (2)$$

The best estimate of the fundamental by agent i is an average of both his signals whose weighting depend upon their relative precision. As shown by MS, the optimal equilibrium action of agent i is a linear combination of his private and public signals, and can be expressed as:

$$\begin{aligned} a_i &= (1 - w_{ms})x_i + w_{ms}y = (1 - r)\mathbb{E}_i(\theta) + r\mathbb{E}_i(\bar{a}) \\ &= (1 - r)\left[\frac{\sigma_\eta^2}{\sigma_\epsilon^2 + \sigma_\eta^2}x_i + \frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + \sigma_\eta^2}y\right] + r\left[(1 - w_{ms})\left[\frac{\sigma_\eta^2}{\sigma_\epsilon^2 + \sigma_\eta^2}x_i + \frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + \sigma_\eta^2}y\right] + w_{ms}y\right] \\ &= \underbrace{\frac{(1 - r)\sigma_\eta^2}{\sigma_\epsilon^2 + (1 - r)\sigma_\eta^2}}_{1 - w_{ms}}x_i + \underbrace{\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1 - r)\sigma_\eta^2}}_{w_{ms}}y, \end{aligned}$$

where $\mathbb{E}_i(\cdot)$ is the posterior expectation conditional on x_i and y . The average action over all agents yields

$$\bar{a} = \underbrace{\frac{(1 - r)\sigma_\eta^2}{\sigma_\epsilon^2 + (1 - r)\sigma_\eta^2}}_{1 - w_{ms}}\bar{x} + \underbrace{\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1 - r)\sigma_\eta^2}}_{w_{ms}}y, \quad (3)$$

where $\bar{x} = \int_i x_i = \theta$.

The weight attributed to the public signal in the equilibrium action w_{ms} in (3) is larger than in the best estimate of the fundamental θ given in (2): agents overreact to the public signal. This overreaction arises because of the coordination motive in the optimal decision rule. Whereas ϵ_i is an idiosyncratic noise, the noise η of the public signal is commonly observed by all agents and the weight assigned to it increases as the coordination motive becomes stronger: strategic complementarities raise the agents' incentive to coordinate their actions around the public signal. At the limit, when r converges to 1, the action of agents in equilibrium is the public signal itself, i.e. $w_{ms} = 1$.

2.1.2 Expected welfare

Given the equilibrium action (3), the unconditional expected social loss can be written as

$$\begin{aligned} \mathbb{E}(L) &= \mathbb{E}\left(\int_i (a_i - \bar{a})^2 di + \lambda(\theta - \bar{a})^2\right) \\ &= (1 - w_{ms})^2\sigma_\epsilon^2 + \lambda w_{ms}^2\sigma_\eta^2 \end{aligned}$$

$$= \frac{(\lambda\sigma_\epsilon^2 + (1-r)^2\sigma_\eta^2)\sigma_\epsilon^2\sigma_\eta^2}{(\sigma_\epsilon^2 + (1-r)\sigma_\eta^2)^2}. \quad (4)$$

To illustrate the transparency debate of MS, let us assume that the public signal is disclosed by the central bank and that it has the choice between disclosing this public signal with precision σ_η^2 (transparency) and withholding this signal (opacity). Under which conditions would the central bank find it optimal to withhold its information? We calculate the unconditional expected loss under opacity, and then compare this result with the unconditional expected loss under transparency given in (4).

When the central bank withholds the public signal, agents' action is merely given by their private signal (i.e. $w_{ms} = 0$) and the average action \bar{a} is equal to the fundamental θ . The corresponding expected loss is then driven by the action dispersion across agents and yields σ_ϵ^2 . It turns out that withholding the public signal is preferable to disclosing it when

$$\lambda - 2(1-r) > \frac{\sigma_\epsilon^2}{\sigma_\eta^2}. \quad (5)$$

Disclosing the public signal is detrimental to welfare when it is too noisy relative to the private signal, when the degree of strategic complementarities r is high, and when the weight assigned to distortion λ is large. Our general loss function shows the extent to which the welfare effect of transparency is related to the social value of coordination. In the case of MS, as $\lambda = 1$, the private signal must be more accurate than the public signal for transparency to be detrimental. This is why Svensson (2006) argues that the detrimental effect of transparency emphasized in MS's beauty-contest framework arises under unrealistic conditions since the information held by public institutions such as central banks is typically more accurate than the information that is privately available. However, if the social value of coordination is smaller than in MS (i.e. $\lambda > 1$), opacity may be preferable even when public information is more accurate than private information.

Moreover, even when transparency is preferable to opacity, reducing the degree of common knowledge about the public signal may improve welfare. The degree of common knowledge about public information can be reduced with two alternative communication strategies. On the one hand, the degree of common knowledge is reduced by means of partial publicity, that is by providing the public signal to a subgroup of agents only, as proposed by Cornand and Heinemann (2008). On the other hand, the degree of common knowledge is reduced by means of partial transparency, that is by providing the public signal to all agents but with an idiosyncratic noise, which captures the ambiguity of central bank's disclosure.

2.2 Partial publicity (PP)

The second informational framework corresponds to that of Cornand and Heinemann (2008) where each agent i receives a private signal x_i and only a subgroup of agents receives a public (or rather semi-public) signal y . Again, these signals deviate from the

fundamental θ by some error terms which are normally distributed. The private signal $x_i = \theta + \epsilon_i$ with $\epsilon_i \sim N(0, \sigma_\epsilon^2)$ is different for each agent i . A proportion P of agents receive a semi-public (common) signal $y = \theta + \eta$ with $\eta \sim N(0, \sigma_\eta^2)$. P is the degree of publicity.

2.2.1 Equilibrium

To derive the optimal average action we treat separately the optimal action of the uninformed $1-P$ agents who only get a private signal from the optimal action of the informed P agents who get both a private and a semi-public signals. The optimal action of uninformed agents is simply given by their private signal:

$$a_{i,1-P} = x_i.$$

As the fundamental is improperly distributed, the optimal action for these agents is their private signal itself.

The optimal equilibrium action of informed agents who get both the private and the semi-public signal is a linear combination of their signals and is derived as

$$\begin{aligned} a_{i,P} &= (1 - w_{pp})x_i + w_{pp}y = (1 - r)\mathbb{E}_i(\theta) + r \left[(1 - P)\mathbb{E}_i(\theta) + P((1 - w_{pp})\mathbb{E}_i(\theta) + w_{pp}y) \right] \\ &= \underbrace{\frac{(1 - rP)\sigma_\eta^2}{\sigma_\epsilon^2 + (1 - rP)\sigma_\eta^2}}_{1-w_{pp}} x_i + \underbrace{\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1 - rP)\sigma_\eta^2}}_{w_{pp}} y. \end{aligned} \quad (6)$$

The weight attributed to the public signal by the fraction P of informed agents, w_{pp} in (6), is smaller than in the MS-treatment (3) if $P < 1$. Since agents know that a fraction $1 - P$ of them do not observe the public signal, they weight it less strongly as partial publicity weakens its focal role.

The average action over both types of agents is given by

$$\begin{aligned} \bar{a} &= (1 - P)\bar{x}_{1-P} + P \left[\frac{(1 - rP)\sigma_\eta^2 \bar{x}_P + \sigma_\epsilon^2 y}{\sigma_\epsilon^2 + (1 - rP)\sigma_\eta^2} \right] \\ &= \underbrace{\frac{(1 - P)\sigma_\epsilon^2 + (1 - rP)\sigma_\eta^2}{\sigma_\epsilon^2 + (1 - rP)\sigma_\eta^2}}_{1-\bar{w}_{pp}} \bar{x} + \underbrace{\frac{P\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1 - rP)\sigma_\eta^2}}_{\bar{w}_{pp}} y. \end{aligned} \quad (7)$$

The weight attributed to the public signal in the average equilibrium action $\bar{w}_{pp} = P \cdot w_{pp}$ in (7) is smaller than that in the MS-treatment given in (3) and increasing in P . This means that reducing the degree of publicity by disclosing the semi-public signal only to a subgroup of agents reduces the overreaction to the public signal. The unconditional variance of weight across both informed and uninformed agents is given by $P(1 - P)w_{pp}^2$.

2.2.2 Expected welfare

Given the equilibrium average action (7), the unconditional expected social loss can be expressed as

$$\begin{aligned}
\mathbb{E}(L) &= \mathbb{E}\left(\int_i (a_i - \bar{a})^2 di + \lambda(\theta - \bar{a})^2\right) \\
&= \mathbb{E}\left(\int_P ((1 - w_{pp})\sigma_\epsilon^2 + (w_{pp} - \bar{w}_{pp})\sigma_\eta^2)^2 di + \int_{1-P} (\sigma_\epsilon^2 - \bar{w}_{pp}\sigma_\eta^2)^2 di + \lambda(\bar{w}_{pp}\sigma_\eta^2)^2\right) \\
&= \left[P(1 - w_{pp})^2 + 1 - P\right]\sigma_\epsilon^2 + \left[P(1 - P + \lambda P)w_{pp}^2\right]\sigma_\eta^2 \\
&= \frac{\sigma_\epsilon^2((\sigma_\epsilon^2 + (1 - rP)\sigma_\eta^2)^2 + \sigma_\epsilon^2 P(\sigma_\eta^2(2rP + \lambda P - P - 1) - \sigma_\epsilon^2))}{(\sigma_\epsilon^2 + (1 - rP)\sigma_\eta^2)^2} \tag{8}
\end{aligned}$$

To determine the optimal degree of publicity P^* , we minimize the loss (8) with respect to P :

$$\frac{\partial \mathbb{E}(L)}{\partial P} = 0 \quad \Leftrightarrow \quad P^* = \frac{\sigma_\epsilon^2 + \sigma_\eta^2}{(2\lambda - 2 + 3r)\sigma_\eta^2}.$$

Since $0 \leq P \leq 1$, the optimal degree of publicity is expressed as

$$P^* = \min \left[\max \left(0, \frac{\sigma_\epsilon^2 + \sigma_\eta^2}{(2\lambda - 2 + 3r)\sigma_\eta^2} \right), 1 \right] \tag{9}$$

and plugging it into the unconditional expected loss (8) delivers the optimal expected loss

$$\mathbb{E}(L^*) = \sigma_\epsilon^2 + \frac{\sigma_\epsilon^4}{4\sigma_\eta^2(1 - r - \lambda)}. \tag{10}$$

2.3 Partial transparency (PT)

The third informational framework corresponds to the case where each agent i receives a private signal x_i and a public (or rather semi-public) signal with an idiosyncratic noise y_i . These signals deviate from the fundamental θ by some error terms which are normally distributed. The private signal is given by $x_i = \theta + \epsilon_i$ with $\epsilon_i \sim N(0, \sigma_\epsilon^2)$. The semi-public signal is defined as $y_i = \theta + \eta + \phi_i$ with $\eta \sim N(0, \sigma_\eta^2)$ and $\phi_i \sim N(0, \sigma_\phi^2)$. The signal y_i is semi-public in the sense that it contains an error term η that is common to all agents and an error term ϕ_i that is private to each agent i .

2.3.1 Equilibrium

To derive the perfect Bayesian equilibrium action of agents, we express the first-order expectation of agent i about the fundamental θ and the average semi-public signal \bar{y} observed by other agents conditional on his private and semi-public information:

$$\mathbb{E}(\theta | x_i, y_i) = \frac{\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\epsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} x_i + \frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} y_i$$

$$\mathbb{E}(\bar{y}|x_i, y_i) = \frac{\sigma_\phi^2}{\sigma_\epsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} x_i + \frac{\sigma_\epsilon^2 + \sigma_\eta^2}{\sigma_\epsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} y_i.$$

The best estimate of the fundamental by agent i is an average of both his signals whose weighting depends upon their relative precision. The optimal equilibrium action of agent i is a linear combination of his private and semi-public signals and can be expressed as:

$$\begin{aligned} a_i &= (1 - w_{pt})x_i + w_{pt}y_i = (1 - r)\mathbb{E}_i(\theta) + r\mathbb{E}_i(\bar{a}) \\ &= (1 - r) \left[\frac{(\sigma_\eta^2 + \sigma_\phi^2)x_i + \sigma_\epsilon^2 y_i}{\sigma_\epsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} \right] + r \left[(1 - w_{pt}) \left[\frac{(\sigma_\eta^2 + \sigma_\phi^2)x_i + \sigma_\epsilon^2 y_i}{\sigma_\epsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} \right] + w_{pt} \frac{\sigma_\phi^2 x_i + (\sigma_\epsilon^2 + \sigma_\eta^2) y_i}{\sigma_\epsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} \right] \\ &= \underbrace{\frac{(1 - r)\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\epsilon^2 + (1 - r)\sigma_\eta^2 + \sigma_\phi^2}}_{1 - w_{pt}} x_i + \underbrace{\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1 - r)\sigma_\eta^2 + \sigma_\phi^2}}_{w_{pt}} y_i. \end{aligned}$$

The average action over all agents yields

$$\bar{a} = \underbrace{\frac{(1 - r)\sigma_\eta^2 + \sigma_\phi^2}{\sigma_\epsilon^2 + (1 - r)\sigma_\eta^2 + \sigma_\phi^2}}_{1 - w_{pt}} \bar{x} + \underbrace{\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1 - r)\sigma_\eta^2 + \sigma_\phi^2}}_{w_{pt}} \bar{y}. \quad (11)$$

The weight attributed to the semi-public signal in the average equilibrium action w_{pt} in (11) is smaller than that in the MS-treatment given in (3) and is decreasing in σ_ϕ^2 . This indicates that reducing the degree of transparency by disclosing the public signal with an idiosyncratic noise to each agent reduces the overreaction to the public signal.

2.3.2 Expected welfare

Given the equilibrium average action (11), the unconditional expected social loss can be expressed as

$$\begin{aligned} \mathbb{E}(L) &= \mathbb{E} \left(\int_i (a_i - \bar{a})^2 di + \lambda(\theta - \bar{a})^2 \right) \\ &= (1 - w_{pt})^2 \sigma_\epsilon^2 + w_{pt}^2 \sigma_\phi^2 + \lambda w_{pt}^2 \sigma_\eta^2 \\ &= \frac{\sigma_\epsilon^2 ((r - 1)^2 \sigma_\eta^4 + \sigma_\phi^2 (\sigma_\epsilon^2 + \sigma_\phi^2) + \sigma_\eta^2 (\lambda \sigma_\epsilon^2 - 2(r - 1) \sigma_\phi^2))}{(\sigma_\epsilon^2 + (1 - r) \sigma_\eta^2 + \sigma_\phi^2)^2} \end{aligned} \quad (12)$$

To determine the optimal degree of transparency σ_ϕ^{2*} , we minimize the loss (12) with respect to σ_ϕ^2 :

$$\frac{\partial \mathbb{E}(L)}{\partial \sigma_\phi^2} = 0 \quad \Leftrightarrow \quad \sigma_\phi^2 = (2\lambda - 3(1 - r))\sigma_\eta^2 - \sigma_\epsilon^2.$$

Since $\sigma_\phi^2 > 0$, the optimal degree of publicity is expressed as

$$\sigma_\phi^{2*} = \max \left[0, (2\lambda - 3(1 - r))\sigma_\eta^2 - \sigma_\epsilon^2 \right] \quad (13)$$

and plugging it into the unconditional expected loss (12) delivers the optimal expected loss

$$\mathbb{E}(L^*) = \sigma_\epsilon^2 + \frac{\sigma_\epsilon^4}{4\sigma_\eta^2(1-r-\lambda)}. \quad (14)$$

2.4 Equivalence between partial publicity and partial transparency

The overreaction to the public signal that arises in an environment of strategic complementarities can be reduced by two alternative communication strategies, namely partial publicity (PP) and partial transparency (PT). We show in this section that both communication strategies are equivalent for reducing overreaction and yield the same average welfare.

