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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, however, makes a case for partial transparency rather than partial publicity because the latter seems increasingly difficult to implement in the present information age and is associated with discrimination as well as fairness issues.

JEL classification: C92, D82, D84, E58.

Keywords: heterogeneous information, public information, overreaction, transparency, coordination, experiment.

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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 knowledge[1]: it conveys valuable information about economic fundamentals, but 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 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)). 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) and Baeriswyl and Cornand (2010)). 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

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

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.

The theoretical analysis shows that partial publicity and partial transparency are equivalent in reducing overreaction to public information and in improving welfare. The degree of publicity is determined by the fraction of market participants who receive the transparent public signal. The degree of transparency, however, is determined by the idiosyncratic inaccuracy of the public signal disclosed to all market participants. 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. 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. 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. 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), who relate this finding to subjects' limited degree of higher order beliefs and analyze the welfare effects of limited degree of reasoning when agents receive both a public and a private signal.[2] The present experiment 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

[2]In a speculative attack game close to Morris and Shin (2004), Cornand (2006) 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.

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.

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 the public. 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. Section 4 gives the results of the experiment. Section 5 discusses the policy recommendations we can draw from our study, and Section 6 concludes.

2 The theoretical model

This section presents the theoretical Keynesian 'beauty contest' formalized by Morris and Shin (2002) (henceforth MS) and derives 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 its decision not only according to its expectation of economic fundamentals but also according to its 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 taken by 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:

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

where λ is 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 accept 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 Private and public signals (MS)

The first considered informational framework corresponds to that of MS where each agent i receives a private signal x_i and a 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 its private and public information:

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

The best estimate of the fundamental by agent i is an average of both its signals whose weighting depend upon their relative precision.

As shown by MS, the optimal equilibrium action of agent i is a linear combination of its private and public signals and can be expressed as:

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

$$
\begin{aligned}
&= (1-r)\Big[\frac{\sigma_\eta^2}{\sigma_\epsilon^2+\sigma_\eta^2}x_i + \frac{\sigma_\epsilon^2}{\sigma_\epsilon^2+\sigma_\eta^2}y\Big] + r\Big[(1-w)\Big[\frac{\sigma_\eta^2}{\sigma_\epsilon^2+\sigma_\eta^2}x_i + \frac{\sigma_\epsilon^2}{\sigma_\epsilon^2+\sigma_\eta^2}y\Big] + wy\Big] \\
&= \underbrace{\frac{(1-r)\sigma_\eta^2}{\sigma_\epsilon^2+(1-r)\sigma_\eta^2}}_{1-w}\,x_i + \underbrace{\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2+(1-r)\sigma_\eta^2}}_{w}\,y,
\end{aligned}
$$

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

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

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

The weight attributed to the public signal in the equilibrium action w in (3) is larger than in the best estimate of the fundamental θ given in (2). This discrepancy 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, equilibrium agents' action is the public signal itself, i.e. $w = 1$.

2.1.2 Expected welfare

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

$$
\begin{aligned}
\mathbb{E}(L) &= \mathbb{E}\Big(\int_i (a_i-\bar{a})^2 di + \lambda(\theta-\bar{a})^2\Big) \\
&= (1-w)^2\sigma_\epsilon^2 + \lambda w^2 \sigma_\eta^2 \\
&= \frac{(\lambda\sigma_\epsilon^2 + (1-r)^2\sigma_\eta^2)\sigma_\epsilon^2\sigma_\eta^2}{(\sigma_\epsilon^2+(1-r)\sigma_\eta^2)^2}.
\end{aligned} \tag{4}
$$

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. $w = 0$) 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 disclosing the public signal is preferable to withholding it when

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

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 coordination is low (large λ). 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 $1-P$ agents who only get a private signal from the optimal action of the P agents who get both a private and a semi-public signals. The optimal action of agents who get only the private signal is simply given by its 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 agents who get both the private and the semi-public signal is a linear combination of their signals and is derived as

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

The weight attributed to the public signal by the fraction P of agents who observe it, w 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

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

The weight attributed to the public signal in the average equilibrium action $\bar{w} = P \cdot w$ 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.

2.2.2 Expected welfare

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

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

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

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

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 its private and semi-public information:

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

The best estimate of the fundamental by agent i is an average of both its signals whose weighting depends upon their relative precision.

The optimal equilibrium action of agent i is a linear combination of its private and semi-public signals and can be expressed as:

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

The average action over all agents yields

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

The weight attributed to the semi-public signal in the average equilibrium action w 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

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

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

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

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

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

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

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

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 in the sense that (i) the weight assigned to the public signal can be equivalently controlled by means of PP or PT, (ii) the optimal weight assigned to the public signal is the same under PP as under PT, and

(iii) for any given weight assigned to the public signal the expected welfare is the same in PP as in PT.

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 weight in PP given in (7) to that in PT given in (11)

$$\frac{P\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1 - rP)\sigma_\eta^2} = \frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1 - r)\sigma_\eta^2 + \sigma_\phi^2}$$

and solve it for P and for σ_ϕ^2

$$P = \frac{\sigma_\epsilon^2 + \sigma_\eta^2}{\sigma_\epsilon^2 + \sigma_\eta^2 + \sigma_\phi^2} \quad (15)$$

$$\sigma_\phi^2 = \frac{1 - P}{P}(\sigma_\epsilon^2 + \sigma_\eta^2). \quad (16)$$

This relation illustrates how partial publicity can be translated into partial transparency for reducing overreaction.

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. Plugging (15) into (9) yields the optimal degree of transparency (13), or plugging (16) into (13) delivers the optimal degree of publicity (9).

Third, it is also straightforward to show that the unconditional expected loss under PP (8) is equal to the unconditional expected loss under PT (12) when (15) or (16) holds. This implies that the expected loss is the same in both models not only at the optimal degree of publicity or transparency as expressed in (10) and (14) but for any weight on public information.

