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While the central bank observes the market activity to assess economic fundamentals, it shapes the market outcome through its policy interventions. The more the central bank influences the market, the more it spoils the informational content of economic aggregates. How should the central bank act and communicate when it derives its information from observing the market? This paper analyses the optimal central bank's action and disclosure under endogenous central bank's information for three operational frameworks: pure communication, action and communication, and signaling action. When the central bank takes an action, it would be optimal for the central bank to be fully opaque to prevent its disclosure from deteriorating the information quality of market outcomes. However, in the realistic case where central bank's action is observable, it may be optimal to refrain from implementing any action.

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# Observing and shaping the market: the dilemma of central banks\*

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# 1 Introduction

To conduct monetary policy, the central bank observes the market to collect information on the state of the economy. In return, it shapes the economy through its policy action and communication strategy. This paper analyses the relationship between central bank's action and communication when the central bank observes the market to assess economic fundamentals.

A growing literature addresses the issue of central banks' communication in coordination games with heterogenous information. Morris and Shin (2002) (henceforth MS) present a Keynesian beauty contest game where the equilibrium behavior of economic agents is driven by both a fundamental and a coordination motive. The focal role that public information exerts on the higher order beliefs of agents gives rise to an overreaction, which may be detrimental to welfare. If public information is poorly accurate, it may distort the market outcome away from the economic fundamental. While MS refer to the case where the provider of public information only discloses information, further works have applied the beauty contest mechanism to more realistic and complex environments. These extensions can be classified along two lines, as shown in Table 1.

First, the beauty contest game has been extended by allowing the provider of public information to take an action, as central banks do in reality. James and Lawler (2011) analyse the optimal disclosure strategy when the central bank also takes an action and find that full opacity is optimal. Indeed, by disclosing its information on the fundamental state to private agents, the central bank induces a distortion in private decisions towards its potentially noisy announcement.<sup>1</sup> Baeriswyl and Cornand (2010) state that taking an action inevitably provides public information as it signals the central bank's belief to agents, qualifying the possibility of taking an action under opacity.<sup>2</sup>

Second, the beauty contest game has been applied to the case where the provider of public information derives its own information about economic fundamentals from observing the economic outcome, rather than from directly observing fundamentals. In the model of MS, central bank's information is exogenously given and is independent of the existence of the market. However, central banks usually assess the state of the economy

	<b>Exogenous information</b>	<b>Endogenous information</b>
<b>Pure communication</b>	Morris and Shin (2002)	Baeriswyl (2011)
<b>Action &amp; communi.</b>	James and Lawler (2011)	This paper
<b>Signaling action</b>	Baeriswyl and Cornand (2010)	This paper

Table 1: Extensions of the beauty contest game by Morris and Shin (2002)

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<sup>1</sup>Angeletos et al. (2016) also study the welfare consequences of public disclosures in micro-founded business cycle model.

<sup>2</sup>There is a large literature that focuses on the interrelations between central bank transparency and stabilization policy as e.g. Cukierman and Meltzer (1986) and Faust and Svensson (2001). However, the framework here is different as it is characterized by heterogenous information and central bank information is not perfect.

by observing the market because there is not such a thing as an observable fundamental in reality. Hayek (1945) underlines the informational role of prices, which aggregate agents' knowledge and beliefs about the state of the economy. The market price is not only an exchange ratio between goods but also an aggregator of information. Yet, market prices (and especially financial prices) are influenced by the central bank itself. Therefore, the central bank is both an observer and a shaper of the market outcome. This ambivalent role of the central bank causes a dilemma with respect to the implementation of monetary policy, which has been documented by Amato and Shin (2006) and Morris and Shin (2005): the more successfully a central bank influences market expectations, the less reliable market outcomes serve as indicators of the fundamental of the economy.