First, the weight assigned to the public signal can be equivalently controlled by means of PP or PT, and there is a clear relationship between the degree of publicity P and the degree of transparency σ_ϕ^2 for implementing a given weight on the public signal. To show this relation, we compare the average weight in PP, \bar{w}_{pp} , given in (7) to that in PT, w_{pt} , given in (11) and solve it for P and for σ_ϕ^2 :

$$P = \frac{\sigma_\epsilon^2 + \sigma_\eta^2}{\sigma_\epsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} \quad \text{or} \quad \sigma_\phi^2 = \frac{1-P}{P}(\sigma_\epsilon^2 + \sigma_\eta^2). \quad (15)$$

This relation illustrates how partial publicity can be translated into partial transparency for reducing overreaction, and *vice versa*.

Second, the optimal degree of publicity is equivalent to the optimal degree of transparency in the sense that both deliver the same average weight on the public (or semi-public) signal. Using (15), it can be shown that the optimal degree of publicity (9) is equivalent to the optimal degree of transparency (13).

Third, the unconditional expected loss under PP (8) is equal to the unconditional expected loss under PT (12) when (15) holds. This implies that the expected loss is the same in both models for any weight on public information and not only at the optimal degree of publicity or transparency as expressed in (10) and (14). Interestingly, the equivalence result is independent of the relative weight of dispersion vs. distortion in the social welfare, as captured by λ .

Fourth, although the average weight can be equivalently controlled with PP or PT, the dispersion of weight across agents is different. Whereas all agents play the same strategy in PT (as well as in MS), they play different strategies in PP depending on whether they are informed or not. The unconditional variance of weight across informed and uninformed agents in PP is given by $P(1-P)w_{pp}^2$.

These results can be summarized as follows:

Result 1 *a) Theoretically, the weight assigned to the public signal can be equivalently controlled by means of PP or PT. b) The optimal weight is the same in PP as in PT. c) For any given weight the unconditional expected*

welfare is the same in PP as in PT. d) However, whereas all agents play the same equilibrium weight in PT, agents play different weights in PP according to whether they are informed or not.

2.5 A graphical illustration

The three disclosure strategies presented above and their welfare effect can be illustrated with a graph. Figure 1 highlights the welfare effect of reducing the degree of common knowledge and the equivalence relationship between partial publicity and partial transparency. The upper panel shows the unconditional expected loss. The transparency debate in MS deals with the two extreme cases where the central bank either discloses a pure public signal (full transparency, dotted line) or completely withholds its information (full opacity, dashed line). Optimal partial publicity and optimal partial transparency yield however the same unconditional expected loss (solid line). The optimal degree of publicity P^* and the optimal degree of transparency σ_ϕ^{2*} are represented in the lower panel.

The parameter values are $r = 0.9$, $\lambda = 1$ (as in MS), and $\sigma_\eta^2 = 0.25$. Comparing the unconditional expected loss under full opacity and full transparency illustrates the debate in the vein of MS. According to condition (5), full opacity is preferable to full transparency if private information is relatively accurate, i.e. if $\sigma_\epsilon^2 < 0.2$. However, the spirit of MS survives the critique of Svensson (2006) once we allow for partial levels of publicity or transparency. Reducing the degree of publicity or transparency improves indeed welfare compared to the full transparency case even if public information is more accurate than private information, i.e. $\sigma_\eta^2 = 0.25 < \sigma_\epsilon^2 < 0.425$. For larger inaccuracy of private information, i.e. $\sigma_\epsilon^2 > 0.425$, reducing the degree of publicity or transparency is not optimal anymore and $P^* = 1$, $\sigma_\phi^{2*} = 0$ as shown in the lower panel.

3 The experiment

The previous section shows that, in theory, overreaction to public information can be indifferently mitigated by reducing the degree of publicity or the degree of transparency of the public signal. One may question whether this theoretical equivalence also holds in practice, when *homines sapientes* are involved in the ‘beauty contest’ instead of *homines oeconomici*. A natural way to test this issue is to run a laboratory experiment which implements the alternative disclosure strategies, as real data may be difficult to collect. The theoretical model in Section 2 is adjusted to an experimental framework, as presented in Appendix A. The model is modified in two respects. First, the number of subjects is finite (instead of a *continuum* of agents) and second, the distribution of error terms is uniform (instead of normal). We discuss in this section the chosen parameters for each treatment, the corresponding theoretical behavior, and the general procedure of the experiment.

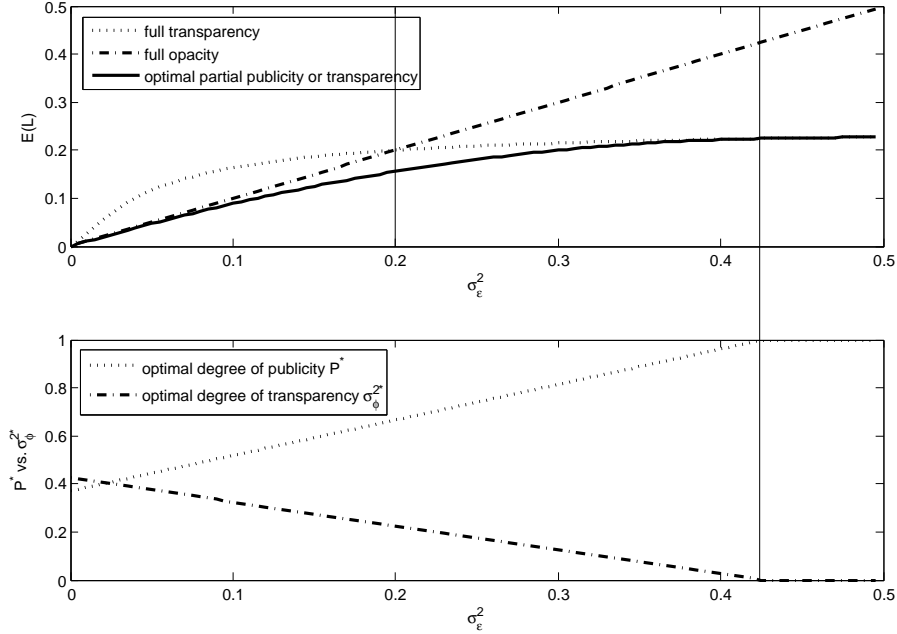


Figure 1: Unconditional expected loss and optimal degree of publicity vs. transparency

3.1 Treatment parameters

We run an experiment with three treatments, each corresponding to a disclosure strategy. In the MS-treatment (Morris and Shin (2002)), derived in Section 2.1 and Appendix A.2, each subject receives a private and a public signal. In the PP-treatment (partial publicity à la Cornand and Heinemann (2008)), derived in Section 2.2 and Appendix A.3, each subject receives a private signal and a subgroup of subjects receives a semi-public signal. Finally, in the PT-treatment (partial transparency), derived in Section 2.3 and Appendix A.4, each subject receives a private signal and a semi-public signal, which contains both a public error term that is common to all subjects and an idiosyncratic error term that is private to each subject.

We conducted 9 sessions with a total of 126 subjects. In each session, the 14 participants were separated into two independent groups (in order to get 2 observations per session and 18 observations in total). Each session consisted of three stages and each stage of 15 periods (total of 45 periods per session). Each stage corresponded to a different treatment. Subjects played within the same group of participants during the whole length of the experiment and did not know the identity of the other subjects of their group.

In every period and for each group, a fundamental state θ is drawn randomly using a uniform distribution from the interval $[50, 950]$.⁴ In every period of the experiment, each subject has to decide on an action a_i , conditional on her signals. The design is close

⁴Note that, contrary to Cornand and Heinemann (2010), we are close to an improper uniform distribution as subjects were not told about the support of the distribution, avoiding the skewness of the posterior distribution.

to that of Cornand and Heinemann (2010).⁵ The payoff function in ECU (experimental currency units) for subject i is given by the formula:

$$400 - 1.5(a_i - \theta)^2 - 8.5(a_i - \bar{a})^2, \quad (16)$$

where \bar{a} is the average action of other subjects of the same group.⁶ To decide on an action, subjects receive some signals on the fundamental θ and are forced to choose as action a weighted average of the signals they get.

The parameters choice for the experiment is summarized in Table 1. In the MS-treatment, each subject receives both a public and a private signal as described in Appendix A.2. The private signal received by each subject is distributed as $x_i \in [\theta - 10, \theta + 10]$. The distribution of the additional public signal differs depending on the session. In sessions 1 to 6, each group of subjects receives a common (public) signal $y \in [\theta - 10, \theta + 10]$. In sessions 7 to 9, each group of subjects receives a common (public) signal $y \in [\theta - 15, \theta + 15]$.

In the PP-treatment, whereas each subject receives a private signal, only a subgroup of subjects receives a semi-public signal as described in Appendix A.3. The private signal received by each subject is uniformly drawn from $x_i \in [\theta - 10, \theta + 10]$. In addition, 5 out of 7 subjects in the group receive a common (semi-public) signal whose distribution depends on the session. In sessions 1 to 6, each subgroup of 5 subjects receives a common (public) signal uniformly drawn from $y \in [\theta - 10, \theta + 10]$. In sessions 7 to 9, each subgroup of 5 subjects receives a common (public) signal uniformly drawn from $y \in [\theta - 15, \theta + 15]$. The 2 subjects who do not receive the semi-public signal (but only their private signal) are drawn randomly and independently each period; they had no choice but playing the value of the private signal they received.

In the PT-treatment, each subject receives a private signal and a semi-public signal as described in Appendix A.4. The private signal received by each subject is uniformly drawn from $x_i \in [\theta - 10, \theta + 10]$. In addition, each subject in the group receives a semi-public signal that contains both a public (common to the whole group) and a private noise. In sessions 1 to 6, each subject receives a semi-public signal uniformly drawn from $y_i \in [y - 8.5, y + 8.5]$ with $y \in [\theta - 10, \theta + 10]$. In sessions 7 to 9, each subject receives a semi-public signal uniformly drawn from $y_i \in [y - 11, y + 11]$ with $y \in [\theta - 15, \theta + 15]$.

As reported in Table 1, the order of play is different in sessions 1 to 3 from that of sessions 4 to 6. This aims at testing order effects (MS, PP, PT versus MS, PT, PP). The change in the precision of the public signal in sessions 7 to 9 compared to sessions 1 to 6 aims at testing comparative statics effects in terms of public signal's relative precision.⁷

⁵The design however differs from that of Cornand and Heinemann (2010) in two main respects. First, while Cornand and Heinemann (2010) matched participants by pairs, we had instead seven participants per group, allowing us to deal with the PP-treatment. Second, while Cornand and Heinemann (2010) authorized subjects to play within a large interval (most of the time $[y - 20; y + 20]$) we allowed subjects to move a cursor only inside the interval defined by the signals to determine their chosen action. By doing so, we restrained subjects from choosing actions outside of their signal interval.

⁶In sessions 7 to 9, the payoff function is adjusted to $450 - 1.5(a_i - \theta)^2 - 8.5(a_i - \bar{a})^2$ for the expected payoff to be constant across sessions.

⁷Choosing the public signal less accurate than the private signal in sessions 7 to 9 may seem at odds with the belief that public information is generally more accurate than private information. However, this

Sessions	Groups	Players	Stage	Treatment	Periods	r	ϵ	η	ϕ	p
Sessions 1-3	1-6	7	1	MS	15	0.85	10	10	0	7
			2	PP	15	0.85	10	10	0	5
			3	PT	15	0.85	10	10	8.5	7
Sessions 4-6	7-12	7	1	MS	15	0.85	10	10	0	7
			2	PT	15	0.85	10	10	8.5	7
			3	PP	15	0.85	10	10	0	5
Sessions 7-9	13-18	7	1	MS	15	0.85	10	15	0	7
			2	PP	15	0.85	10	15	0	5
			3	PT	15	0.85	10	15	11	7

Table 1: Experiment parameters

3.2 Equilibrium weights and expected payoff under rational behavior

Reducing the degree of publicity or the degree of transparency aims at mitigating the overreaction to the public signal that occurs in MS. The parameters presented above are chosen in such a way that the equilibrium weight assigned to the semi-public signal in PP and PT coincides with the weight assigned to the public signal in the first-order expectation of the fundamental θ in MS. This corresponds to the case where the communication strategy aims at avoiding the overreaction to public disclosure compared to the case of a purely public signal.

The equilibrium weights on y are reported in Table 2. Column $\mathbb{E}_i(\theta)$ shows the weight assigned to the public or semi-public signal in the first-order expectation of the fundamental θ , column w shows the equilibrium weight in the rational behavior for (informed) subjects who get the public or semi-public signal, and column \bar{w} shows the equilibrium weight in the rational behavior over all subjects.

Table 2 also reports the expected payoff in ECU under rational behavior. Column $u(1-P)$ shows the expected payoff for uninformed subjects in PP who do not get the semi-public signal. Their expected payoff is naturally lower than that of informed subjects who get the semi-public signal $u(P)$. The overall expected payoff is reported in column u . Note that expected payoffs in PP and PT are lower than in MS because of the simple payoff function (16) chosen in the experiment, as discussed in Appendix A.1. Moreover, expected payoffs in PP and PT are not identical because the number of subjects is finite and because error terms are not normally distributed in the experiment, as reported in Appendix A.5.

3.3 Procedure

Sessions were run in January 2011 at the LEES (Laboratoire d'Economie Expérimentale de Strasbourg). Each session had 14 participants who were mainly students from Strasbourg University (most were students in economics, mathematics, biology and psychology). Sub-

allows us to emphasize that overreaction comes from the focal role of the public signal and not from its relative accuracy.

Treat.	r	ϵ	η	ϕ	p	$\mathbb{E}_i(\theta)$	w	\bar{w}	u(1-P)	u(P)	u
MS	0.85	10	10	0	7	0.5	0.8696	0.8696		356.5	356.5
MS	0.85	10	15	0	7	0.4	0.8163	0.8163		363.8	363.8
PP	0.85	10	10	0	5	0.5	0.6977	0.4983	-29.1	329.9	227.3
PP	0.85	10	15	0	5	0.4	0.6061	0.4329	-45.9	330.9	223.3
PT	0.85	10	10	8.5	7	0.3509	0.5	0.5		244.0	244.0
PT	0.85	10	15	11	7	0.2777	0.4301	0.4301		246.3	246.3

Table 2: Equilibrium weights on the public signal Y and expected payoff under rational behavior

jects were seated in random order at PCs. Instructions were then read aloud and questions answered in private. Throughout the sessions, students were not allowed to communicate with one another and could not see each others' screens. Each subject could only participate in one session. Before starting the experiment, subjects were required to answer a few questions to ascertain their understanding of the rules. Examples of instructions, questionnaires, and screens are given in Appendices D, E, and F. The experiment started after all subjects had given the correct answers to these questions.