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 under full transparency (dotted line), under full opacity (dashed line), and under optimal partial publicity or transparency (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 uncondition 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

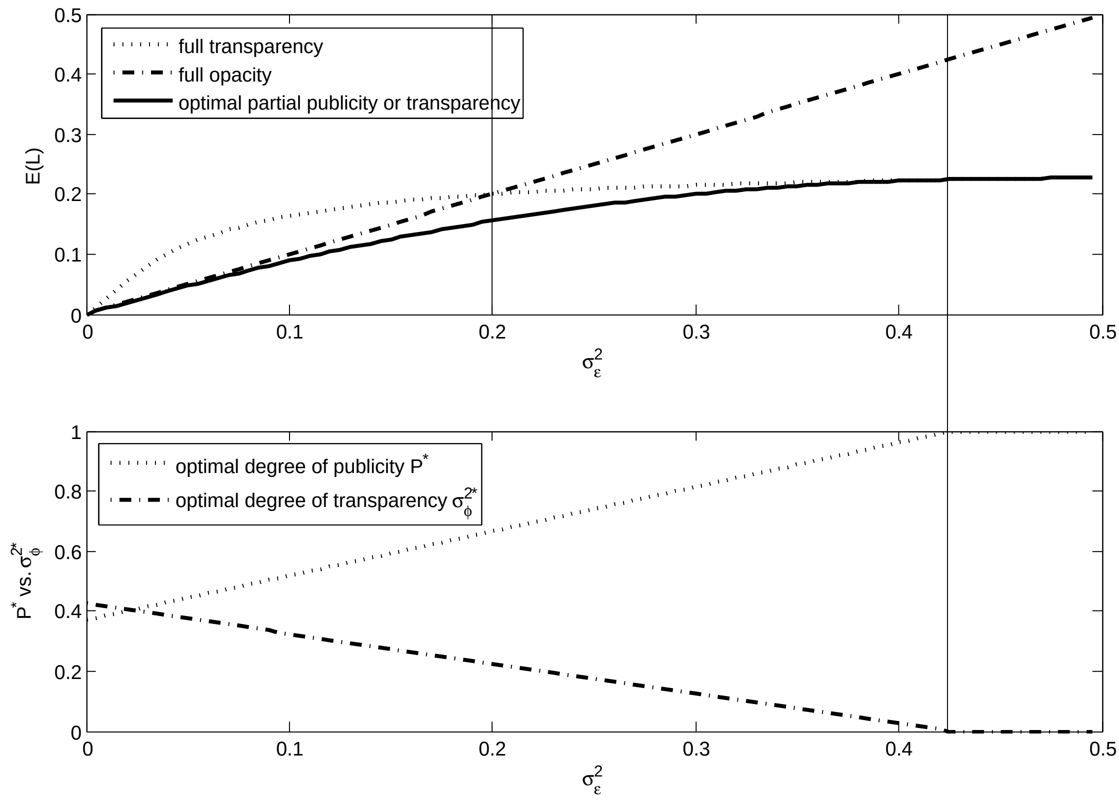


Figure 1: Unconditional expected loss and optimal degree of publicity vs. transparency

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 *homos sapiens sapiens* are involved in the 'beauty contest' instead of *homos oeconomicus*. 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 run an experiment with three treatments, each corresponding to a disclosure strategy. In the MS-treatment (Morris and Shin (2002)), derived in Sections 2.1 and A.1, each subject receives a private and a public signal. In the PP-treatment (partial publicity à la Cornand and Heinemann (2008)), derived in Sections 2.2 and A.2, 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 Sections 2.3 and A.3, 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. The experiment is calibrated in such a way that the equilibrium weight assigned to the semi-public signal in the PP-treatment is equal to that in the PT-treatment.

We discuss in this section the general development of the experiment, the chosen parameters for each treatment, and the corresponding theoretical behavior.

3.1 Experimental development

Sessions were run at the LEES (Laboratoire d'Economie Expérimentale de Strasbourg), which is part of the BETA (Bureau d'Economie Théorique et Appliquée) laboratory in Strasbourg in January 2011. Each session had 14 participants who were mainly students from Strasbourg University (most were students in economics, mathematics, biology and psychology). Subjects 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 and questionnaires are given in the Appendix. The experiment started after all subjects had given the correct answers to these questions. 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 (to be declined in different treatments) and each stage of 15 periods (total of 45 periods per session). Each stage contained a different treatment. In each period, subjects played within the same group so that there was no re-matching during the whole experiment (subjects played with the same participants of the same group throughout the experiment). Subjects 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 $[50, 950]$. In every period of the experiment, each subject has to decide on an action a_i, conditional on her signals. The payoff function in ECU (experimental currency units) for subject i is given by the formulas: $400 - 1.5(a_i - \theta)^2 - 8.5(a_i - \bar{a})^2$, where $\bar{a}$ is the average action of other subjects of the same group.[3] 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.[4]

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.

[3] In 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.

[4] Concretely, subjects move a cursor inside the interval defined by their signals to determine their chosen action. By doing so, we restrain subjects from choosing actions outside of their signal interval.

At the end of each session, the ECU earned were summed up and converted into euros. 1000 ECU were converted to 2 euros.[5] Payoffs ranged from 8 to 28 euros. The average payoff was about 20 euros. Sessions lasted for around 60 minutes.

3.2 Parameters

The parameters choice for the experiment is summarized in Table 1.

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

In the MS-treatment, each subject receives both a public and a private signal as described in Section A.1. 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 Section A.2. The private signal received by each subject is uniformly drawn from $x_i \in [\theta - 10, \theta + 10]$. In addition, 5 out 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.

In the PT-treatment, each subject receives a private signal and a semi-public signal as described in Section A.3. 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

[5] In 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.

$y_i \in [y - 8.5, y + 8.5]$ 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 the first group of sessions (1 to 3) from that of the second group of sessions (4 to 6). This change in order aims at testing order effects (MS, PP, PT versus MS, PT, PP). The change in the precision of the public signal in the third group of sessions (7 to 9) compared to the first two groups aims at testing comparative statics effects in terms of public signal's relative precision.

3.3 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 would occur in the MS-treatment, where signals are either purely private or purely public. The parameters presented above are chosen in such a way that the equilibrium weight assigned to the semi-public signal in PP- and PT-treatment coincides with the weight assigned to the public signal in the first-order expectation of the fundamental θ in the MS-treatment. 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 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 subjects in the PP-treatment who do not get the semi-public signal. Their expected payoff is naturally lower than that of subjects who get the semi-public signal u(P). The overall expected payoff is reported in column u. For sessions 1 to 6, the expected gain with rational behavior over the whole experiment is $(356.5 + 227.3 + 244.0) * 15/500 = 25$, while for sessions 7 to 9, the expected gain is $(363.8 + 223.3 + 246.3) * 15/500 = 25$.

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

4 The results

This section presents the results of the experiment. We first describe the data and then analyze them by confronting observed weights to theoretical weights, analyzing overreaction effects, comparing weights in different treatments (MS - PP - PT), looking at order effects, and comparative statics effects in terms of relative precision.[6] We use non-parametric statistics to test our hypotheses.[7]

4.1 Data description

Table 3 presents the average action within a group of participants captured by the observed weight on the public signal for each treatment calculated as the group average of $\frac{|Decision_i - x_i|}{|y - x_i|}$. A value of one indicates that agents have taken a decision equal to the public signal y, while a value of zero indicates that agents have taken a decision equal to their private signal. We also recall the corresponding theoretical values.