In an empirical analysis of U.S. data, Ehrmann and Fratzscher (2005) show that with increasing transparency "markets attach more importance to the statements and the balance-of-risk assessments at FOMC meetings and less importance to news about macroeconomic fundamentals." They conclude that "the reaction of financial markets to the release of macroeconomic fundamentals can be an important source of information for the central bank about the markets' diverse and possibly deviating views," and that "under its new disclosure strategy, the Federal Reserve has less such information available." Baeriswyl (2011) extends the model of MS to the case where the central bank observes the economic outcome to draw its information about the fundamental (endogenous information). He shows that while a higher degree of transparency strengthens the influence of the central bank on agents' decision, it deteriorates the accuracy of its information. Central bank's endogenous information therefore represents an additional argument challenging the presumed benefit of central bank's transparency. As in MS, Baeriswyl (2011) does not account for central bank's action.

The contribution of the present paper is twofold. First, it derives the welfare implications of endogenous information when the central bank takes an action (i.e. James and Lawler (2011)) and when the action of the central bank provides a public signal (i.e. Baeriswyl and Cornand (2010)). Second, it compares the social welfare in the different operational frameworks (pure communication, action and communication, and signaling action) both under exogenous and endogenous information.

Choosing an optimal action under full opacity yields a higher welfare than under the pure communication and signaling action frameworks. However, in a context where full opacity cannot be reached, because central bank's action publicly reveals central bank's beliefs about economic fundamentals, it may be optimal for the central bank to refrain from implementing any action. Interestingly, endogenous information enlarges the range of parameter values for which the absence of action is superior. Acknowledging the ambivalent role of the central bank, as an observer and a shaper of market outcomes, shows that the attempt to stabilise the economy does not always improve welfare, as it deteriorates the informational content of market prices.

Our paper contributes to a growing literature that accounts for the endogenous nature of information. In coordination games under heterogenous information, endogenous

information often refers to the case where market participants have an incentive to acquire exogenous, market-independent, information. This is the case in Burguet and Vives (2000), Hellwig and Veldkamp (2009), Myatt and Wallace (2012) or Paciello and Wiederholt (2014), where agents put effort at collecting private information. By contrast, our definition of endogenous information means that agents glean information from observing the market outcome, which results from the behavior of market participants, as in the works by Grossman and Stiglitz (1980), Amador and Weill (2010), Hellwig and Venkateswaran (2011), Amador and Weill (2012), Atolia and Chahrour (2013), or Vives (2013). While these papers focus on the learning by market participants from information conveyed by prices, we focus on the learning by the policy maker. We are not the first to draw attention to the issue of the decision maker learning from market prices. Bond et al. (2010) show that if the decision maker, such as the firm management, relies on market prices when deciding on corrective actions, prices may become less revealing about the true fundamental of the firm as they may already incorporate the corrective actions expected by market participants. They conclude that it may be desirable for the decision maker to rely less extensively on market-based information. Goldstein et al. (2011) analyse the theoretical implications of the informational feedback from market activities to policy decisions into a model of currency attacks. The central bank learns from the speculative trading in currency markets about the viability of its currency regime and uses the inferred information to guide its policy decisions. Again, they conclude that the central bank can improve the effectiveness of its policy by putting a lower weight on the information gleaned from the market. The same conclusion is drawn by Bond and Goldstein (2015), in the context of financial stability measures taken by governments such as bailouts or lending facilities.

Our paper departs from this recent literature as the central bank has no direct sources of private information about the economic fundamental and, thus, must observe the market activity to glean information. While the central bank may have market-independent sources of information in the context of speculative attacks (i.e. the level of its foreign exchange reserves) or financial stability (i.e. the balance sheet of financial institutions), typically the conduct of monetary policy does not benefit from such direct information about fundamentals.

The remaining of this paper is structured as follows. Section 2 presents the general set-up. Section 3 derives and compares welfare for three operational frameworks under exogenous information. Section 4 reconsiders these operational frameworks under endogenous information. Finally, section 5 concludes.

## 2 The general set-up of the beauty contest game

This section adapts the theoretical Keynesian beauty contest to encompass in a unified set-up the various extensions of Morris and Shin (2002). The economy is populated by a continuum of economic agents  $i$  indexed on the unit interval  $[0, 1]$  and a central bank which can take an action and disclose information to stabilise the economy.