After each period, subjects were informed about the true state, their partner's decision and their payoff. Information about past periods from the same stage (including signals and own decisions) was displayed during the decision phase on the lower part of the screen. At the end of each session, the ECU earned were summed up and converted into euros. 1000 ECU were converted to 2 euros.⁸ Payoffs ranged from 8 to 28 euros. The average payoff was about 20 euros. Sessions lasted for around 60 minutes.

4 The results

This section presents the results of the experiment. The average weight assigned to the public signal in the experiment is reported on columns 2 to 5 of Table 3 (aggregated by group) and on Figure 2 (aggregated by period).⁹ Figure 3 shows the variance of weights across subjects aggregated by period. The realized average payoffs are reported on columns 6 to 10 of Table 3 (aggregated by group) and on Figure 4 (aggregated by period).

We analyze the experimental data by looking at overreaction effects and comparing weights in different treatments (MS - PP - PT). The fact that we cannot detect order effect¹⁰ allows us to pool data from groups 1 to 12 together for the remaining analysis.¹¹

⁸In all stages, it was possible to earn negative points. Realized losses were of a size that could be counterbalanced by positive payoffs within a few periods. In total, no subject earned a negative payoff in any session.

⁹Appendix B provides plots of average weights assigned to the public signal for each group.

¹⁰We compare the observed weight in either PP or PT in groups where PP is played before PT (groups 1 to 6) to the observed weight in groups where treatments are played in reversed order (groups 7 to 12). Student's t-tests do not show any order effect on subjects' behavior. First, the behavior in PP in groups 1 to 6 is not different from that in groups 7 to 12 ($p = 0.432$). Second, the same is true for PT in groups 1 to 6 compared with groups 7 to 12 ($p = 0.847$). Third, one can also test the order effect by comparing the

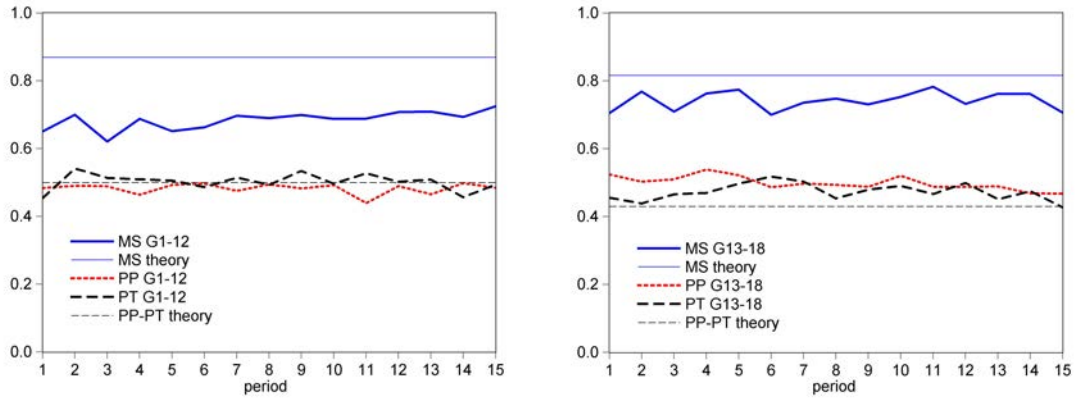


Figure 2: Average weight assigned to the public signal: groups 1-12 (lhs) and groups 13-18 (rhs)

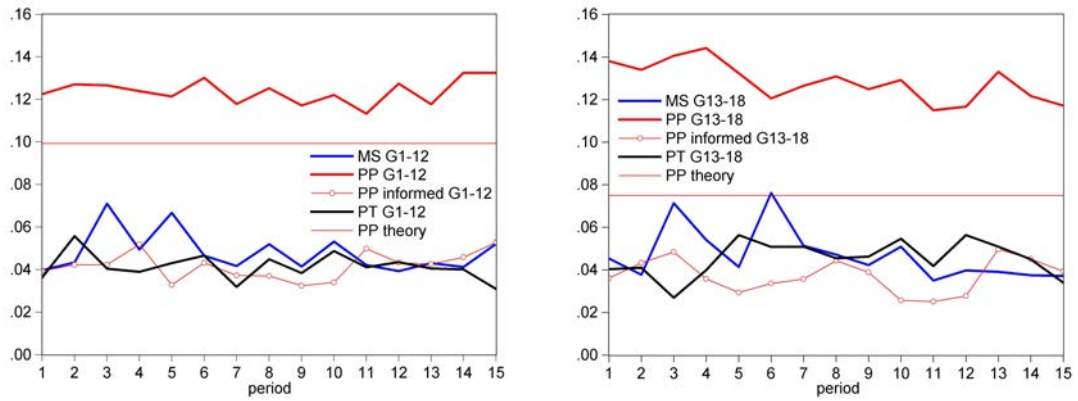


Figure 3: Variance of weights: groups 1-12 (lhs) and groups 13-18 (rhs)

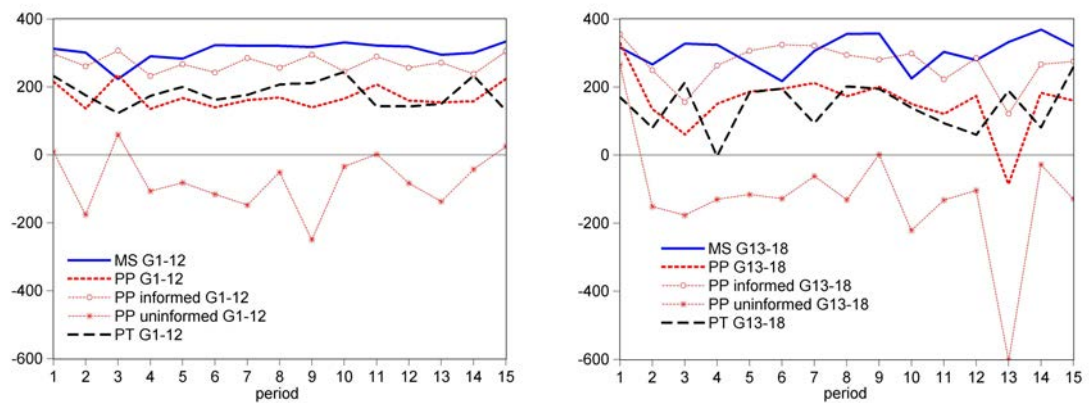


Figure 4: Average payoff: groups 1-12 (lhs) and groups 13-18 (rhs)

Group	Average weights on Y				Average payoffs				
	MS	PP		PT	MS	PP			PT
		inf.	aver.			inf.	uninf.	aver.	
1	.6278	.6238	.4456	.5089	293.9	260.9	-13.2	182.6	246.2
2	.7012	.6966	.4976	.4208	294.3	317.0	8.8	229.0	166.7
3	.8089	.8308	.5934	.5225	322.8	273.6	-57.6	179.0	100.8
4	.6355	.6896	.4926	.5306	296.1	306.4	-11.0	215.7	211.3
5	.7484	.6587	.4705	.5700	317.4	246.2	-152.4	132.3	148.8
6	.6526	.6420	.4586	.4772	308.5	260.1	-114.9	152.9	162.2
7	.6167	.6433	.4595	.4896	311.3	302.1	-38.8	204.7	189.8
8	.7244	.6678	.4770	.4595	326.0	279.6	-11.2	196.5	187.8
9	.7071	.5748	.4106	.5205	315.8	255.7	-199.1	125.8	192.7
10	.6530	.6395	.4568	.5312	313.4	259.3	-31.4	176.3	157.5
11	.6319	.6922	.4944	.5662	284.4	235.0	-81.8	144.5	243.1
12	.7085	.7382	.5273	.4282	294.0	242.4	-201.1	115.7	158.6
Average	.6846	.6747	.4819	.5021	306.1	269.9	-75.3	171.2	180.4
Theory	.8696	.6976	.4983	.5000	356.5	329.9	-29.1	227.3	244.0
13	.7979	.7171	.5122	.4746	344.4	267.7	-81.5	168.0	113.7
14	.6972	.6482	.4630	.4166	233.8	313.4	-53.0	208.7	231.3
15	.7706	.7710	.5507	.5036	336.3	276.3	-91.7	171.1	153.6
16	.6749	.6838	.4884	.4929	292.2	266.9	-195.0	134.9	152.4
17	.7849	.6874	.4910	.4737	314.5	220.3	-214.7	96.0	95.8
18	.7276	.6800	.4857	.4733	308.8	264.6	-100.1	160.4	115.0
Average	.7422	.6979	.4985	.4724	305.0	268.2	-122.7	156.5	143.6
Theory	.8163	.6061	.4329	.4301	363.8	330.9	-45.9	223.3	246.3

Table 3: Average weights and realized payoffs in the experiment

4.1 Measuring overreaction

The experiment exhibits overreaction to public information in the sense of Morris and Shin (2002). For each treatment, the weight assigned to the public signal is significantly larger than the weight justified by its face value, i.e. by the first-order expectation of the fundamental. Student's t-tests (for all treatments and all groups) exhibit a significantly larger weight on the public signal in experimental data compared to that in the first-order expectation of the fundamental (in all cases, the p-value is 0.000).

Whereas subjects clearly do overreact to the public or semi-public signal, overreaction is not always as strong as theory predicts.¹² We compare the weight observed in the experiment to the equilibrium weight predicted by theory. For MS, the weight observed in the experiment is significantly lower than its theoretical value. The hypothesis according to which there is no difference between equilibrium and observed weight is rejected by the

weight difference in PP and PT in groups 1 to 6 with the weight difference in groups 7 to 12 ($p = 0.710$).

¹¹We also test for convergence effects by comparing the average weights on the public signal of the first half of periods to the second half of periods for each treatment but cannot find any difference in the samples.

¹²This has already been shown in the experiment of Cornand and Heinemann (2010) for the MS case.

Student's t-test for both groups 1-12 (p -value: $p = 0.000$) and groups 13-18 ($p = 0.005$). For PP and PT, the result depends on the groups considered. The weight assigned to the semi-public signal in PP does not significantly differ from its theoretical value for groups 1-12 ($p = 0.230$), but is significantly larger than its theoretical value for groups 13-18 ($p = 0.000$). For PT, there is no significant difference between the weight observed in the experiment and its theoretical value for groups 1-12 ($p = 0.880$), whereas the weight assigned to the semi-public signal in the experiment is significantly larger than its theoretical value for groups 13-18 ($p = 0.006$).

From these results, we can deduce that:

Result 2 *a) Subjects do overreact in all treatments. b) They overreact less than theory predicts in the MS-treatment. c) Whereas the weight assigned to the semi-public signal in the PP- and PT-treatment is not significantly different from its theoretical value when the private signal is as accurate as the (average) semi-public signal, it is larger than its theoretical value when the (average) semi-public signal is less accurate than the private signal.*

4.2 Testing communication strategies (treatment comparison)

As derived in Section 2.4 and Appendix A.5, PP and PT are equivalent in theory for reducing the overreaction to the public signal (relative to MS) and are calibrated in the experiment such that they induce the same average behavior of subjects. We compare observed weights of MS, PP, and PT with each other.

Average weight The average weight assigned to the public signal is significantly larger in MS than in PP or PT. The Student's t-test rejects the hypothesis that the average weight in MS is not different from the average weight in PP or PT with $p = 0.000$ for both groups 1-12 and 13-18. By contrast, there is no significant difference between PP and PT for groups 1 to 12 ($p = 0.348$). However, the weight assigned to the semi-public signal is larger in PP than in PT for groups 13 to 18 ($p = 0.028$).

Weight of informed subjects Although the average weight assigned to the semi-public signal is not significantly different in PP and PT when the private signal is as accurate as the semi-public signal (groups 1 to 12), the distribution of weights across subjects differs between both treatments. While only a subgroup of subjects receives the semi-public signal in PP, all subjects observe a semi-public signal in PT.

The weight assigned to the semi-public signal by the informed subjects in PP is not significantly different from the weight assigned to the public signal in MS for groups 1-12 ($p = 0.565$ for the paired Student's t-test). For groups 13-18, however, the weight put by informed subjects in PP on the semi-public signal is slightly smaller than the weight put on the public signal in MS, though almost not significantly so ($p = 0.051$).

Weight dispersion The difference between PP and PT also appears in the variance of weights across subjects within the same treatment. The theoretical variance of weights is zero in MS and PT because all subjects are expected to play the same strategy. By contrast, since informed subjects play a different strategy from uninformed subjects, the variance of weights is given by $P(1 - P)w$ in PP. In the experiment, all treatments yield variances that are higher than theoretically predicted.

The variances of weights in MS, PP for informed subjects, and PT do not significantly differ from each other, as illustrated on Figure 3. Indeed, the variance of weights in MS is not significantly different from that in PT (in groups 1-12 $p = 0.223$ for the paired Student's t-test; in groups 13-18 $p = 0.962$) and from that of weights put by informed subjects in PP (in groups 1-12 $p = 0.167$; in groups 13-18 $p = 0.113$). The variance of weights in PT is not significantly different from that of weights put by informed subjects in PP (in groups 1-12 $p = 0.818$; in groups 13-18 $p = 0.350$).

By contrast, the variance of weights over all – informed and uninformed – subjects in PP is significantly larger than in MS and PT.

Payoff The large variance of weights across subjects in PP is reflected in the payoff distribution, as illustrated in Figure 4. As theory predicts, the average payoff in MS significantly exceeds the average payoff in PP and PT, as well as the average payoff of informed subjects in PP ($p = 0.001$ for each paired Student's t-test). However, the average payoff in PP is not significantly different from the average payoff in PT ($p = 0.870$). But the average payoff of informed subjects in PP is significantly larger than the average payoff of subjects in PT and, of course, of uninformed subjects in PP ($p = 0.001$ for each paired Student's t-test). The large difference in payoffs between informed and uninformed subjects in PP raises fairness issues ex post if the game would not be repeated.

Comparative statics Our experimental design allows to test the effect of the relative precision of public and private signals on subjects' behavior. Whereas the private and the public signals have the same precision for groups 1 to 12, the private signal is more accurate than the public one for groups 13 to 18. To test the effect of relative precision, we compare the weight assigned to the public signal in groups 1 to 12 with groups 13 to 18, owing to a Student's t-test for each treatment (MS, PP, PT). Student's t-tests reject the hypothesis that weights are different depending on the relative precision of public and private signals ($p = 0.056$ for MS, $p = 0.44$ for PP, and $p = 0.19$ for PT).

Although there is no apparent effect of the relative precision on the weight assigned to the public signal, the weight tends to be larger in PP than in PT when the private signal is more accurate than the semi-public signal, as mentioned above. Indeed, it seems that when the private signal is more accurate, PT is more successful than PP to reduce overreaction.

Result 3 *As theory predicts, the experiment shows that, in aggregate, a) the average weight on the public signal is larger in the MS- than in the PP- and*

PT-treatments, b) and the difference between the average weight on the public signal in the PP- and PT-treatments is hardly significant. c) However, the average weight on the public signal of informed subjects in the PP-treatment is not significantly different from the average weight on the public signal in the MS-treatment.

5 Explaining behavior

In the aggregate data analysis of section 4, it is intriguing to observe that the average subjects' behavior is significantly different from the theoretical equilibrium in MS but not in PP and PT (see Section 4.1). Moreover, it may be surprising that PP yields an average weight which is broadly equivalent to that of PT, although the information structure and the reaction of subjects are fundamentally different in both treatments.