Session	Group	MS	PP	PT
1	1	.6278	.4456	.5089
1	2	.7012	.4976	.4208
2	3	.8089	.5934	.5225
2	4	.6355	.4926	.5306
3	5	.7484	.4705	.5700
3	6	.6526	.4586	.4772
4	7	.6167	.4595	.4896
4	8	.7244	.4770	.4595
5	9	.7071	.4106	.5205
5	10	.6530	.4568	.5312
6	11	.6319	.4944	.5662
6	12	.7085	.5273	.4282
Average groups 1-12		**.6846**	**.4819**	**.5021**
Theory groups 1-12		**.8696**	**.4983**	**.5000**
7	13	.7979	.5122	.4746
7	14	.6972	.4630	.4166
8	15	.7706	.5507	.5036
8	16	.6749	.4884	.4929
9	17	.7849	.4910	.4737
9	18	.7276	.4857	.4733
Average groups 13-18		**.7422**	**.4985**	**.4724**
Theory groups 13-18		**.8163**	**.4329**	**.4301**

Table 3: Observed and theoretical average weights on the public signal

The evolution of the average weight assigned to the public signal over the 15 periods

[6] We 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.

[7] Systematic test results are available by the authors upon request.

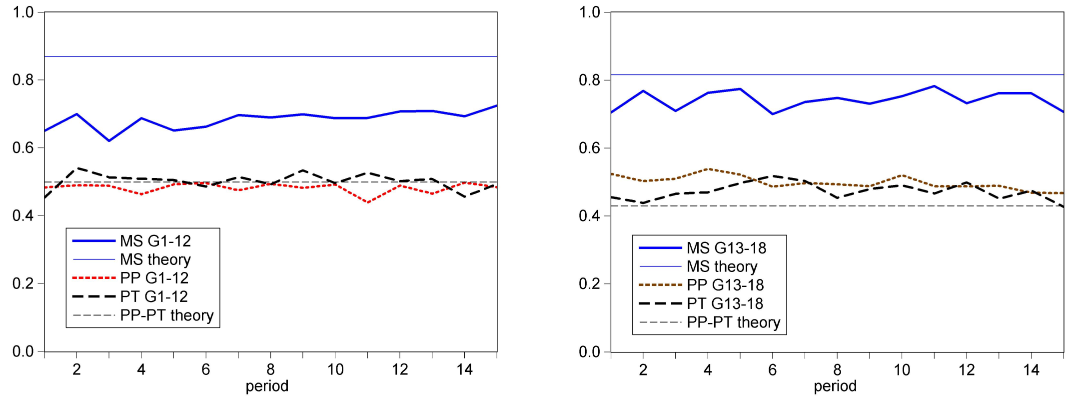


Figure 2: Average weight assigned to the public signal: groups 1-12 (lhs) and groups 13-18 (rhs)

of each treatment is illustrated on Figure 2 for groups 1 to 12 (where private and public signals have the same accuracy) and for groups 13 to 18 (where private signals are more accurate). It is obvious at first glance that the weight assigned to the public signal is much larger in the MS-treatment than in the PP- or PT-treatments. Figure 3 illustrates the evolution over the periods of the average weight on the public signal for each group.

4.2 Experiment and theory

We first analyze whether the observed average weight assigned to the public signal in the experiment is significantly different from the weight derived in the theory. We define the null hypothesis H01-T-G as follows:

> **H01-T-G** The observed weight assigned to the public signal by groups G in treatment T is not different from the equilibrium theoretical weight of treatment T.

We test the null hypothesis H01-T-G for each treatment T (MS - PP - PT) owing to a Wilcoxon matched pairs signed rank test.[8] For the MS-treatment, the weight observed in the experiment is significantly lower than its theoretical value (for both groups 1-12 and 13-18). Test results reject H01-MS-1-12 (Null hypothesis H01, treatment MS, groups 1 to 12) (p-value: $p = 0.000$) and H01-MS-13-18 ($p \leq 0.031$). For the PP-treatment, the result depends on the groups considered. Whereas the weight observed in the experiment does no significantly differ from its theoretical value for groups 1-12, it is significantly larger than its theoretical value for groups 13-18. Test results do not reject H01-PP-1-12 ($p \leq 0.109$), but reject H01-PP-13-18 ($p \leq 0.031$). Overall, H01-PP-(1-18) is not rejected ($p \leq 0.495$). For the PT-treatment, there is no significant difference between the weight

[8]The Wilcoxon matched pairs signed rank test is used to determine the magnitude of difference between matched groups. This test can be used for comparing estimates with fixed values.