## 2.1 Economic agents

In a beauty contest game, the utility function of each agent  $i$  exhibits strategic complementarities and can be written

$$u_i(a, \theta) = -r(a_i - \bar{a}) - (1 - r)(a_i - \theta + g),$$

where  $a_i$  is the decision taken by agent  $i$ ,  $\bar{a} = \int_i a_i di$  is the average decision over all agents,  $\theta \in \mathbb{R}$  represents the fundamental of the economy,  $g \in \mathbb{R}$  is the policy action taken by the central bank, and  $0 < r < 1$  is the constant weight assigned to the strategic component which drives the strength of the coordination motive in agents' decision rule.

Under uncertainty about the fundamental and others' decision, the optimal decision of agent  $i$  can be expressed as:

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

where  $\mathbb{E}_i(\cdot)$  is the expectation operator of agent  $i$  (conditional on his information set).<sup>3</sup>

To make his decision, each agent receives two signals. First, each agent gets a private signal  $x_i$  about the fundamental, which can be interpreted as agent's own assessment. The private signal is centered on the true value of  $\theta$  and has a normally distributed error term:

$$x_i = \theta + \epsilon_i, \quad \text{with } \epsilon_i \sim \mathcal{N}(0, \sigma_\epsilon^2), \quad (2)$$

where  $\epsilon_i$  are identically and independently distributed across agents.

Second, the central bank provides agents with its viewpoint about the fundamental. The central bank communicates its information  $y$  with more or less ambiguity. We capture this ambiguity with the degree of opacity of its disclosure as in Baeriswyl (2011).<sup>4</sup> The signal disclosed by the central bank and received by agent  $i$  is written as

$$y_i = y + \phi_i, \quad \text{with } \phi_i \sim \mathcal{N}(0, \sigma_\phi^2). \quad (3)$$

The dispersion of individual noises  $\sigma_\phi^2$  determines the degree of opacity of the central bank. The signal  $y_i$  can be considered as a "semi-public" signal.<sup>5</sup> Under transparency, all agents get the same unequivocal signal ( $\sigma_\phi^2 = 0$ ). Then, the central bank disclosure  $y$  is a public signal that is common knowledge among agents. Under opacity, the individual signal received by each agent has an infinite idiosyncratic noise ( $\sigma_\phi^2 \rightarrow \infty$ ). The central

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<sup>3</sup>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.

<sup>4</sup>This specification is more general than the public signal considered in Morris and Shin (2002) and James and Lawler (2011), who focus on fully transparent signal and ask whether the central bank should disclose fully transparent signal or not. On top of being more realistic, such a formulation of the public signal allows to get a unique solution for the optimal instrument  $g$  as we shall see later.

<sup>5</sup>For more details on the characteristics of semi-public information in these games, see Cornand and Heinemann (2008) and Baeriswyl and Cornand (2014).

bank disclosure thus does not contain any valuable information.

## 2.2 Welfare

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

$$W = - \int_0^1 (a_i - \bar{a})^2 di - \lambda(\bar{a} - \theta - g)^2, \quad (4)$$

where  $\lambda$  is the weight assigned to the distortion of the average decision from the fundamental. The welfare function used in the transparency debate initiated by Morris and Shin (2002) is a controversial matter because the welfare effect of transparency is driven by the discrepancy between the equilibrium degree of coordination  $r$  and the efficient degree of coordination  $\lambda$ , as highlighted by Angeletos and Pavan (2007). The social welfare function in the form of (4) includes many welfare specifications. It is reminiscent of the welfare of the representative household derived from a micro-founded monopolistic competitive economy. When  $\lambda = 1 - r$ , the efficient degree of coordination coincides with the equilibrium degree of coordination: this is the case where  $W = \int_i u_i(a, \theta)$ . The welfare in Morris and Shin (2002) given by  $-\int_i (a_i - \theta)^2 di$  also corresponds to the welfare (4) with  $\lambda = 1$ .