We consider alternative explanations for the observed behavior. Depending on the treatment, agents behave according to different schemes. In what follows we discuss the concept of limited level of reasoning, the existence of focal points, and the disregard of partial information dissemination as reasonable interpretation for the observed behavior.

5.1 Limited levels of reasoning

The relative difference in subjects' behavior across treatments suggests that subjects do not operate the same level of reasoning when playing MS or PP and PT. Given the degree of publicity and transparency of their signals, subjects attach indeed less importance to the coordination motive in MS than in PP and PT. The importance attached to the coordination motive can be measured with the number of reasoning (iteration) about common knowledge information that subjects operate when they make their decision.

As in Cornand and Heinemann (2010), the level-1 of reasoning is defined as the best response of subject i if he ignores the coordination motive in the payoff function, which corresponds to the first-order expectation $\mathbb{E}_i(\theta)$. The level-2 of reasoning is defined as the best response of subject i if he assumes that other agents play according to the level-1 of reasoning. And so on. Generally, the level- k of reasoning is defined as the best response of subject i if he assumes that other agents play according to the level- $k - 1$ of reasoning. The equilibrium behavior corresponds to the case where all subjects operate an infinite number of reasoning. Appendix C derives the weight assigned to the public signal for limited levels of reasoning.

Table 4 reports the results of Student's t-tests testing whether the observed weight assigned to the public signal is different or not from the theoretical weight for each treatment and each level of reasoning.¹³

For MS, the difference between the equilibrium and observed average weight is significant. This difference may be explained by limited levels of reasoning. For groups 1-12,

¹³The level of reasoning tested does not correspond to the average level of reasoning over subjects but to the level of reasoning of the average subject.

Treatment Groups	MS		Informed PP		PT	
	1-12	13-18	1-12	13-18	1-12	13-18
Level-1 (p-value)	.5000 (.000) rejected	.4000 (.000) rejected	.5000 (.000) rejected	.4000 (.000) rejected	.3509 (.000) rejected	.2778 (.000) rejected
Level-2 (p-value)	.7125 (.110) accepted	.6040 (.000) rejected	.6417 (.089) accepted	.5360 (.000) rejected	.4555 (.003) rejected	.3762 (.000) rejected
Level-3 (p-value)	.8028 (.001) rejected	.7080 (.120) accepted	.6818 (.710) accepted	.5822 (.000) rejected	.4867 (.280) accepted	.4110 (.001) rejected
Level-4 (p-value)	.8412 (.000) rejected	.7611 (.380) accepted	.6932 (.330) accepted	.5980 (.000) rejected	.4960 (.674) accepted	.4233 (.003) rejected
Level-5 (p-value)	.8575 (.000) rejected	.7882 (.048) rejected	.6964 (.260) accepted	.6033 (.000) rejected	.4988 (.820) accepted	.4277 (.005) rejected
Level-6 (p-value)	.8644 (.000) rejected	.8020 (.015) rejected	.6973 (.240) accepted	.6051 (.000) rejected	.4996 (.860) accepted	.4293 (.006) rejected
Level- ∞ (p-value)	.8696 (.000) rejected	.8163 (.005) rejected	.6977 (.230) accepted	.6061 (.000) rejected	.5000 (.880) accepted	.4301 (.006) rejected
Obs. weight	.6846	.7422	.6747	.6979	.5021	.4724

Table 4: Theoretical weights according to levels of reasoning and Student’s t-test results - Hypothesis test: the observed weight in the experiment is not different from the theoretical weight at specific levels of reasoning

we observe that subjects play on average strategies between level-1 and level-2 in MS (the theoretical weight in level-2 of reasoning is not significantly different from the weight observed in the experiment). This finding is in line with Cornand and Heinemann (2010) although with a slightly different design. However for groups 13-18, subjects seemed to have higher levels of reasoning, with an average located between level-3 and level-4. These levels of reasoning rather coincide with the findings of Nagel (1995) who considers a different, pure beauty contest, game. The fact that the weight is not significantly influenced by the relative precision of private and public signals is reflected by the higher level of reasoning in groups 13 to 18 than in groups 1 to 12. This analysis is also related to Shapiro et al. (2009) who analyze the predictive power of level-k reasoning in a game that combines features of Morris and Shin (2002) with the guessing game of Nagel (1995). They try to identify whether individual strategies are consistent with level-k reasoning. They argue that the predictive power of level-k reasoning is positively related to the strength of the coordination motive and the symmetry of information.

For PP, in groups 1 to 12, subjects play on average strategies between level-2 and level-3 of reasoning. Level-2 of reasoning and higher levels cannot however be rejected.

In groups 13 to 18, the observed weight is significantly larger than the equilibrium weight (level- ∞ of reasoning).

For PT, the weight observed in groups 1 to 12 and 13 to 18 is, on average, larger than the equilibrium weight implied by the level- ∞ of reasoning. However level-3 of reasoning and higher cannot be rejected for groups 1-12, whereas the observed average weight is significantly larger than the equilibrium weight for groups 13-18.

Overall, the behavior observed in MS can reasonably well be described in terms of limited levels of reasoning. However, limited levels of reasoning do not seem appropriate to explain the behavior observed in PP and PT because it would be suspicious to expect subjects to play a strategy corresponding to an infinite (or even higher) level of reasoning. This analysis suggests that the complexity of PP and PT makes subjects play differently from level- k reasoning. The subjects' behavior in PP and PT may rather be driven by focal points.

5.2 Distribution of individual weights and focal points

The distribution of individual weights allows us to classify the various strategies played by subjects and to identify the existence of focal points.¹⁴ Figure 9 plots the relative frequency of individual weights assigned to the public signal for each treatment.¹⁵ For PP, the weight distribution of informed subjects only is represented, as uninformed subjects do not react to the public signal. The dashed black line on each plot represents the theoretical equilibrium weight.

The distribution of individual weights reflects the existence of focal points in each treatment. In MS and for the informed subjects of PP, the relative frequency of the weights 0.5 and 1 clearly exceeds the frequency of the weights in their vicinity. This indicates that 0.5 and 1 qualify as focal points in MS and informed PP since subjects tend to focus their action on these arbitrary values.

In PT, 0.5 is clearly the most frequently played weight. Since 0.5 is the equilibrium weight for groups 1 to 12, one cannot distinguish whether subjects frequently play this weight because of its role as equilibrium or as focal point. However, the comparison with groups 13 to 18 suggests that it is rather the focal role which explains the behavior. Indeed, although the equilibrium value is smaller than 0.5 in groups 13 to 18, the relative frequency of playing 0.5 is even higher than in groups 1 to 12. The lower equilibrium weight in groups 13 to 18 does not significantly influence the relative frequency of the weight 0.5, emphasizing its role as focal point. The ambiguity surrounding PT induces subjects to play frequently the middle point of the weight interval for precautionary reason.

¹⁴In the guessing game of Nagel (1998), focal points mattered as well: while it was obvious for the subjects not to play 50 in large groups, in small groups ($n=3$) however, subjects play indeed 50.

¹⁵Appendix B provides plots for each group.

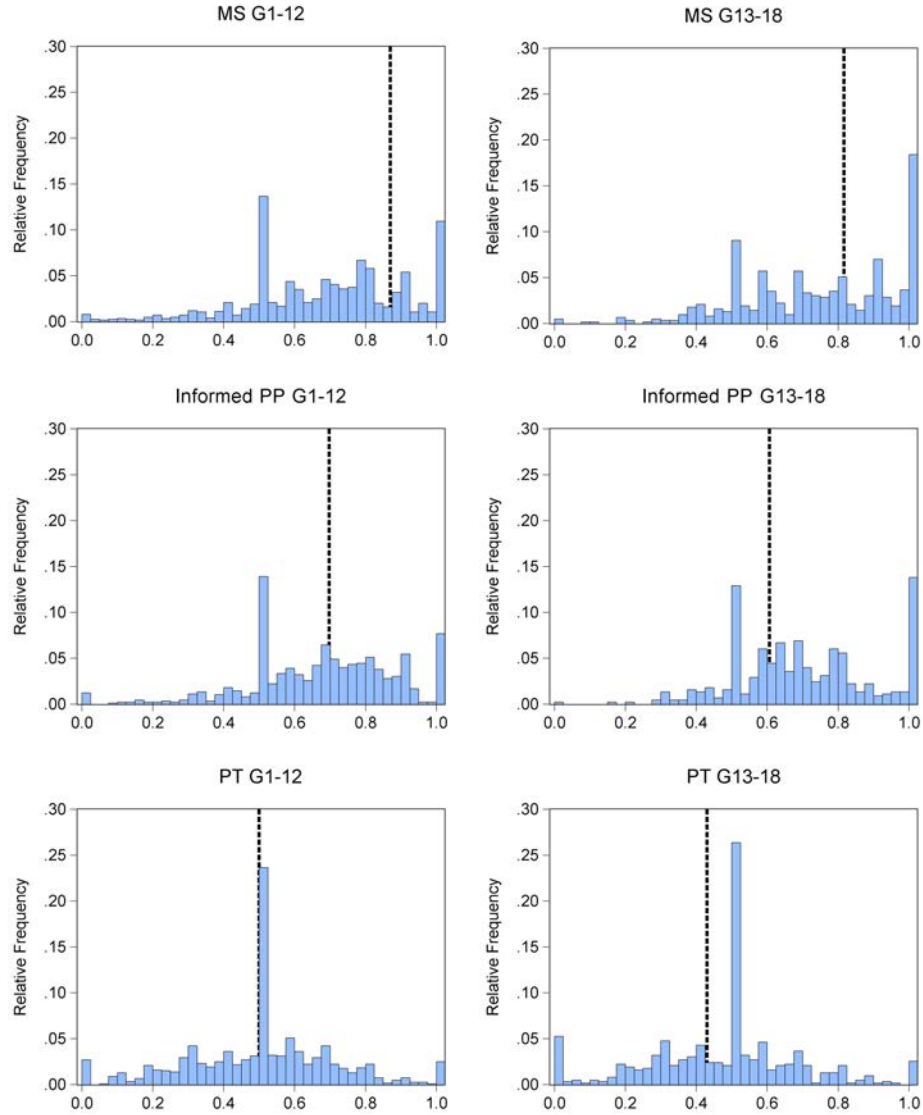


Figure 5: Relative frequency of weights assigned to the public signal

5.3 Playing equilibrium or disregarding partial publicity?

The behavior observed in PP for informed subjects cannot be significantly differentiated from the equilibrium behavior (as stated in section 4.1 for groups 1 to 12) and from the behavior in MS (as stated in section 4.2). Whereas the first observation suggests that informed subjects play on average the equilibrium weight in PP, the second is that informed subjects behave in PP according to the same scheme as in MS.

To distinguish between both conjectures, we analyze whether the individual behavior of any subject in MS helps predicting his own behavior in PP and PT. Regularities in the individual behavior in both MS and PP would suggest that informed subjects perceive PP not differently from MS. By contrast, the absence of regularities between MS and PP

Dependent Variable: Groups:	Weight informed PP		Weight PT	
	1-12	13-18	1-12	13-18
Independent Variable				
Constant	0.1983 (3.27)***	0.1896 (2.58)**	0.4230 (6.63)***	0.5132 (5.70)***
Weight MS	0.6928 (8.01)***	0.6800 (7.01)***	0.1156 (1.27)	-0.0550 (-0.46)
Observations (subjects)	84	42	84	42
Adj. R^2	0.4321	0.5400	0.0073	-0.0196

Note: Estimations conducted by OLS. Standard errors in parentheses. ***/**/* denote the significance level at 1%/5%/10% respectively.

Table 5: Correlation of individual average weights in MS and in informed PP vs. PT.

would rather speak for the ability of subjects to play the equilibrium strategy in PP.

We regress the individual average weight that each subject assigns to the public signal in PP or PT on the average weight he assigns in MS. Table 5 reports that the individual average weight in MS is significantly correlated with the individual average weight in PP, but not with the individual average weight in PT. This suggests that subjects tend to play according to the same strategy in MS and PP, but adopt a different strategy in PT.¹⁶

The fact that informed subjects play according to the same strategy in MS and PP can be rationalized in two ways. On the one hand, informed subjects in PP may have learned the focal role of public information in MS (which is played first) and tend then to play the same strategy, expecting other subjects to behave as in MS as well.¹⁷ On the other hand, independently of the experience gained in MS, informed subjects in PP may disregard the fact that some subjects do not observe the public signal and tend to play the same strategy as if they were facing MS.

Although we cannot directly disentangle between the two interpretations, it seems that the second one is more reasonable. Indeed, if subjects behaved routinely, they would play both in PP and in PT as they do in MS. Moreover, the fact that subjects of groups 7 to 12 play in PP as in MS after having played PT suggests that they disregard partial publicity, rather than they behave routinely.

These analyses indicate that PP succeeds in reducing the average overreaction simply

¹⁶Comparing the individual average weights in MS with those in PP leads to the same conclusion. The paired Student's t-test does not reject the hypothesis that individual average weights in MS are not different from individual average weights in PP for groups 1 to 12 ($p = 0.373$). This is however not true for groups 13 to 18 ($p = 0.005$) or for PT ($p = 0.000$). Moreover, the Student's t-test rejects the hypothesis that individual average weights in PP are not different from the equilibrium weight ($p = 0.000$).

¹⁷A way to check this issue would be to play PP first. But we are not directly interested in doing so because we want subjects to overreact to public information in the first place to analyze how much they adjust to communication strategies PP and PT.

because uninformed subjects are deprived of public signal, rather than because informed subjects react less strongly. By contrast, the ambiguity surrounding PT reduces the overreaction by influencing the behavior of subjects.

Result 4 *a) The concept of limited levels of reasoning rationalizes the average weight on the public signal observed in the MS-treatment, but not in the PP- and PT-treatments. b) The existence of focal points is identified with individual behavior in each treatment and particularly drives the outcome in the PT-treatment. c) Informed subjects in the PP-treatment behave according to the similar scheme as in the MS-treatment, suggesting that they disregard partial publicity.*

6 Policy recommendations

While practitioners in central banks agree on the desirability of informative announcements and promote higher transparency on the grounds that any information is valuable to markets,¹⁸ public announcements may, at the same time, destabilize markets by generating overreaction, as highlighted by Morris and Shin (2002). Since public announcements serve as focal points for market participants in predicting others' beliefs, they affect agents' behavior more than what would be justified by their informational contents. If public announcements are inaccurate or contain information that exacerbates economic inefficiencies, market overreaction can be detrimental to social welfare. Communicating with the public is therefore a challenging task for a central bank as its disclosures, relayed by the press, typically attract the full attention of financial markets.

From a theoretical point of view, we have shown that the central bank can control the overreaction of agents by reducing either the degree of publicity or the degree of transparency of its disclosure. Moreover, both communication strategies are equivalent in terms of efficiency for reducing overreaction, as shown in Section 2.4. Our experimental analysis is supportive of the theoretical prediction that both partial publicity and partial transparency equivalently succeed in reducing overreaction to the public signal. Indeed, the average weight on the public signal observed in the experiment is not significantly different in PP and in PT. Therefore our experiment does not directly allow us to formulate a clear preference for one or the other disclosure strategy. It however provides a basis for discussing the choice of either disclosure strategy.