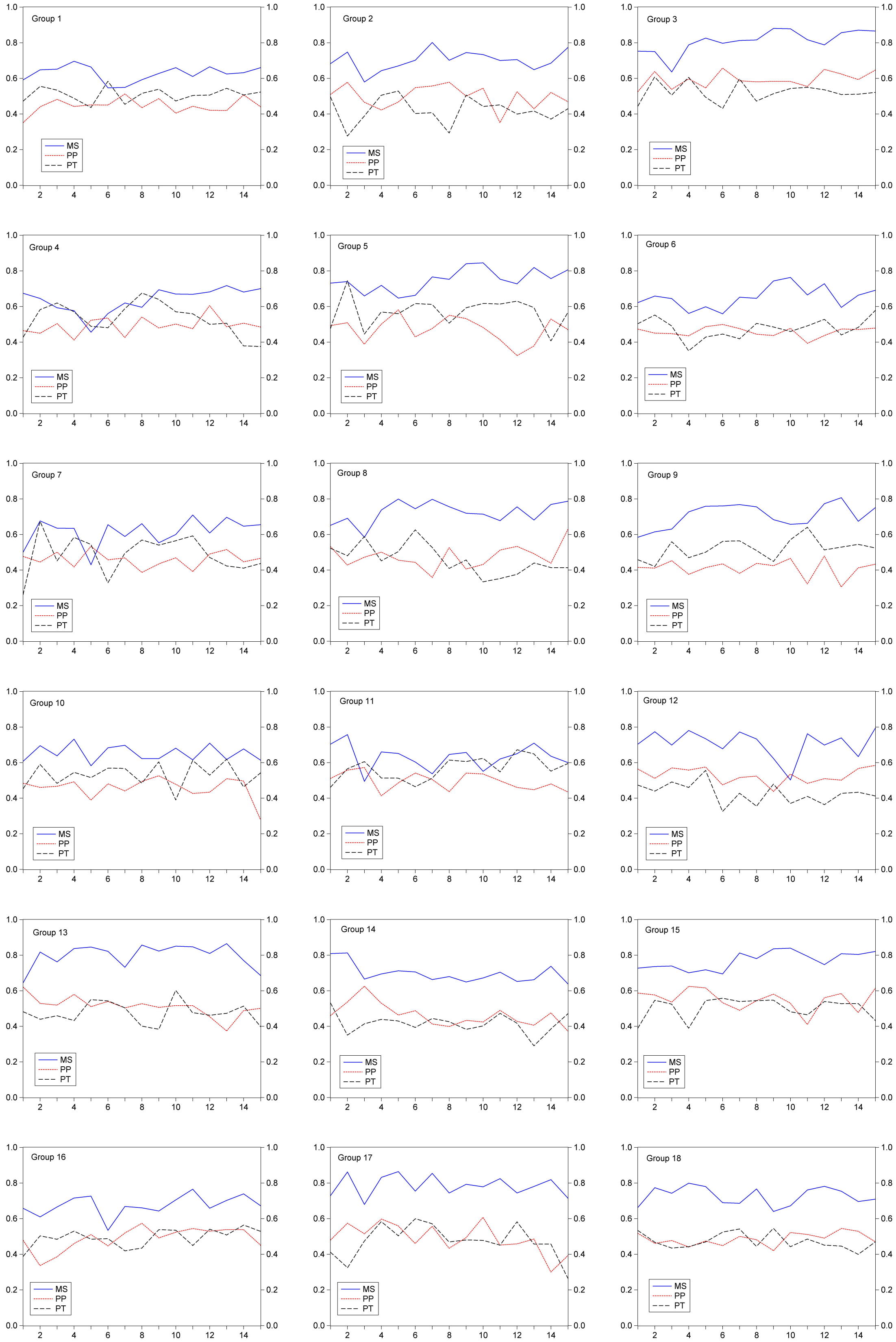


Figure 3: Average weight assigned to the public signal for each group

observed in the experiment and its theoretical value. Test results do not reject H01-PT-1-12 ($p \leq 0.969$) and H01-PT-13-18 ($p \leq 0.062$). Although the hypothesis H01-PT-13-18 cannot be rejected at the 5% confidence level, the weight observed in the experiment tends to be larger than its theoretical value in groups 13-18, which is also true for the PP-treatment H01-PP-13-18.

We can thus state our first result:

> **Result H01-MS** For the MS-treatment, the weight assigned to the public signal in the experiment is significantly lower than its theoretical value.
>
> **Result H01-PP** For the PP-treatment, the weight assigned to the semi-public signal in the experiment does not significantly differ from its theoretical value when the private signal is as accurate as the semi-public signal (groups 1 to 12), but is significantly larger than its theoretical value when the private signal is more accurate than the semi-public signal (groups 13 to 18).
>
> **Result H01-PT** For the PT-treatment, the weight assigned to the semi-public signal in the experiment does not significantly differ from its theoretical value at the 5% confidence level when the private signal is either as accurate as or more accurate than the average semi-public signal. However, at the 10% confidence level, the weight assigned to the semi-public signal in the experiment is significantly larger than its theoretical value when the private signal is more accurate than the average semi-public signal (groups 13 to 18).

4.3 Overreaction

Although the previous analysis suggests that subjects do not respond to the public signal as strongly as theory predicts in the MS-treatment, they may still overreact to the public signal if the weight they assign to it is larger than the weight justified by its face value, i.e. by the first-order expectation of the fundamental. To analyze whether there is overreaction in the sense of Morris and Shin (2002), we test the following null hypothesis:

> **H02-T-G** The observed weight assigned to the public signal by groups G in treatment T is not different from the theoretical weight in the first-order expectation of the fundamental.

We test the null hypothesis H02-T-G for each treatment T owing to a Wilcoxon matched pairs signed rank test. All 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. Test results show that we can reject H02-MS-1-12 ($p = 0.000$), H02-MS-13-18 ($p \leq 0.031$), H02-PP-1-12 ($p = 0.000$), H02-PP-13-18 ($p \leq 0.031$), H02-PT-1-12 ($p = 0.000$) and H02-PT-13-18 ($p \leq 0.031$)). We can therefore state our second result:

> **Result H02** For all treatments, the weight assigned to the public signal is significantly larger than the theoretical weight in the first-order expectation of the fundamental. Subjects do overreact to the public or semi-public signal.

From results H01 et H02, we can deduce that although subjects do overreact in all treatments, they overreact less than theory predicts in the MS-treatment. One reason may be that, contrary to theoretical agents, experimental subjects have limited levels of reasoning (see Cornand and Heinemann (2010) for more details and section 4.7 below). This observation is no more true for the PP- and PT-treatments. Whereas the weight assigned to the semi-public signal is not significantly different from its theoretical value when the private signal is as accurate as the (average) semi-public signal, it tends to be larger than its theoretical value when the private signal is more accurate than the (average) semi-public signal.

4.4 Treatment comparison

As derived in Sections 2.4 and A.4, the PP- and PT-treatments are equivalent in theory for reducing the overreaction to the public signal (relative to the MS-treatment) and are calibrated in the experiment such that they induce the same behavior of subjects. To test whether the alternative treatments induce the same behavior in the experiment, we state the following hypothesis:

> **H03-T1-T2-G** The observed weight assigned to the public signal by group G in treatment T1 is not different from the weight in treatment T2.

We compare observed data of the MS-, PP-, and PT-treatments with each other owing to a Student-t test[9] and a Wilcoxon test. We observe a significant difference between MS and PP on the one hand, and MS and PT on the other hand. Indeed, test results indicate that we can reject H03-MS-PP-1-12, H03-MS-PP-13-18 and H03-MS-PT-1-12, H03-MS-PT-13-18 ($p = 0.000$ for both the Student t-test and the Wilcoxon test for each hypothesis). By contrast, there is no significant difference between PP and PT for groups 1 to 12: we cannot reject H03-PP-PT-1-12 ($p \leq 0.348$ for the Student t-test and $p \leq 0.339$ for the Wilcoxon test). However, the result is more ambiguous for groups 13 to 18 as H03-PP-PT-13-18 can be rejected according to the Student t-test ($p \leq 0.040$) and but not according to the Wilcoxon test ($p \leq 0.062$), indicating that the weight assigned to the semi-public signal tends to be larger in the PP- than in the PT-treatment when the private signal is more accurate than the (average) semi-public signal. Overall (taking all groups together), we cannot reject H03-PP-PT-1-18 ($p \leq 0.743$ for the Student t-test and $p \leq 0.766$ for the Wilcoxon test). We can thus state our third result:

> **Result H03-MS-PP and H03-MS-PT** The weight assigned to the public signal is significantly larger in the MS-treatment than in the PP- or PT-treatment.
>
> **Result H03-PP-PT** Whereas the weight assigned to the semi-public signal is not significantly different in the PP- and PT-treatments when the private signal is as accurate as the (average) semi-public signal (groups 1 to 12), the

[9]This test is appropriate to compare data from different treatments.

weight tends to be larger in the PP- than in the PT-treatment when the private signal is more accurate than the (average) semi-public signal (groups 13 to 18).