## 2.3 The central bank

The central bank seeks to minimise the unconditional expected loss (4) by disclosing information about the fundamental to economic agents and/or taking a policy action, depending on the operational framework. Three operational frameworks are under scrutiny. Under pure communication, the central bank can solely disclose information. Under action and communication, the central bank can take an action and disclose information. Under signaling action, the action taken by the central bank is common knowledge.

These three operational frameworks are solved for two processes of information gathering by the central bank. With the exogenous process, the central bank directly observes the fundamental with some noise. The precision of central bank information is then exogenously determined and it is independent of its disclosure strategy and of its influence on the economy (section 3). With the endogenous process, the central bank does not directly observe the fundamental  $\theta$  but instead watches the economic outcome to evaluate the state of the fundamental. In this case, the precision of central bank information is endogenous because it depends on its disclosure strategy and on how it influences the economy (section 4).

For the sake of generality, we define the central bank's information about the fundamental as  $y$  and the variance of the central bank's expectation error as

$$\text{Var}[\mathbb{E}(\theta|y) - \theta] \equiv \sigma_\mu^2. \quad (5)$$

This definition allows us to solve generally for the equilibrium behavior of agents before specifying whether central bank's information is exogenous or endogenous.

Based on its information, the central bank takes an action (when provided by the operational framework) to stabilise the economy owing to its instrument

$$g = \rho(\sigma_\epsilon^2, \sigma_\mu^2, \sigma_\phi^2, r, \lambda) \cdot y,$$

where  $\rho$  is the monetary policy coefficient.

## 2.4 Equilibrium

This section derives the perfect Bayesian equilibrium behavior of agents. To calculate the optimal rule (1), we built the first-order and higher-order expectations of agent  $i$  about the fundamental  $\theta$  conditional on his information. Given agents' information (2), (3), and (5), the expectation of degree one about the fundamental  $\mathbb{E}_i(\theta)$  yields

$$\mathbb{E}_i(\theta) = \frac{\sigma_\mu^2 + \sigma_\phi^2}{\sigma_\epsilon^2 + \sigma_\mu^2 + \sigma_\phi^2} x_i + \frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + \sigma_\mu^2 + \sigma_\phi^2} y_i. \quad (6)$$

The best estimate of the fundamental by agent  $i$  is an average of both his signals, which weights depend on their relative precision. To compute the higher-order expectations of firm  $i$ , one needs also to know the expectation of degree one of the central bank average disclosure  $\mathbb{E}_i(y)$ . This delivers

$$\mathbb{E}_i(y) = \frac{\sigma_\phi^2}{\sigma_\epsilon^2 + \sigma_\mu^2 + \sigma_\phi^2} x_i + \frac{\sigma_\epsilon^2 + \sigma_\mu^2}{\sigma_\epsilon^2 + \sigma_\mu^2 + \sigma_\phi^2} y_i. \quad (7)$$

Because the equilibrium decision is a linear combination of expectations ( $E_i(\theta)$  and  $E_i(\bar{a})$ ) and that  $E_i(\theta)$  is itself a linear combination of signals, we can assume that the equilibrium decision of any agent  $i$  is a linear combination of  $x_i$  and  $y_i$ :

$$a_i = \gamma_1 x_i + \gamma_2 y_i, \quad (8)$$

and the average decision yields:

$$\bar{a} = \gamma_1 \theta + \gamma_2 y.$$

Plugging this in (1) and using the expressions of expectations (6) and (7), we get an expression of  $a_i$  as a function of  $x_i$  and  $y$ . This expression is also equal to (8), which allows to identify coefficients  $\gamma_1$  and  $\gamma_2$ :

$$\gamma_1 = \frac{(1-r)\sigma_\mu^2 + (1+\rho)\sigma_\phi^2}{\sigma_\epsilon^2 + (1-r)\sigma_\mu^2 + \sigma_\phi^2}, \quad \gamma_2 = \frac{(1+\rho)\sigma_\epsilon^2 + \rho(1-r)\sigma_\mu^2}{\sigma_\epsilon^2 + (1-r)\sigma_\mu^2 + \sigma_\phi^2}, \quad \text{with } \gamma_1 + \gamma_2 = 1 + \rho. \quad (9)$$