Implementation of partial publicity and partial transparency To what extent can the central bank reduce overreaction by disclosing information with a limited degree of publicity or transparency? In the real world, as in our theoretical and experimental setup, the central bank can choose to release its information to a selected audience or to

¹⁸See for example Bernanke (2007) for the recent evolution of the Fed's communication of monetary policy.

release its information with ambiguity, such that its disclosure does not become common knowledge among market participants.

Partial publicity can be achieved by disclosing information to specific groups through media that reach only a part of all economic agents. There are several means by which central banks release information. Most important are central bank's own publications (hardcopies and Internet), press releases, press conferences, speeches and interviews, which are aimed at as wide an audience as possible. For publications, since the release date is announced beforehand, everybody has the chance of receiving the new information at the same time. Speeches and interviews, on the other hand, are directed first of all at those who are physically present, plus listeners if a speech is broadcasted. To reach a wider audience and avoid misinterpretation, the texts of important speeches are also disclosed and sometimes released via the Internet. However, speeches delivered in front of a small group of market participants are less widely reported than formal announcements and require more time to penetrate the whole community. Beliefs about the beliefs of other agents are less affected by these speeches than by formal publications at predetermined dates.¹⁹ The use of various communication channels to reach various target groups was advocated by Otmar Issing, former member of the board of the Deutsche Bundesbank and of the Executive Board of the European Central Bank, according to whom, there is a "*need to address various target groups, including academics, the markets, politicians, and the general public. Such a broad spectrum may require a variety of communication channels geared to different levels of complexity or different time horizons*" (Issing, 2005, p. 72).

However, one may question whether limiting the degree of publicity regarding important information is feasible in our information age, as media would quickly relay important information and raise the degree of publicity above the primary proportion of informed economic agents. Even if the central bank discloses information to a limited audience, this information is likely to be relayed by the press on a large scale, particularly if it seems important. In this sense, the degree of partial publicity can never be under the full control of the central bank.

Partial transparency can be achieved by disclosing information to every market participant but with some ambiguity. Partial transparency was common practice as central bankers were known for speaking with ambiguity. In 1987, the then chairman of the Federal Reserve Board, Alan Greenspan, took pride in being secretive: "*Since I've become a central banker, I've learned to mumble with great incoherence. If I seem unduly clear to you, you must have misunderstood what I said.*" More recently, Laurence Meyer, a former member of the Board of Governors of the Fed, emphasized that the interpretation of a

¹⁹For a discussion, see Cornand and Heinemann (2008) and Walsh (2006). For the limited attention attributed to speeches in comparison to written information Walsh (2006) argues (p. 230-231) that "*partial announcements can occur when, for example, central bankers make speeches about the economy that may not be as widely reported as formal announcements would be. Speeches and other means of providing partial information play an important role in the practice of central bankers, and these means of communication long predated publication of inflation reports. Speeches, like academic conferences, can be viewed as one means of providing information to only a limited subset of the public.*"

central banker's speech can be extremely different from what the central banker planned to say. In an interview with Fetting (1998), Meyer argues: "*the primary difficulty is the variety of interpretations that are given to what you say, especially by the different wire services. So, you try to be disciplined and communicate as effectively as you can, and then you give a speech and get 10 varying interpretations of what you said, often with a lot of liberties taken in the interpretation*". This statement suggests that overreaction can be easily controlled by means of partial transparency, as disclosures naturally tend to be interpreted with ambiguity by the audience.

The choice of controlling overreaction by means of partial publicity or transparency also depends on the type of information disclosed. The central bank may prefer implementing either communication strategy according to the nature of its information. Typically, partial transparency appears inappropriate for controlling the disclosure of numerical or quantitative information. It seems *a priori* difficult to imagine how the central bank could potentially disclose a numerical value with ambiguity. In this case, the central bank may prefer to disclose its information through channels which are less widely reported in order to reduce the audience.

Nevertheless, the central bank can also disclose quantitative information such as inflation forecast or balance sheet positions with ambiguity. The central bank can indeed control the ambiguity surrounding its inflation forecast by varying the spread of the confidence interval of the fan chart. Widening the confidence interval contributes to raising uncertainty in the interpretation of the central bank's forecast. Or, for example, the central bank which intervenes on the foreign exchange market can create ambiguity about the extent of its interventions by muddling up on the same balance sheet position its reserves resulting from straight interventions with that resulting from currency swaps.

Discrimination and fairness Another drawback associated with disclosing information by means of partial publicity (and which makes a case in favor of partial transparency) rests on discriminatory issues. Disclosing information only to a limited audience seems unfair and arbitrary.²⁰ In democratic societies, central banks' independence needs to be underpinned by accountability and transparency. Hence, the central bank may find it politically untenable to withhold important information from even parts of the public. By contrast, providing the same information with the same degree of ambiguity to the public as a whole does not create any discrimination. In this respect, partial transparency can be preferable to partial publicity. This may explain why central banks increasingly promote more publicity, as illustrated by the first press conference in the history of the Fed, held in April 2011. As quoted in the Financial Times (2011), Fed officials '*note the importance of fair and equal access by the public to information*'. This is one reason why, as of recently, the Fed holds regular press conferences to better explain monetary policy to the public,

²⁰Compared to a one shot game, discrimination and unfairness are reduced in the experiment because uninformed subjects in the partial publicity treatment are drawn randomly and independently in each of the 15 periods.

as is already common practice among many central banks.²¹

7 Conclusion

Central banks give much importance to their communication strategy because financial markets are known for overreacting to public information. Since shaping market expectations plays a key role in the conduct of monetary policy, central banks often seek to exert the maximal impact on market expectations with their public disclosures. However, they may sometimes prefer to avoid overreaction to their disclosures either when disclosures are uncertain or when disclosures contain information which creates economic inefficiencies. Controlling the level of overreaction is therefore an important and challenging task for a central bank.

The central bank can control the degree of overreaction by means of two different communication strategies. First, the central bank can reduce overreaction with partial publicity, that is by disclosing information to a subgroup of market participants only. Second, the central bank can reduce overreaction with partial transparency, that is by disclosing information to all market participants but with some ambiguity. We show that both strategies are equivalent from a theoretical perspective in the sense that overreaction can be controlled equivalently by means of partial publicity or partial transparency, and that both communication strategies yield the same expected welfare. These theoretical predictions are tested within a laboratory experiment, which confirms the effectiveness of both communication strategies for reducing overreaction. Moreover, the equivalence of both strategies cannot be rejected, as they both lead to the same degree of common knowledge in the lab.

Although neither the theory nor the experiment allows the formulation of a clear preference in favor of either communication strategy, when both strategies are possible, this paper makes a case for partial transparency rather than partial publicity, because the latter seems increasingly difficult to implement in the information age and is associated with discrimination as well as fairness issues.

²¹The announcement of regular press briefings of the Fed chairman is an additional step toward more transparency at the Fed. A previous important step was taken in 1994, when the Fed started to communicate its interest rate decisions in a statement released at the end of the meetings of its Monetary Policy Committee.

References

- Allen, F., Morris, S., and Shin, H. S. (2006). Beauty contests and iterated expectations in asset markets. *Review of Financial Studies*, 19:719–752.
- Amato, J., Morris, S., and Shin, H. S. (2002). Communication and monetary policy. *Oxford Review of Economic Policy*, 18(4):495–503.
- Angeletos, G.-M. and Pavan, A. (2004). Transparency of Information and Coordination in Economies with Investment Complementarities. *American Economic Review (Papers and Proceedings)*, 94(2):91–98.
- Angeletos, G.-M. and Pavan, A. (2007). Efficient use of information and social value of information. *Econometrica*, 75(4):1103–1142.
- Baeriswyl, R. (2011). Endogenous central bank information and the optimal degree of transparency. *International Journal of Central Banking*, 7(2):85–111.
- Baeriswyl, R. and Cornand, C. (2010). The signaling role of policy actions. *Journal of Monetary Economics*, 57(6):682–695.
- Bernanke, B. S. (2007). Federal reserve communications. *Speech at the Cato Institute 25th Annual Monetary Conference, Washington, D.C., November 14*.
- Cabrales, A., Nagel, R., and Armenter, R. (2007). Equilibrium selection through incomplete information in coordination games: An experimental study. *Experimental Economics*, 10(3):221–234.
- Cornand, C. (2006). Speculative attack and informational structure: An experimental study. *Review of International Economics*, 14:797–817.
- Cornand, C. and Heinemann, F. (2008). Optimal degree of public information dissemination. *Economic Journal*, 118:718–742.
- Cornand, C. and Heinemann, F. (2010). Measuring agents’ reaction to private and public information in games with strategic complementarities. *Mimeo*.
- Fettig, D. (1998). Interview with federal reserve governor laurence meyer. *The Region, Federal Reserve Bank of Minneapolis*, (September, http://www.minneapolisfed.org/publications_papers/pub_display.cfm?id=3598).
- Financial Times (2011). Fed unveils plan for regular press conferences. (25 mars).
- Gai, P. and Shin, H. (2003). Transparency and financial stability. *Financial Stability Review*, 15:91–98.
- Gao, P. (2008). Keynesian beauty contest, accounting disclosure, and market efficiency. *Journal of Accounting Research*, 46:785–807.

- Heinemann, F. and Illing, G. (2002). Speculative attacks: Unique sunspot equilibrium and transparency. *Journal of International Economics*, 58:429–450.
- Heinemann, F., Nagel, R., and Ockenfels, P. (2004). The theory of global games on test: Experimental analysis of coordination games with public and private information. *Econometrica*, 72(5):1583–1599.
- Hellwig, C. (2005). Heterogeneous information and the welfare effects of public information disclosures. *mimeo*, www.econ.ucla.edu/people/papers/Hellwig/Hellwig283.pdf.
- Hellwig, C. and Veldkamp, L. (2009). Knowing what others know: Coordination motives in information acquisition. *Review of Economic Studies*, 76:223–251.
- Morris, S. and Shin, H. S. (2002). Social value of public information. *American Economic Review*, 92(5):1521–1534.
- Morris, S. and Shin, H. S. (2004). Coordination risk and the price of debt. *European Economic Review*, 48:133–153.
- Nagel, R. (1995). Unraveling in guessing games: An experimental study. *American Economic Review*, 85:1313–1326.
- Nagel, R. (1998). A survey on experimental 'beauty-contest games': bounded rationality and learning. In D. Budescu, I. E. and R. Zwick, editors, *Games and Human Behavior, Essays in Honor of Amnon Rapoport*, volume pp. 105-142. Lawrence Erlbaum Associates, Inc., New Jersey.
- Shapiro, D., Shi, X., and Zillante, A. (2009). Robustness of level-k reasoning in modified beauty contest games. *mimeo*.
- Stahl, D. O. and Wilson, P. W. (1994). Experimental evidence on players' models of other players. *Journal of Economic Behavior and Organization*, 25:309–327.
- Svensson, L. E. (2006). Social value of public information: Morris and Shin (2002) is actually pro transparency, not con. *American Economic Review*, 96(1):448–451.
- Walsh, C. E. (2006). Transparency, flexibility, and inflation targeting. In Mishkin, F. and Schmidt-Hebbel, K., editors, *Monetary Policy under Inflation Targeting*. Central Bank of Chile, Santiago, Chile.

A The experimental setup

This Appendix discusses our choice of subjects' utility function for the experiment and presents how the theoretical model in Section 2 is adjusted to the experimental framework. The model is modified in two respects. First, the number of subjects is finite and is written n (instead of a *continuum* of agents) and second, the distribution of error terms is uniform (instead of normal).

A.1 Agents' utility and social welfare

The utility function for agent i is chosen to deliver the optimal action of agent i (the first order condition) in the form:

$$a_i = (1 - r)\mathbb{E}_i(\theta) + r\mathbb{E}_i(\bar{a}). \quad (17)$$

Many possible utility functions yield an optimal action in this form.

A.1.1 The utility function of Morris and Shin (2002)

A natural choice of the utility function would be that proposed by Morris and Shin (2002), in which the beauty contest term is a zero-sum game:

$$u_{i,MS}(a, \theta) \equiv -(1 - r)(a_i - \theta)^2 - r(F_i - \bar{F}), \quad (18)$$

with $F_i \equiv \int_0^1 (a_j - a_i)^2 dj$ and $\bar{F} \equiv \int_0^1 F_j dj$.

Averaging (and normalizing) utility (18) over all agents delivers the social loss:

$$L_{MS}(a, \theta) \equiv \frac{-1}{(1 - r)} \int_0^1 u_{i,MS}(a, \theta) di = \int_0^1 (a_i - \theta)^2 di = \int_i (a_i - \bar{a})^2 di + (\theta - \bar{a})^2. \quad (19)$$

This social loss has the same form as (1) in the text with $\lambda = 1$.

Although this specification of utility proposed by MS has some appealing features, we do not borrow this specification for our experiment because of its complexity. There is indeed a strong presumption that subjects would have difficulties to understand the formulation of (18) and to derive their optimal action. For this reason, we prefer a simplified utility function which also yields the optimal action (17).

A.1.2 A simple utility function

The chosen utility function of agent i is given by:

$$u_i(a, \theta) \equiv -(1 - r)(a_i - \theta)^2 - r(a_i - \bar{a})^2. \quad (20)$$

Averaging utility (20) over all agents delivers the social loss:

$$L(a, \theta) \equiv - \int_0^1 u_i(a, \theta) di = \int_i (a_i - \bar{a})^2 di + (1 - r)(\theta - \bar{a})^2. \quad (21)$$

This social loss has also the same form as (1) in the text but with $\lambda = 1 - r$.

Recall that the choice of the utility function (between (20) and (18)) has no incidence on the theoretical optimal action of agents given by (17). Therefore, it does not alter the purpose of the experiment, namely testing agents' reaction given their optimal action (17) for alternative disclosure strategies.

However, the choice of the utility function has an impact on the social loss defined as the average agents' utility and, thereby, on the optimal disclosure strategy. If the social loss is defined as (21), it becomes evident from equations (9) and (13) in the text, and with $\lambda = 1 - r$, that full publicity vs. transparency would be the optimal communication strategy, as in Hellwig (2005). This explains why, in the experiment, agents' utility is inferior in the PP- and PT-treatments than in the MS-treatment. But the question whether the implemented disclosure strategies are optimal given the social loss (19) or (21) is without relevance for the purpose of the experiment. If we would have chosen the same agents' utility as Morris and Shin (2002), then the social loss would have been smaller with limited publicity vs. transparency, but the utility function would have been too complicated for the experiment.

Since the experiment is run with a limited number of subject (instead of a *continuum* of agents), the utility function of subject i can be written

$$u_i(a, \theta) \equiv -(1 - r)(a_i - \theta)^2 - r(a_i - a_{-i})^2, \quad (22)$$

where a_i is the action taken by subject i and a_{-i} is the average action taken by the other subjects $-i$.

A.2 Pure public signal (MS)

In the MS-treatment, subjects receive two signals that deviate from the fundamental θ by some error terms with uniform distribution. All subjects receive the same public signal $y \sim U[\theta \pm \eta]$. In addition, each subject receives a private signal $x_i \sim U[\theta \pm \epsilon]$. Noise terms $x_i - \theta$ of distinct subjects and the noise $y - \theta$ of the public signal are independent and their distribution is treated as exogenously given.