Comparing the hypothesis H01 to H03, results can be summarized as follows. When the private signal is as accurate as the (average) semi-public signal (groups 1 to 12), the PP- and PT-treatments do not significantly differ from the theoretical predictions as shown in H01 and do not significantly differ from each other as shown in H03. On the contrary, when the private signal is more accurate than the (average) semi-public signal (groups 13 to 18), the weight assigned to the semi-public signal in the PP- and PT- treatments tends to be significantly larger than its theoretical value and the weight tends to be larger in the PP- than in the PT-treatment.

4.5 Treatment order

Although the weight assigned to the semi-public signal is not significantly different in the PP- and PT-treatments when the private signal is as accurate as the (average) semi-public signal (groups 1 to 12), the weight may differ depending on whether the PP- or the PT-treatment is played directly after the MS-treatment in the experiment. To establish whether there are effects from treatment order, we formulate the null hypothesis:

H04-T The observed weight assigned to the semi-public signal in treatment T is not influenced by the treatment order.

We compare the observed weight in either the PP- or the PT-treatment in groups where the PP-treatment is played before the PT-treatment (groups 1 to 6) to the observed weight in groups where treatments are played in reversed order (groups 7 to 12). Student-t tests do not show any order effect on subjects' behavior. First, comparing the behavior in the PP-treatment in groups 1 to 6 with that in groups 7 to 12 shows that the hypothesis H04-PP cannot be rejected ($p \leq 0.432$). Second, the same is true for the PT-treatment in groups 1 to 6 compared with groups 7 to 12. The hypothesis H04-PT cannot be rejected ($p \leq 0.847$). Third, one can also test the order effect by comparing the weight difference in the PP- and PT-treatments in groups 1 to 6 with the weight difference in groups 7 to 12. The hypothesis H04-PP-PT cannot be rejected ($p \leq 0.3773$). This allow us to state our fourth result:

Result H04 The weight assigned to the semi-public signal is not significantly influenced by the order of treatment in the experiment.

4.6 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 define the null hypothesis:

H05-T The observed weight assigned to the public signal in treatment T is not influenced by the relative precision of the public signal.

We compare the weight assigned to the public signal in groups 1 to 6 with groups 13 to 18, owing to a Student-t test for each treatment.[10] Hypotheses H05-MS, H05-PP and H05-PT cannot be rejected ($p \leq 0.2229$, $p \leq 0.8302$ and $p \leq 0.2089$ respectively).

This allow us to state our fifth result:

Result H05 The weight assigned to the public signal is not significantly influenced by the relative precision of private and public signals.

Although there is no apparent effect of the relative precision on the weight assigned to the public signal[11], we can nevertheless notice that, as shown in H03-PP-PT of Section 4.4, the weight tends to be larger in the PP- than in the PT-treatment when the private signal is more accurate than the semi-public signal. Indeed, it seems that when the private signal is more accurate, the PT-treatment is more successful than the PP-treatment to reduce the overreaction.

4.7 Limited levels of reasoning

It is intriguing that subjects' behavior is significantly different from the equilibrium in the MS-treatment but not in the PP- and PT-treatments (see 4.2). This suggests that, given the degree of publicity and transparency of their signals, subjects attach less importance to the coordination motive in the MS-treatment than in the PP- and PT-treatments. In other words, subjects seem to operate different levels of reasoning when playing the MS-treatment or the PP- and PT-treatments. 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.

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 B derives the equilibrium weight assigned to the public signal for limited degree of reasoning. Table 4 below provides a summary statistics of theoretical weights on y according to treatments and levels of reasoning. We formulate the null hypothesis:

[10] Although this is one of the main feature of the theoretical literature on global games and coordination games under heterogeneous information, this hypothesis has never been experimentally tested.

[11] Note that our design may not be appropriate to test the comparative statics effect in the relative precision as the chosen value of r is high. Maybe, with lower r some effects could be detected. Another reason why we could not detect any comparative statics effect may be that the change in relative precision was done from one session to the next and not within a session.

H06-T-G-Lx The observed weight assigned to the public signal by groups G in treatment T is not different from the theoretical weight for level-x of reasoning in treatment T.

Table 5 reports the results of Wilcoxon matched pairs signed rank tests of the hypothesis H06 for each treatment and each level of reasoning.[12]

Treatment	MS		PP		PT	
Groups	1-12	13-18	1-12	13-18	1-12	13-18
Level-1	.5000	.4000	.3571	.2857	.3509	.2778
Level-2	.7125	.6040	.4583	.3829	.4555	.3762
Level-3	.8028	.7080	.4870	.4159	.4867	.4110
Level-4	.8412	.7611	.4951	.4271	.4960	.4233
Level-5	.8575	.7882	.4974	.4309	.4988	.4277
Level-6	.8644	.8020	.4981	.4322	.4996	.4293
Level-∞ (equilibrium)	.8696	.8163	.4983	.4329	.5000	.4301
Observed weight	.6846	.7422	.4819	.4985	.5021	.4724

Table 4: Theoretical average weights on the public signal according to treatments and levels of reasoning

Treatment	MS		PP		PT	
Groups	1-12	13-18	1-12	13-18	1-12	13-18
Level-1	reject	reject	reject	reject	reject	reject
p-value	.000	.031	.000	.031	.000	.031
Level-2	**accept**	reject	**accept**	reject	reject	reject
p-value	.176	.031	.110	.031	.012	.031
Level-3	reject	**accept**	**accept**	reject	**accept**	reject
p-value	.001	.219	.424	.031	.301	.031
Level-4	reject	**accept**	**accept**	reject	**accept**	**accept**
p-value	.000	.563	.151	.031	.677	.063
Level-5	reject	**accept**	**accept**	reject	**accept**	**accept**
p-value	.000	.094	.129	.031	.733	.063
Level-6	reject	reject	**accept**	reject	**accept**	**accept**
p-value	.000	.031	.110	.031	.910	.063
Level-∞	reject	reject	**accept**	reject	**accept**	**accept**
p-value	.000	.031	.110	.031	.970	.063