In equilibrium, the optimal average action over all subjects is given by

$$\bar{a} = \underbrace{\frac{(1 - r)\eta}{\epsilon + (1 - r)\eta}}_{1 - w_{ms}} \bar{x} + \underbrace{\frac{\epsilon}{\epsilon + (1 - r)\eta}}_{w_{ms}} y. \quad (23)$$

To compute the expected payoff in the experiment, we derive the corresponding ex-

pected utility (22) of subject i for the optimal behavior (23)

$$\begin{aligned}\mathbb{E}\left(u_i(a, \theta)\right) &= \mathbb{E}\left(- (1-r)\left((1-w_{ms})(\theta+\epsilon)+w_{ms}(\theta+\eta)-\theta\right)^2\right. \\ &\quad \left.-r\left((1-w_{ms})(\theta+\epsilon)+w_{ms}(\theta+\eta)-(1-w_{ms})\theta-w_{ms}(\theta+\eta)\right)^2\right) \\ &= -(1-w_{ms})^2\text{Var}(\epsilon)-(1-r)w_{ms}^2\text{Var}(\eta).\end{aligned}$$

A.3 Partial publicity (PP)

In the PP-treatment, subjects may receive two kinds of signals that deviate from the fundamental θ by some error terms with uniform distribution. Each subject receives a private signal $x_i \sim U[\theta \pm \epsilon]$. A proportion $P = p/n$ of subjects receives a semi-public (common) signal $y \sim U[\theta \pm \eta]$. p/n is the degree of publicity. If the subject i gets the public signal, $(p-1)/(n-1)$ is the fraction of other players who also gets the public signal.

The optimal action of uninformed subjects who get only the private signal is

$$a_{i,-p} = x_i.$$

The optimal action of informed subjects who get both the private and the semi-public signal is

$$\begin{aligned}a_{i,p} &= (1-w_{pp})x_i + w_{pp}y = (1-r)\mathbb{E}_i(\theta) + r\left[\frac{n-p}{n-1}\mathbb{E}_i(\theta) + \frac{p-1}{n-1}((1-w_{pp})\mathbb{E}_i(\theta) + w_{pp}y)\right] \\ &= \underbrace{\frac{(1-r\frac{p-1}{n-1})\eta}{\epsilon + (1-r\frac{p-1}{n-1})\eta}}_{1-w_{pp}}x_i + \underbrace{\frac{\epsilon}{\epsilon + (1-r\frac{p-1}{n-1})\eta}}_{w_{pp}}y.\end{aligned}$$

In equilibrium, the average action over all subjects is given by

$$\begin{aligned}\bar{a} &= \left(1 - \frac{p}{n}\right)\bar{x}_{-p} + \frac{p}{n}\left[\frac{(1-r\frac{p-1}{n-1})\eta\bar{x}_p + \epsilon y}{\epsilon + (1-r\frac{p-1}{n-1})\eta}\right] \\ &= \underbrace{\frac{\frac{n-p}{n}\epsilon + (1-r\frac{p-1}{n-1})\eta}{\epsilon + (1-r\frac{p-1}{n-1})\eta}}_{1-\bar{w}_{pp}}\bar{x} + \underbrace{\frac{\frac{p}{n}\epsilon}{\epsilon + (1-r\frac{p-1}{n-1})\eta}}_{\bar{w}_{pp}}y.\end{aligned}\tag{24}$$

To express the expected utility for subject i , we define $\tilde{w}_{pp} = \frac{p}{n-1}w_{pp}$ and $\hat{w}_{pp} = \frac{p-1}{n-1}w_{pp}$. The expected utility of subject without public signal is given by (we assume that $\bar{\theta} = \theta$)

$$\begin{aligned}\mathbb{E}\left(u_i(a, \theta)\right) &= \mathbb{E}\left(- (1-r)\left(\theta + \epsilon - \theta\right)^2 - r\left(\theta + \epsilon - (1-\tilde{w}_{pp})\theta - \tilde{w}_{pp}(\theta + \eta)\right)^2\right) \\ &= -\text{Var}(\epsilon) - r\tilde{w}_{pp}^2\text{Var}(\eta),\end{aligned}$$

while the expected utility for subjects with public signal yields

$$\begin{aligned}\mathbb{E}\left(u_i(a, \theta)\right) &= \mathbb{E}\left(- (1-r)\left((1-w_{pp})(\theta+\epsilon)+w_{pp}(\theta+\eta)-\theta\right)^2\right. \\ &\quad \left.-r\left((1-w_{pp})(\theta+\epsilon)+w_{pp}(\theta+\eta)-(1-\hat{w}_{pp})\theta-\hat{w}_{pp}(\theta+\eta)\right)^2\right) \\ &= -(1-w_{pp})^2\text{Var}(\epsilon)-(1-r)w_{pp}^2\text{Var}(\eta)-r(w_{pp}-\hat{w}_{pp})^2\text{Var}(\eta).\end{aligned}$$

Aggregating over all subjects, we get

$$\begin{aligned}\mathbb{E}\left(u_i(a, \theta)\right) &= -\left[\frac{n-p}{n}+\frac{p}{n}(1-w_{pp})^2\right]\text{Var}(\epsilon) \\ &\quad -\left[\frac{n-p}{n}r\hat{w}_{pp}^2+\frac{p}{n}(1-r)w_{pp}^2+\frac{p}{n}r(w_{pp}-\hat{w}_{pp})^2\right]\text{Var}(\eta).\end{aligned}\quad (25)$$

A.4 Partial transparency (PT)

In the PT-treatment, subjects receive two signals that deviate from the fundamental θ by some error terms with uniform distribution. Each subject receives a private signal $x_i \sim U[\theta \pm \epsilon]$ and a semi-public signal $y_i \sim U[\theta \pm \eta \pm \phi]$, where y_i is drawn for each subject i individually from $U[y \pm \phi]$ and where $y \sim U[\theta \pm \eta]$.

In equilibrium, the optimal average action over all subjects is given by

$$\bar{a} = \underbrace{\frac{(1-r)\eta + \phi}{\epsilon + (1-r)\eta + \phi}}_{1-w_{pt}} \bar{x} + \underbrace{\frac{\epsilon}{\epsilon + (1-r)\eta + \phi}}_{w_{pt}} \bar{y}, \quad (26)$$

and the expected utility yields

$$\begin{aligned}\mathbb{E}\left(u_i(a, \theta)\right) &= \mathbb{E}\left(- (1-r)\left((1-w_{pt})(\theta+\epsilon)+w_{pt}(\theta+\eta+\phi)-\theta\right)^2\right. \\ &\quad \left.-r\left((1-w_{pt})(\theta+\epsilon)+w_{pt}(\theta+\eta+\phi)-(1-w_{pt})\theta-w_{pt}(\theta+\eta)\right)^2\right) \\ &= -(1-w_{pt})^2\text{Var}(\epsilon)-w_{pt}^2\text{Var}(\phi)-(1-r)w_{pt}^2\text{Var}(\eta).\end{aligned}\quad (27)$$

A.5 Equivalence between partial publicity and partial transparency

As expressed in Section 2.4, we can show that both the PP- and PT-treatments are equivalent for reducing overreaction to the public signal. The equivalence relationship between the degree of publicity p/n and the degree of transparency ϕ is obtained by equalling the optimal average weight \bar{w}_{pp} on the public signal in the PP-treatment (24) with the optimal average weight w_{pt} on the public signal in the PT-treatment (26):

$$\frac{\frac{p}{n}\epsilon}{\epsilon + (1-r)\frac{p-1}{n-1}\eta} = \frac{\epsilon}{\epsilon + (1-r)\eta + \phi},$$

which implies

$$\frac{p}{n} = \frac{(n-1)(\epsilon + \eta) + r\eta}{(n-1)(\epsilon + \eta + \phi) + r\eta} \quad \text{or} \quad \phi = \frac{n-p}{p} \left(\epsilon + \eta + \frac{r\eta}{n-1} \right). \quad (28)$$

It can be shown that the expected utility in PP (25) is equivalent to the expected utility in PT (27) when the equivalence relationship (28) holds if the variance of error terms satisfy $\text{Var}(\epsilon) = \epsilon$, $\text{Var}(\eta) = \eta$, and if the number of subjects is infinite, i.e. n and $p \rightarrow \infty$.

However, these last three conditions do not hold in the experiment because error terms are uniformly distributed and because the number of subject is limited. Consequently, expected utilities in PP and in PT are not exactly identical in the experiment. The fact that the PP- and the PT-treatments are not equivalent in terms of subjects' expected utility does not sap the purpose of the experiment since it aims at testing the behavior of subjects in the face of two alternative information structures and not at testing whether utility or welfare is identical in both treatments.

B Average weights and distribution of weights per group

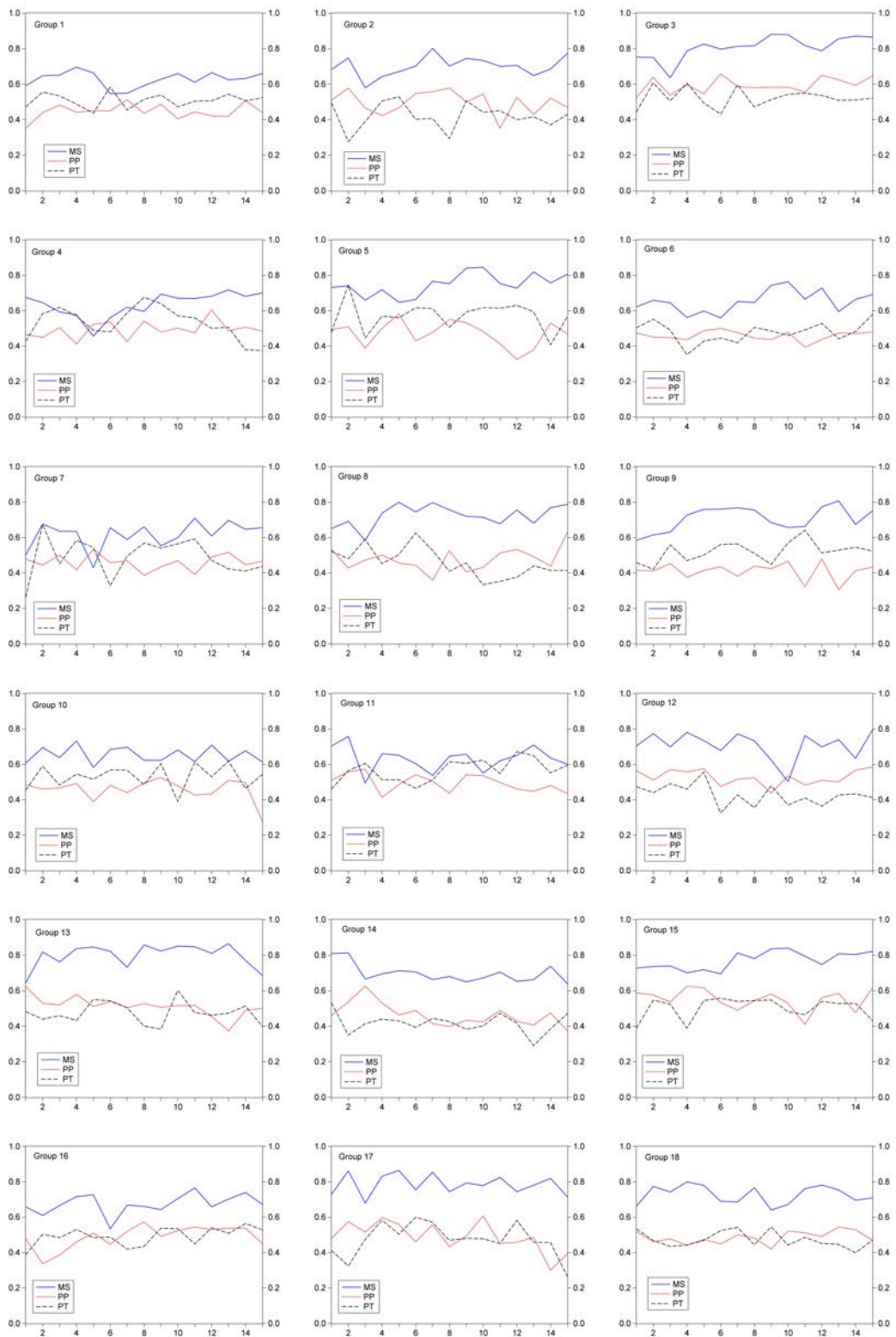


Figure 6: Average weight assigned to the public signal for each group over 15 periods

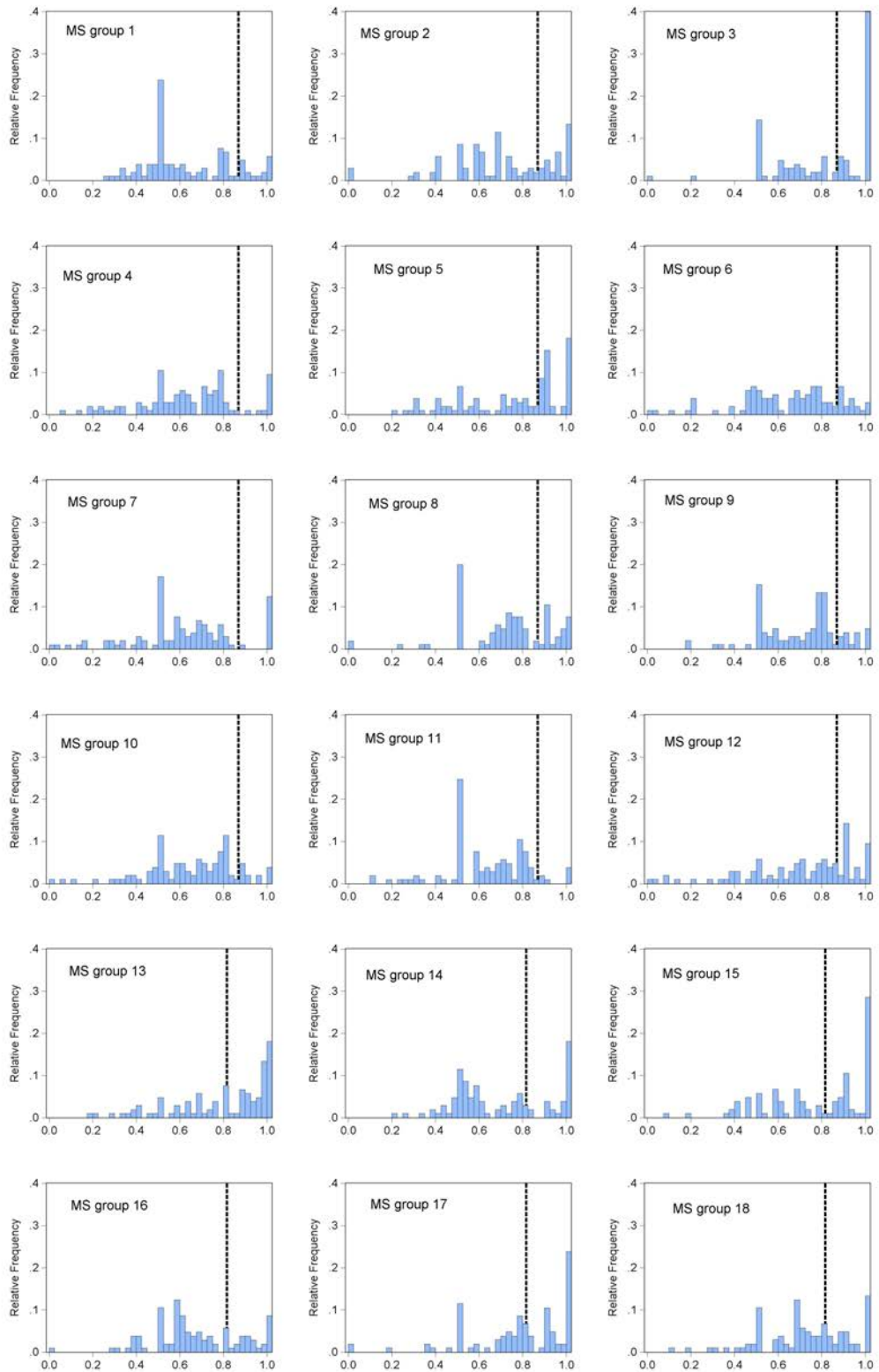


Figure 7: Relative frequency of weights assigned to the public signal in the MS-treatment

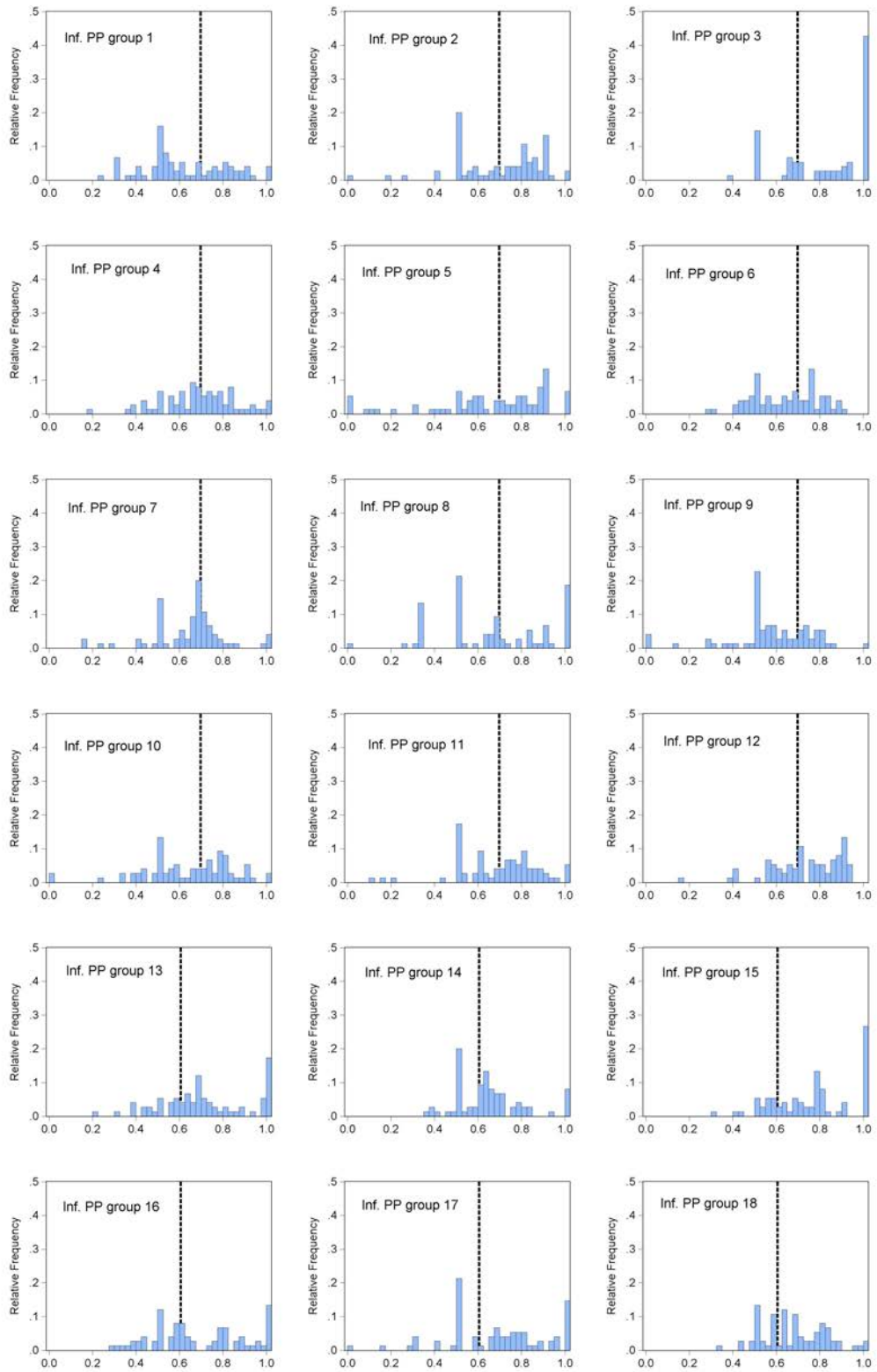


Figure 8: Relative frequency of weights assigned to the public signal in the informed PP-treatment

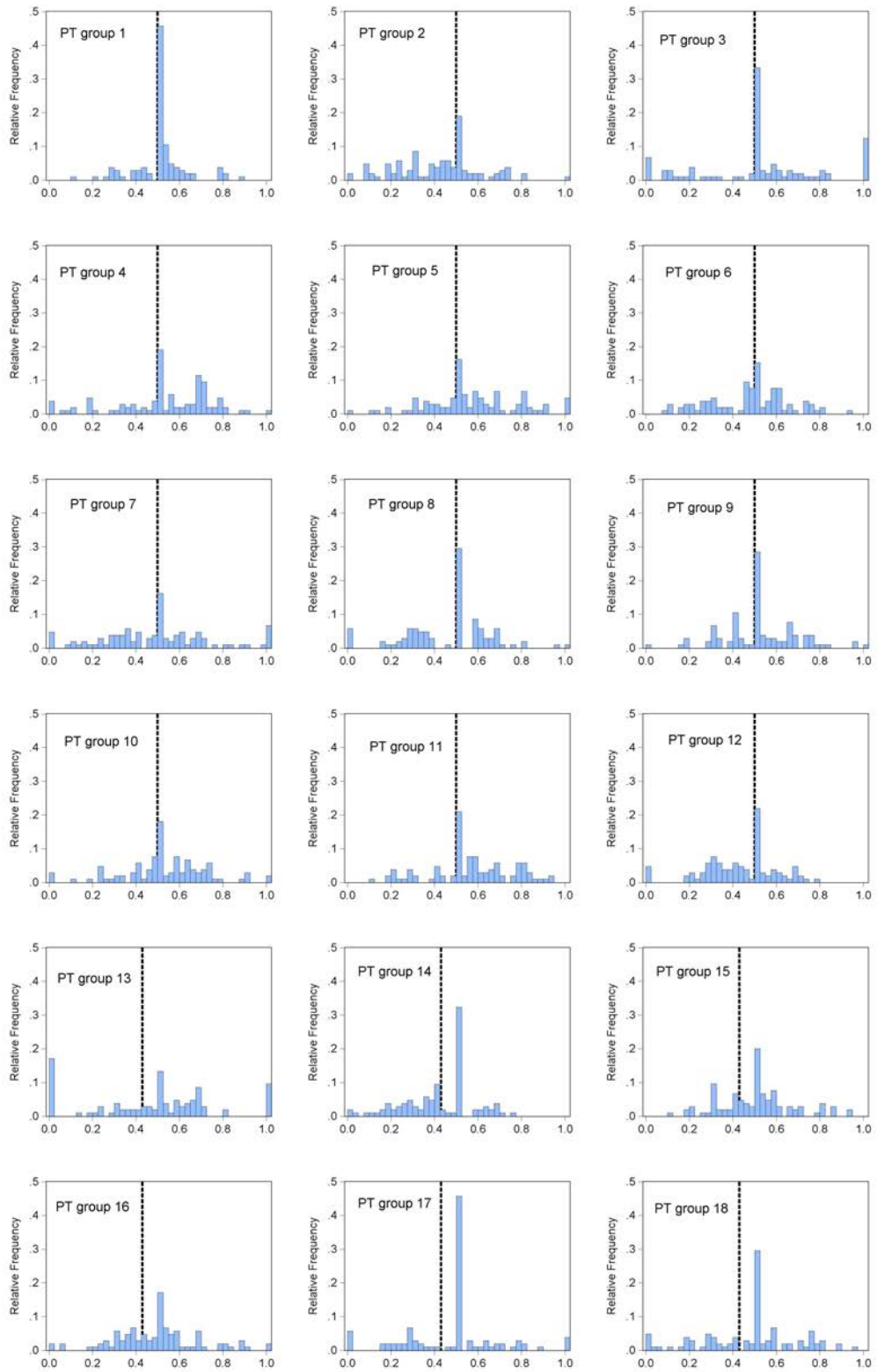


Figure 9: Relative frequency of weights assigned to the public signal in the PT-treatment

C Limited level of reasoning

This appendix presents the derivation of weights put on the public signal in actions corresponding to limited levels of reasoning about decisions of others for the version of the model set in appendix A.

We define level-1 players as players who ignore the strategic part of the payoff function so that $a_i^1 = \mathbb{E}_i(\theta)$.²² This also corresponds to the level-1 in Cornand and Heinemann (2010). The weight on the public signal for agents with limited levels of reasoning depends on the considered treatment as well as parameter values. In this appendix, we derive level-1 and levels of higher order for the MS-, PP- and PT-treatments respectively.

C.1 Pure public signal (MS)

Starting from the definition of level-1, actions for higher levels of reasoning in the MS-treatment can be calculated as follows.

Suppose that the players $-i$ (all players except player i) attach weight ρ_k to the public signal. The best response of player i to such behavior is:

$$\begin{aligned} a_i^{k+1} &= (1-r)\mathbb{E}_i(\theta) + r\mathbb{E}_i(a_{-i}) \\ &= (1-r)\mathbb{E}_i(\theta) + r(1-\rho_k)\mathbb{E}_i(x_{-i}) + r\rho_k y. \end{aligned}$$

Since the expected private signal of the other player equals the expected state,

$$\begin{aligned} a_i^{k+1} &= [(1-r\rho_k)]\mathbb{E}_i(\theta) + r\rho_k y \\ &= \frac{(1-r\rho_k)\eta}{\epsilon + \eta} x_i + \left[\frac{(1-r\rho_k)\epsilon}{\epsilon + \eta} + r\rho_k \right] y. \end{aligned}$$

Hence the weight on the public signal for the next level of reasoning is:

$$\rho_{k+1} = \frac{\epsilon + r\eta\rho_k}{\epsilon + \eta}.$$

With the experimental parameters of groups 1 to 12, we get the following weights for the level of reasoning k : $\rho_1 = 0.5$, $\rho_2 = 0.7125$, $\rho_3 = 0.8028$, $\rho_4 = 0.8412$, $\rho_5 = 0.8575$, and $\rho_\infty = 0.8696$. With the experimental parameters of groups 13 to 18, we get: $\rho_1 = 0.4$, $\rho_2 = 0.6040$, $\rho_3 = 0.7080$, $\rho_4 = 0.7611$, $\rho_5 = 0.7882$, and $\rho_\infty = 0.8163$.

C.2 Partial publicity (PP)

Starting from the definition of level-1, actions for higher levels of reasoning in the PP-treatment can be calculated as follows.

²²Nagel (1995) and Stahl and Wilson (1994) define level-0 types as subjects who choose an action randomly from a uniform distribution over all possible actions. For $k > 0$, a level- k type is playing best response to level- $k-1$. The best response to a uniform distribution over all reals is $a_i^1 = \mathbb{E}_i(\theta)$.

For subjects who only receive the private signal, they have no choice but playing $a_{i,-p} = x_i$.

For subjects who receive both signals, we proceed as in C.1 and suppose that the players $-i$ (all players except player i) attach weight ρ_k to the public signal. The best response of player i to such behavior is:

$$\begin{aligned} a_{i,p}^{k+1} &= (1 - \rho_{k+1})x_i + \rho_{k+1}y = (1 - r)\mathbb{E}_i(\theta) + r \left[\frac{n-p}{n-1}\mathbb{E}_i(\theta) + \frac{p-1}{n-1}((1 - \rho_k)\mathbb{E}_i(\theta) + \rho_k y) \right] \\ &= \underbrace{\frac{(n-1 - (p-1)\rho)\eta}{(n-1)(\epsilon + \eta)}}_{1-\rho_{k+1}} x_i + \underbrace{\frac{(n-1)\epsilon + (p-1)r\eta\rho_k}{(n-1)(\epsilon + \eta)}}_{\rho_{k+1}} y. \end{aligned}$$

Hence the weight on the public signal for the next level of reasoning is:

$$\rho_{k+1} = \frac{(n-1)\epsilon + (p-1)r\eta\rho_k}{(n-1)(\epsilon + \eta)}.$$

Averaging over all agents:

$$\begin{aligned} \bar{a}_{i,p}^{k+1} &= (1 - \bar{\rho}_{k+1})x_i + \bar{\rho}_{k+1}y \\ &= \underbrace{1 - \frac{p((n-1)\epsilon + (p-1)r\eta\rho_k)}{n(n-1)(\epsilon + \eta)}}_{1-\bar{\rho}_{k+1}} x_i + \underbrace{\frac{p((n-1)\epsilon + (p-1)r\eta\rho_k)}{n(n-1)(\epsilon + \eta)}}_{\bar{\rho}_{k+1}} y. \end{aligned}$$

With the experimental parameters of groups 1 to 12, we get the following weights for the level of reasoning k : $\bar{\rho}_1 = 0.3571$, $\bar{\rho}_2 = 0.4583$, $\bar{\rho}_3 = 0.4870$, $\bar{\rho}_4 = 0.4951$, $\bar{\rho}_5 = 0.4974$, and $\bar{\rho}_\infty = 0.4983$, or $\rho_1 = 0.5$, $\rho_2 = 0.6416$, $\rho_3 = 0.6818$, $\rho_4 = 0.6932$, $\rho_5 = 0.6964$, and $\rho_\infty = 0.6977$. With the experimental parameters of groups 13 to 18, we get: $\bar{\rho}_1 = 0.2857$, $\bar{\rho}_2 = 0.3829$, $\bar{\rho}_3 = 0.4159$, $\bar{\rho}_4 = 0.4271$, $\bar{\rho}_5 = 0.4309$, and $\bar{\rho}_\infty = 0.4329$ or $\rho_1 = 0.4$, $\rho_2 = 0.536$, $\rho_3 = 0.5822$, $\rho_4 = 0.5980$, $\rho_5 = 0.6033$, and $\rho_\infty = 0.6061$.

C.3 Partial transparency (PT)

Proceeding as earlier,

$$\begin{aligned} a_i^{k+1} &= (1 - r)\mathbb{E}_i(\theta) + r\mathbb{E}_i(a_{-i}) \\ &= (1 - r)\mathbb{E}_i(\theta) + r(1 - \rho_k)\mathbb{E}_i(x_{-i}) + r\rho_k y. \end{aligned}$$

Since the expected private signal of the other player equals the expected state,

$$\begin{aligned} a_i^{k+1} &= [(1 - r\rho_k)]\mathbb{E}_i(\theta) + r\rho_k y \\ &= \frac{(1 - r\rho_k)(\eta + \phi)}{\epsilon + \eta + \phi} x_i + \left[\frac{(1 - r\rho_k)\epsilon}{\epsilon + \eta + \phi} + r\rho_k \right] y. \end{aligned}$$

Hence the weight on the public signal for the next level of reasoning is:

$$\rho_{k+1} = \frac{\epsilon + r\eta\rho_k}{\epsilon + \eta + \phi}.$$

With the experimental parameters of groups 1 to 12, we get the following weights for the level of reasoning k : $\rho_1 = 0.3509$, $\rho_2 = 0.4555$, $\rho_3 = 0.4867$, $\rho_4 = 0.4960$, $\rho_5 = 0.4988$, and $\rho_\infty = 0.5$. With the experimental parameters of groups 13 to 18, we get: $\rho_1 = 0.2778$, $\rho_2 = 0.3762$, $\rho_3 = 0.4110$, $\rho_4 = 0.4233$, $\rho_5 = 0.4277$, and $\rho_\infty = 0.4301$.