Table 5: Hypothesis tests: the observed weight in the experiment is not different from the theoretical weight at specific levels of reasoning

As noted in result H01-MS in Section 4.2, for the MS-treatment, there is a significant difference between the equilibrium and observed data. This difference may be explained by limited levels of reasoning. For groups 1-12, we observe that subjects play on average

[12] As we test the hypothesis H06 with the observed weights averaged over subjects of a group and over periods, the 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.

strategies between level-1 and level-2 in the MS-treatment. Test results do not reject H06-MS-1-12-L2 (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. Test results do not reject H06-MS-13-18-L3, H06-MS-13-18-L4, and H06-MS-13-18-L5. These levels of reasoning rather coincide with the findings of Nagel (1995) who considers a different, pure beauty contest, game. The fact that, as stated in our result H05, 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.[13]

For the PP-treatment, subjects play in groups 1 to 12 on average strategies between level-2 and level-3 of reasoning. The hypothesis H06-PP-1-12 however cannot be rejected for level-2 of reasoning and higher. In groups 13 to 18, the observed weight is significantly larger than the equilibrium weight (level-∞ of reasoning) as stated in result H01-PP and the hypothesis H06-PP-13-18 is rejected for each level of reasoning.

For the PT-treatment, 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. The hypothesis H06-PT-1-12 however cannot be rejected for level-3 of reasoning and higher, whereas the hypothesis H06-PT-13-18 cannot be rejected for level-4 of reasoning and higher.

Overall, we observe that subjects operate different levels of reasoning depending on the treatment. The fact that the level of reasoning in the MS-treatment tends to be lower than in the PP- and PT-treatments suggests that subjects tend to underestimate the de-coordination effect (the reduction in overreaction to public information) induced by limiting the degree of publicity or transparency. In other words, if subjects would operate the same level of reasoning in the PP- and PT-treatments as in the MS-treatment, reducing the degree of publicity or transparency would even more effectively mitigate the overreaction to public signal than it is observed in the experiment.

5 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,[14] 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'

[13]See also 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.

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

behavior more than what would be justified by their informational contents. If public announcements are inaccurate – because of inevitable forecast and perception errors – private actions are drawn away from the fundamental value.[15] 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, H03-PP-PT states that the weight on the public signal observed in the experiment is not significantly different in the PP- and in the PT-treatment (when the private signal is as accurate as the public signal). Therefore our experiment does not allow us to formulate a clear preference for one or the other disclosure strategy.

Other issues, which go beyond efficiency considerations, may also matter, however, with regard to the choice of the disclosure strategy. In this section, we discuss the realism and feasibility of disclosing information with a limited degree of publicity or transparency and the discriminatory nature of disclosing information with partial publicity.

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 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 a 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

[15] In this respect, Morris and Shin (2002) have shown that noisy public announcements may be detrimental to welfare and conclude that central banks should commit to withholding relevant information or deliberately reduce its precision. This result has received a great deal of attention in the academic literature, in the financial press (see for example The Economist (2004)), and among central banks.

agents are less affected by these speeches than by formal publications at predetermined dates.[16] The use of various communication channels to reach various target groups was advocated by 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.

Partial transparency can be achieved by disclosing information to every market participant but with some ambiguity. Is it possible for a central bank to achieve partial transparency with ambiguous disclosure? 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, Meyer (2004), a former member of the Board of Governors of the Fed, emphasized that the interpretation of a central banker's speech can be extremely different from what the central banker planned to say. In an interview by Fettig (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 full transparency is more challenging to implement than partial transparency, and that ambiguity remains difficult to avoid completely. As soon as reducing overreaction to disclosure improves welfare when the central bank is uncertain about the true economic conditions (which is the rule rather than the exception), controlling the overreaction by means of partial transparency seems easier to implement than partial publicity, as ambiguous interpretation naturally emerges whenever information is disclosed.

Discrimination and fairness The second drawback associated with disclosing information by means of partial publicity (and which makes a case in favor of partial trans-

[16]For 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.*".

parency) rests on discriminatory issues. Disclosing information only to a limited audience seems unfair and arbitrary. 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. 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, as is already common practice among many central banks.[17] 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.

6 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 communication 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, this paper makes a case for partial transparency rather than partial publicity, because the latter seems increasingly difficult to

[17]The 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.

implement in the information age and is associated with discrimination as well as fairness issues.

A The experimental setup

This Appendix presents how the theoretical model in Section 2 is adjusted to an 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).

The utility function for subject i is given by:

$$u_i(a_i, \theta) \equiv -(1-r)(a_i - \theta)^2 - r(a_i - a_{-i})^2, \tag{17}$$

where θ is the fundamental, a_i is the action taken by the subject i, and a_{-i} is the average action taken by the other subjects $-i$. Maximizing utility yields the optimal action of subject i:

$$a_i = (1-r)\mathbb{E}_i(\theta) + r\mathbb{E}_i(a_{-i}).$$

A.1 Private and public signals (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

$$\bar{a} = \underbrace{\frac{(1-r)\eta}{\epsilon + (1-r)\eta}}_{1-w} \bar{x} + \underbrace{\frac{\epsilon}{\epsilon + (1-r)\eta}}_{w} y. \tag{18}$$

To compute the expected payoff in the experiment, we derive the corresponding expected utility (17) of subject i for the optimal behavior (18)

$$\begin{aligned}
\mathbb{E}\Big(u_i(a_i, \theta)\Big) &= \mathbb{E}\Big(-(1-r)\Big((1-w)(\theta+\epsilon) + w(\theta+\eta) - \theta\Big)^2 \\
&\quad -r\Big((1-w)(\theta+\epsilon) + w(\theta+\eta) - (1-w)\theta - w(\theta+\eta)\Big)^2\Big) \\
&= -(1-w)^2\mathrm{Var}(\epsilon) - (1-r)w^2\mathrm{Var}(\eta).
\end{aligned}$$

A.2 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 subjects who get only the private signal is

$$a_{i,-p} = x_i. \tag{19}$$

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

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

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

$$\begin{aligned} \bar{a} &= \Big(1 - \frac{p}{n}\Big)\bar{x}_{-p} + \frac{p}{n}\Big[\frac{(1-r\frac{p-1}{n-1})\eta\bar{x}_p + \epsilon y}{\epsilon + (1-r\frac{p-1}{n-1})\eta}\Big] \\ &= \underbrace{\frac{\frac{n-p}{n}\epsilon + (1-r\frac{p-1}{n-1})\eta}{\epsilon + (1-r\frac{p-1}{n-1})\eta}}_{1-\tilde{w}} \bar{x} + \underbrace{\frac{\frac{p}{n}\epsilon}{\epsilon + (1-r\frac{p-1}{n-1})\eta}}_{\tilde{w}} y. \end{aligned} \tag{20}$$