D Instructions

Instructions to participants varied according to the treatments. We present the instructions for a treatment with order of stages: 1, 2 and 3 (and parameter values: $r = 0.85$, $\varepsilon = 10$, $\eta = 10$, $\phi = 0$, $p = 7$). For the other treatments, instructions were adapted accordingly and are available upon request.²³

Instructions

General information

Thank you for participating in an experiment in which you can earn money. These earnings will be paid to you in cash at the end of the experiment.

We ask you not to communicate from now on. If you have a question, then raise your hand and the instructor will come to you.

You are a group of 14 persons in total participating in this experiment and you are allocated into two groups of 7 persons. These two groups are totally independent and do not interact one with another during the whole length of the experiment. Each participant interacts only with other participants in his group and not with the participants of the other group. The current instructions describe the rules of the game for a group of 7 participants.

The rules are the same for all the participants. The experiment consists of 3 stages, each including 15 periods. At each of the 15 periods, you are asked to make a decision. Your payoff depends on the decisions you make all along the experiment. The stages differ from one another by the hints (indicative values) that will be given to you to make your decisions.

Section A describes how your payoff is calculated at each stage. Sections B, C and D describe the indicative values you have at stages 1, 2 and 3 respectively.

A - Rule that determines your payoff at each of the 45 periods (3 stages of 15 periods)

Z is an unknown positive number. This unknown positive number is different at each period but identical for all the participants (of the same group).

At each period, you are asked to make a decision by choosing a number. Your payoff in ECU (Experimental Currency Unit) associated with your decision is given by the following formula:

$$400 - 1,5(\text{your decision} - Z)^2 - 8,5(\text{your decision} - \text{the average decision of the others})^2.$$

This formula indicates that your payoff gets higher the closer you decision to

- on the one hand the unknown number Z and
- on the other hand the average decision of the other participants.

²³What follows is a translation (from French to English) of the instructions given to the participants.

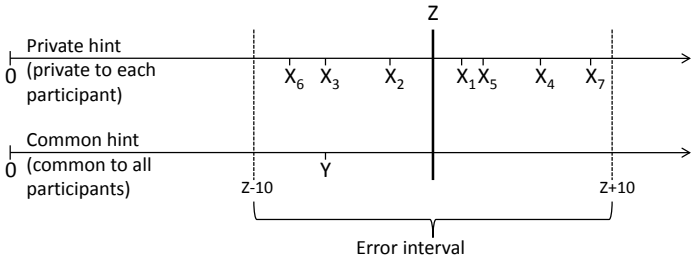
To maximize your payoff you have to make a decision that is as close as possible to the unknown number Z and to the decision of the other participants. Note however that it is more important to be close to the average decision of the other participants than to the unknown number Z . No participant knows the true value of Z when making his decision. However, each participant receives some hints on the unknown number Z as explained in sections B, C and D.

B - Your hints on Z during stage 1 (15 periods)

At each period of the first stage, you receive two hints (numbers) on the unknown number Z to make your decision. These hints contain unknown errors.

- **Private hint X** Each participant receives at each period a private hint X on the unknown number Z . The private hints are selected randomly over the error interval $[Z - 10, Z + 10]$. All the numbers of this interval have the same probability to be drawn. Your private hint and the private hint of any of the other participants are selected independently from one another over the same interval, so that in general **each participant receives a private hint that is different from that of the other participants.**
- **Common hint Y** On top of this private hint X , you, as well as the other members of your group, receive at each period, a common hint Y on the unknown number Z . This common hint is also randomly selected over the interval $[Z - 10, Z + 10]$. All the numbers of this interval have the same probability to be selected. This common hint Y is the **same for all participants.**

Example:



Distinction between private hint X and common hint Y

Note that your private hint X and the common hint Y have the same precision: each is drawn from the same error interval. The sole distinction between the two hints is that each participant observes a private hint X that is different from that of the other participants whereas all the participants observe the same common hint Y .

How to make a decision? As you do not know the errors associated with your hints, it is natural to choose, as a decision, a number that is between your private hint X and the common hint Y . To make your decision, you are asked to select, owing to a cursor, a number that is between your private hint X and the common hint Y . You thus have to choose how to combine your two hints in order to maximize your payoff.

Once you have set the cursor on the decision of your choice, click on the 'Validate' button. Once all the participants have done the same, a period ends and you are told about the result of the period. Then a new period starts.

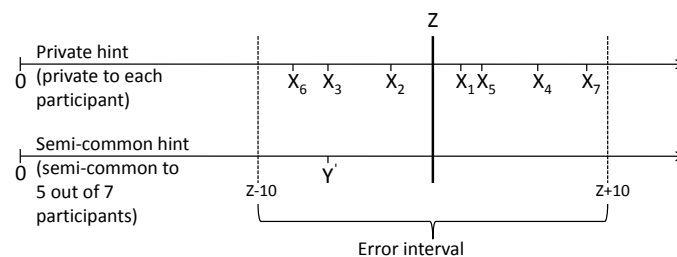
As soon as the 15 periods of the first stage are over, the second stage of the experiment starts.

C - Your hints on Z during stage 2 (15 periods)

The second stage is different from the first in that some participants do not observe the common hint. You get either one or two hints on Z to make your decision.

- **Private hint X** In accordance with stage 1, each participant receives at each period a private hint X on the unknown number Z. The private hints are selected randomly over the error interval $[Z - 10, Z + 10]$. All the numbers of this interval have the same probability to be selected. Your private hint and the private hint of each other participant are selected independently from one another over the same interval, so that in general **each participant receives a private hint that is different from that of the other participants.**
- **Semi-common hint Y'** On top of this private hint X, **5 out of the 7 participants of your group**, randomly selected at each period, receive a so-called semi-common hint Y' on the unknown number Z. This semi-common hint is also randomly selected on the interval $[Z - 10, Z + 10]$. All the numbers of this interval have the same probability to be selected. This hint is semi-common in that only 5 out of the 7 participants of your group receive this common hint. This semi-common hint Y' is the same for the **5 participants who receive it. The 2 remaining participants do not observe this semi-common hint and simply get their private hint.**

Example:



How to make your decision?

To make your decision, you are asked to select, owing to a cursor, a number that is between your private hint X and the semi-common hint Y' as long as you are among the participants who observe the semi-common hint Y'. The participants who only receive a private hint X have no choice but to make a decision equal to their private hint.

Once you have set the cursor on the decision of your choice, click on the 'Validate' button. Once all the participants have done the same, a period ends and you are told about the result of the period. Then a new period starts.

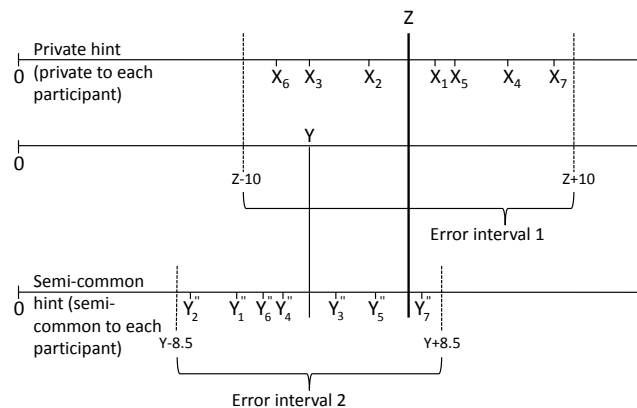
As soon as the 15 periods of the second stage are over, the third stage of the experiment starts.

D - Your hints on Z during stage 3 (15 periods)

At each period of the third stage, you receive two hints on Z to make your decision.

- **Private hint X** In accordance with stages 1 and 2, each participant receives at each period a private hint **X** on the unknown number **Z**. The private hints are selected randomly over the error interval $[Z - 10, Z + 10]$. All the numbers of this interval have the same probability to be selected. Your private hint and the private hint of each other participant are selected independently from one another over the same interval, so that in general **each participant receives a private hint that is different from that of the other participants.**
- **Semi-common hint Y''** On top of this private hint **X**, each participant receives a semi-common hint **Y''** on the unknown number **Z**. This semi-common hint contains two errors, one that is common and one that is private.
 - First, as in the first stage, a common hint Y is selected randomly over the interval $[Z - 10, Z + 10]$. The hint Y (and the error it contains) is **common** to all participants (it is the same for all the participants). However, you do not observe this hint Y directly.
 - Instead, you observe the common hint Y to which a **private** error is added, this error being selected randomly over the interval $[-8, +8]$. The semi-common hint **Y''** that you observe is thus randomly selected over the interval $[Y - 8, Y + 8]$. Your private error and the private error of any of the other participants are selected independently from one another over the same interval, so that in general each participant receives a semi-common hint **Y''** that is different from that of the other participants.

Example:



Distinction between private hint X and common hint Y''

Your private hint \mathbf{X} and the semi-common hint \mathbf{Y}'' can be distinguished in two ways. First, the private hint \mathbf{X} is more precise than the semi-common hint \mathbf{Y}'' . The error interval of the private hint \mathbf{X} is $[Z - 10, Z + 10]$ while the error interval of the semi-common hint \mathbf{Y}'' is $[Z - 18.5, Z + 18.5]$. Indeed, the semi-common hint \mathbf{Y}'' contains on the one hand an error that is common to all the participants $[Z - 10, Z + 10]$ and on the other hand a private error that is different for every participant $[Y - 8.5, Y + 8.5]$. Second, while the error in the private hint \mathbf{X} is different for each participant, the semi-common hint \mathbf{Y}'' contains an error that is common to all the participants.

How to make a decision? To make a decision, you are asked to selected, owing to a cursor, a number that is between your private hint \mathbf{X} and the semi-common hint \mathbf{Y}'' .

Once you have set the cursor on the decision of your choice, click on the 'Validate' button. Once all the participants have done the same, a period ends and you are told about the result of the period. Then a new period starts.

As soon as the 15 periods of the third stage are over, the experiment ends.

You will be told about each change in stage.

Questionnaires:

At the beginning of the experiment, you are asked to fill in an understanding questionnaire on the computer; when all the participants have responded properly to this questionnaire, the experiment starts. At the end of the experiment, you are asked to fill on a personal questionnaire on the computer. All information will remain secret.

Payoffs: At the end of the experiment, the ECUs you have obtained are converted into Euros and paid in cash. 1000 ECUs correspond to 2 Euros.

If you have any question, please ask them at this time.

Thanks for participating in the experiment!

E Training questionnaire

The training questionnaire varied according to the treatments.²⁴ We present the questionnaire for a treatment with order of stages: 1, 2 and 3 (and parameter values: $r=0.85$, $\alpha=10$, $\beta=10$, $\gamma=0$, $p=7$). For the other treatments, the training questionnaires were adapted accordingly and are available upon request.²⁵ Each of the 10 following questions had to be answered by right or wrong, yes or no or multiple choices.

Question 1: "During each period of the 3 stages of the experiment, you always interact with the same participants." Answer: "True" (Explanation message: "It is true. You always interact with the same participants during the whole length of the experiment.")

Question 2: "At each period of the 3 stages, all the participants of the same group receive the same private hint X." Answer: "Wrong" (Explanation message: "It is wrong. In general, the participants receive different private hints X.")

²⁴Questions 6, 8, 9 and 10 had to be adapted to the treatment.

²⁵What follows is a translation (from French to English) of the training questionnaire given to the participants.

Question 3: "At each period of stage 1, all the participants of the same group receive the same common hint Y." Answer: "True" (Explanation message: "It is true. At each period of stage 1, all the participants of the same group receive the same common hint Y.")

Question 4: "Is it natural to make a decision outside the interval defined by your two hints?" Answer: "No" (Explanation message: "Indeed, as, in average, the errors of the two hints are zero (distributed over -10,+10), it is natural to combine these two hints to make your decision. Therefore the cursor will allow you only to make decisions inside the interval defined by your two hints. Note however that it is possible that the true value of Z is outside this interval.")

Question 5: "To maximize your payoff, it is more important that your decision be close to the unknown number Z than to the decision of the others." Answer: "Wrong" (Explanation message: "Indeed, your payoff depends more on the distance between your decision and the average decision of the others than on the distance between your decision and the unknown number Z. ")

Question 6: "Suppose the true value of Z is equal to 143 and the average decision of the other participants of the group is equal to 133. What is your payoff in ECUs if your decision is equal to 138?" Answer: 150 (Explanation message: "Indeed, the payoff associated to your decision is equal to $150 (=400-1.5(138-143)^2-8.5(138-133)^2)$.")

Question 7: "Generally, at stage 1, the private hint X is as informative on the average decision of the others as the common hint Y." Answer: "Wrong" (Explanation message: "It is wrong. While the private hint X is as precise as the common hint Y on the number Z, the common hint Y is generally more informative on the average decision of the others because all the participants observe it.")

Question 8: "The difference between stages 1 and 2 is that the common hint Y is observed by all the participants at stage 1 while it is observed only by 5 out of the 7 participants at stage 2." Answer: "True" (Explanation message: "It is true.")

Question 9: "The difference between stages 1 and 3 is that the same common hint Y is observed by all the participants at stage 1 while at stage 3 each participant observes a different semi-common hint Y'." Answer: "True" (Explanation message: "It is true.")

Question 10: "At all stages of the experiment, the private hint X is as precise as the (semi-)common hint Y (Y', Y'') on the number Z." Answer: "Wrong" (Explanation message: "It is wrong. At stages 1 and 2, the private hint X is equally precise as the (semi-)common hint Y (Y') on the number Z. However, at stage 3, the private hint X is more precise on the number Z than the semi-common hint Y'".)

F Example of screens

Etape 1
Période 2

Vous recevez deux valeurs indicatives sur le nombre inconnu Z.

La valeur indicative privée que vous recevez en propre, X, est

La valeur indicative commune à tous les participants, Y, est

votre décision : **175,4**

168,8

▼

182

Y
X

Veillez prendre votre décision en déplaçant le curseur entre les 2 bornes, puis cliquez sur 'Valider'.

Historique des périodes précédentes:

Période	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Valeur indicative privée X	610,4														
Valeur indicative commune Y	615,2														
Vraie valeur de Z	619,9														
Vraie décision moyenne des autres	616,918														
abs(X-décision moyenne des autres participants)	6,518														
abs(Y-décision moyenne des autres participants)	1,718														
Votre Décision	612,8														
Gain pour la période	230,24														
Gains cumulés	230,24														

Etape 1
Résultats de la période 2

Vous recevez deux valeurs indicatives sur le nombre inconnu Z.

Valeur indicative privée X

Valeur indicative commune à tous les participants Y

Vraie décision moyenne des autres

Votre décision

Valeur absolue(X-décision moyenne des autres participants)

Valeur absolue(Y-décision moyenne des autres participants)

Gain total pour la période

Gains cumulés