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

$$\begin{aligned} \mathbb{E}\Big(u_i(a_i,\theta)\Big) &= \mathbb{E}\Big(-(1-r)\Big(\theta + \epsilon - \theta\Big)^2 - r\Big(\theta + \epsilon - (1-\tilde{w})\theta - \tilde{w}(\theta+\eta)\Big)^2\Big) \\ &= -\mathrm{Var}(\epsilon) - r\tilde{w}^2\mathrm{Var}(\eta), \end{aligned}$$

while the expected utility for subjects with public signal yields

$$\begin{aligned} \mathbb{E}\Big(u_i(a_i,\theta)\Big) &= \mathbb{E}\Big(-(1-r)\Big((1-w)(\theta+\epsilon) + w(\theta+\eta) - \theta\Big)^2 \\ &\quad -r\Big((1-w)(\theta+\epsilon) + w(\theta+\eta) - (1-\hat{w})\theta - \hat{w}(\theta+\eta)\Big)^2\Big) \\ &= -(1-w)^2\mathrm{Var}(\epsilon) - (1-r)w^2\mathrm{Var}(\eta) - r(w-\hat{w})^2\mathrm{Var}(\eta). \end{aligned}$$

Aggregating over all subjects, we get

$$\begin{aligned} \mathbb{E}\Big(u_i(a_i,\theta)\Big) &= -\Big[\frac{n-p}{n} + \frac{p}{n}(1-w)^2\Big]\mathrm{Var}(\epsilon) \\ &\quad -\Big[\frac{n-p}{n}r\tilde{w}^2 + \frac{p}{n}(1-r)w^2 + \frac{p}{n}r(w-\hat{w})^2\Big]\mathrm{Var}(\eta). \end{aligned}$$

A.3 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

$$\bar{a} = \underbrace{\frac{(1-r)\eta + \phi}{\epsilon + (1-r)\eta + \phi}}_{1-w} \bar{x} + \underbrace{\frac{\epsilon}{\epsilon + (1-r)\eta + \phi}}_{w} \bar{y}, \tag{21}$$

and the expected utility yields

$$\begin{aligned}
\mathbb{E}\Big(u_i(a_i,\theta)\Big) &= \mathbb{E}\Big(-(1-r)\Big((1-w)(\theta+\epsilon) + w(\theta+\eta+\phi) - \theta\Big)^2 \\
&\quad -r\Big((1-w)(\theta+\epsilon) + w(\theta+\eta+\phi) - (1-w)\theta - w(\theta+\eta)\Big)^2\Big) \\
&= -(1-w)^2\mathrm{Var}(\epsilon) - w^2\mathrm{Var}(\phi) - (1-r)w^2\mathrm{Var}(\eta).
\end{aligned}$$

A.4 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 $\bar{w}$ on the public signal in the PP-treatment (20) with the optimal average weight w on the public signal in the PT-treatment (21):

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

which implies

$$\begin{aligned}
\frac{p}{n} &= \frac{(n-1)(\epsilon+\eta) + r\eta}{(n-1)(\epsilon+\eta+\phi) + r\eta} \qquad \text{or} \\
\phi &= \frac{n-p}{p}\Big(\epsilon + \eta + \frac{r\eta}{n-1}\Big).
\end{aligned}$$

B 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 $a_i^1 = \mathbb{E}_i(\theta)$.[18] 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.

[18] Nagel (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 $a_i^1 = \mathbb{E}_i(\theta)$.

B.1 Private and 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 $\rho_\infty = 0.8163$.

B.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.

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

For sujects who receive both signals, we proceed as in B.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:

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

With the experimental parameters of groups 1 to 12, we get the following weights for the level of reasoning k: $\rho_1 = 0.3571$, $\rho_2 = 0.4583$, $\rho_3 = 0.4870$, $\rho_4 = 0.4951$, $\rho_5 = 0.4974$, and $\rho_\infty = 0.4983$. With the experimental parameters of groups 13 to 18, we get: $\rho_1 = 0.2857$, $\rho_2 = 0.3829$, $\rho_3 = 0.4159$, $\rho_4 = 0.4271$, $\rho_5 = 0.4309$, and $\rho_\infty = 0.4329$.

B.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 $\rho_\infty = 0.4301$.

C 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.[19]

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.

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.

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

However, each participant receives some hints on the unknown number **Z** as explained in sections B, C and D.

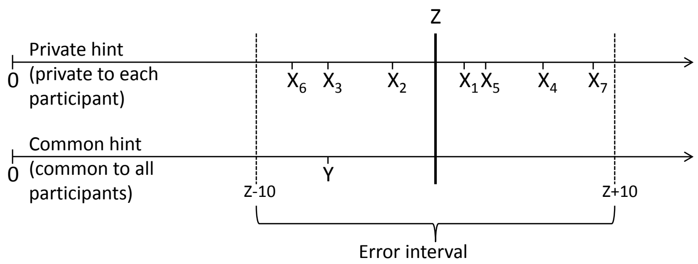
B - Your hints on Z during stage 1 (15 periods)

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.

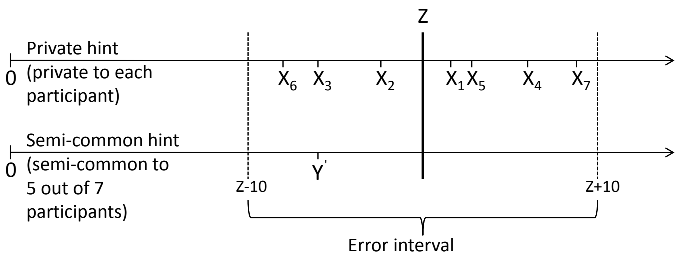
As soon as the 15 periods of the first stage are over, the second stage of the experiment starts.

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)

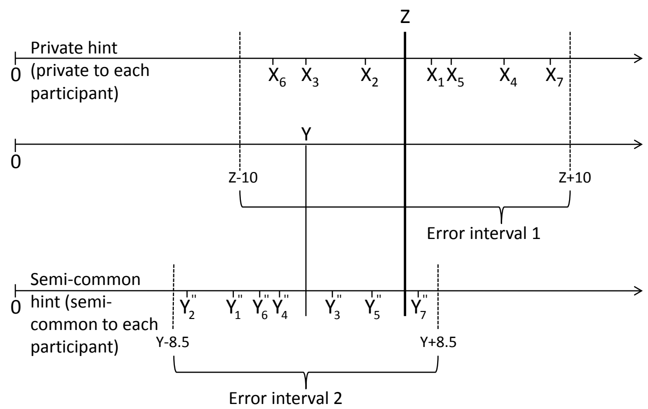
At each period of the third stage, you receive two hints on Z to make your decision.

- **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 commin 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 **X** and the semi-common hint **Y”** can be distinguished in two ways. First, the private hint **X** is more precise than the semi-common hint **Y”**. The error interval of the private hint **X** is $[Z-10, Z+10]$ while the error interval of the semi-common hint **Y”** is $[Z-18.5, Z+18.5]$. Indeed, the semi-common hint **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 **X** is different for each participant, the semi-common hint **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 **X** and the semi-common hint **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!

D Training questionnaire

The training questionnaire varied according to the treatments.[20] We present the questionnaire for a treatment with order of stages: 1, 2 and 3 (and parameter values: r=0.85, =10, =10, =0, p=7). For the other treatments, the training questionnaires were adapted accordingly and are available upon request.[21] 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.")

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

[20] Questions 6, 8, 9 and 10 had to be adapted to the treatment.

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

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).")

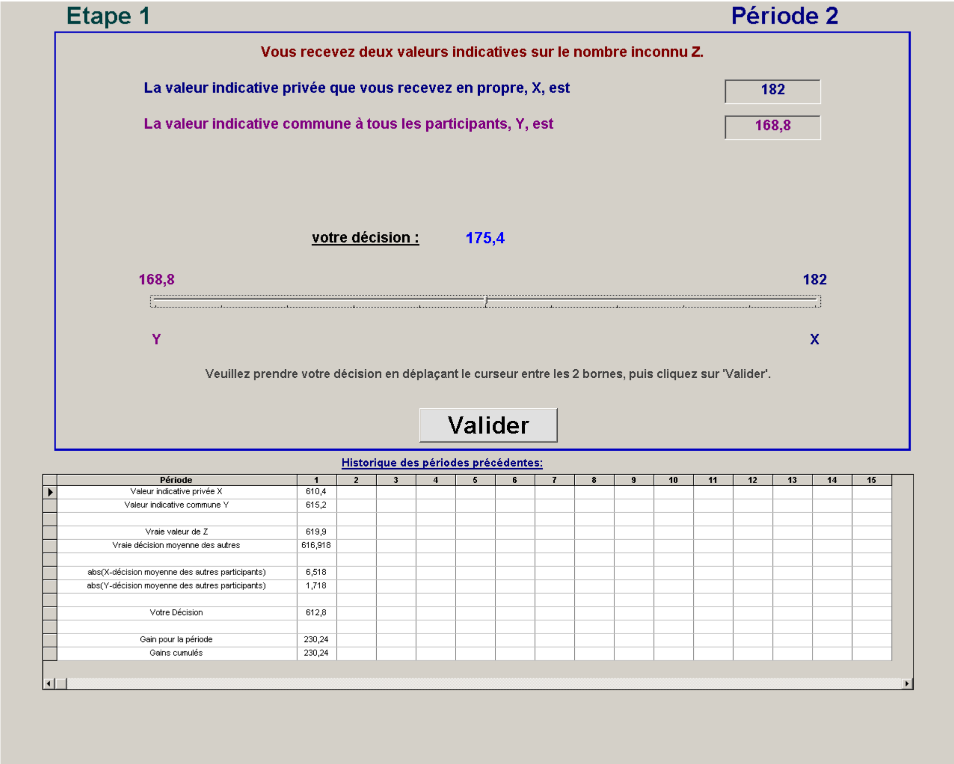
Question 7: "Generally, at stage 1, the private hint X is as informative on the average decision of the others as the common hint Y." Answer: "Wrong" (Explanation message: "It is wrong. While the private hint X is as precise as the common hint Y on the number Z, the common hint Y is generally more informative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

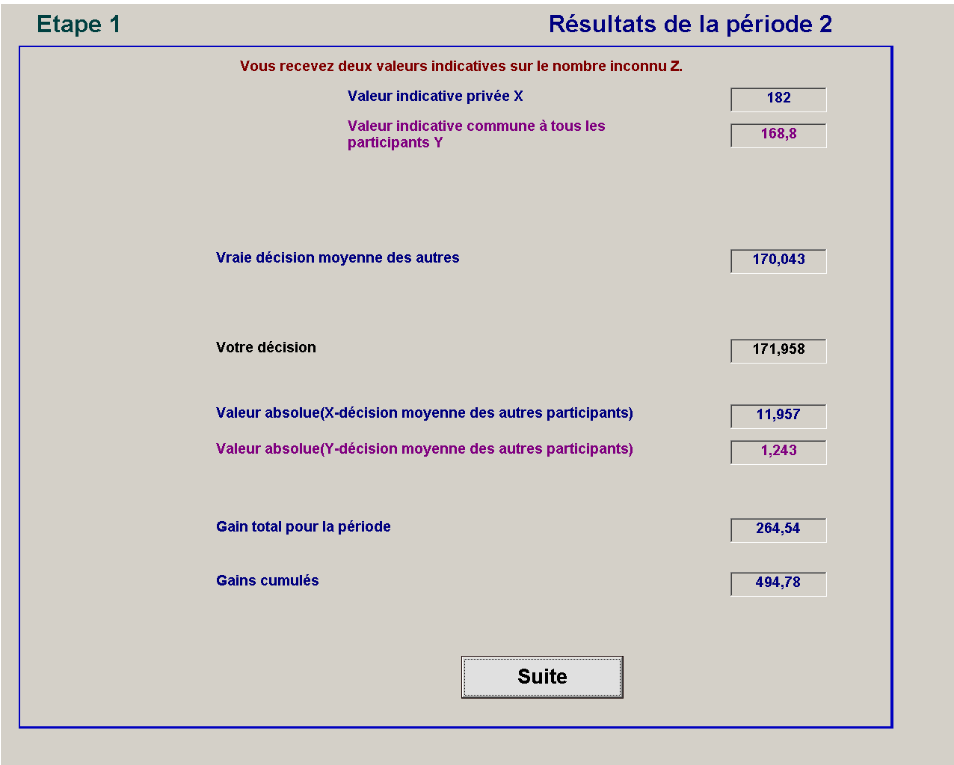
Question 8: "The difference between stages 1 and 2 is that the common hint Y is observed by all the participants at stage 1 while it is observed only by 5 out of the 7 participants at stage 2." Answer: "True" (Explanation message: "It is true.")

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".")

E Example of screens





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