Given the equilibrium behavior of agents (9) and central bank's information as described in the previous section, the unconditional expected social welfare (4) can be written



as

$$\mathbb{E}(W) = -\gamma_1^2 \sigma_\epsilon^2 - \gamma_2^2 \sigma_\phi^2 - \lambda(\gamma_2 - \rho)^2 \sigma_\mu^2. \quad (10)$$

The central bank chooses its disclosure and action to maximise the unconditional expected welfare.

### 3 Exogenous information

This section analyses the welfare effects of disclosure and policy action when central bank's information is exogenous. The central bank directly observes the fundamental with some noise. According to the error term of central bank's information (5), the central bank receives a signal  $y$  on the fundamental that is centered on its true value  $\theta$  and contains an error term  $\mu$ :

$$y = \theta + \mu, \quad \text{with } \mu \sim \mathcal{N}(0, \sigma_\mu^2).$$

The precision of central bank's information  $\sigma_\mu^2$  is exogenous and independent of its behavior. The present section serves as a benchmark for the analysis under endogenous information presented in section 4.

#### 3.1 Optimal central bank's behavior

We derive the optimal central bank's disclosure and/or action under three operational frameworks before comparing these operational frameworks with each other. Under pure communication, the central bank can only choose its communication policy. Under action and communication, the central bank can take a policy action and disclose information. Under signaling action, the action taken by the central bank is common knowledge and reveals some information on the central bank's beliefs.

##### 3.1.1 Pure communication

The first operational framework corresponds to Morris and Shin (2002), where the central bank discloses information but takes no action. This case is captured in our general set-up by imposing  $\rho = 0$ . Plugging the equilibrium response of agents (9) into (10) yields the unconditional expected welfare

$$\mathbb{E}(W|_{\rho=0}) = -\frac{\left( \left( (1-r)\sigma_\mu^2 + \sigma_\phi^2 \right)^2 + \sigma_\epsilon^2 (\lambda\sigma_\mu^2 + \sigma_\phi^2) \right) \sigma_\epsilon^2}{\left( \sigma_\epsilon^2 + (1-r)\sigma_\mu^2 + \sigma_\phi^2 \right)^2}.$$

Differentiating with respect to  $\sigma_\phi^2$  and setting the resulting expression to zero gives the optimal degree of opacity:

$$\sigma_\phi^{2*} = \max[0, (2\lambda - 3 + 3r)\sigma_\mu^2 - \sigma_\epsilon^2]. \quad (11)$$

The degree of opacity increases with the inaccuracy of public information  $\sigma_\mu^2$ , with the weight assigned to distortion in the welfare function  $\lambda$ , and with the degree of strategic complementarities  $r$ . When full transparency is optimal, i.e.  $\sigma_\phi^{2*} = 0$ , the expected welfare is given by

$$\mathbb{E}(W|_{\rho=0, \sigma_\phi^{2*}=0}) = -\frac{(\lambda\sigma_\epsilon^2 + (1-r)^2\sigma_\mu^2)\sigma_\epsilon^2\sigma_\mu^2}{(\sigma_\epsilon^2 + (1-r)\sigma_\mu^2)^2}.$$

When partial transparency is optimal, i.e.  $\sigma_\phi^{2*} = (2\lambda - 3 + 3r)\sigma_\mu^2 - \sigma_\epsilon^2$ , the expected welfare is

$$\mathbb{E}(W|_{\rho=0, \sigma_\phi^{2*}=(2\lambda-3+3r)\sigma_\mu^2-\sigma_\epsilon^2}) = -\sigma_\epsilon^2 + \frac{\sigma_\epsilon^4}{4(\lambda - 1 + r)\sigma_\mu^2}.$$

In the particular case where the efficient degree of coordination coincides with the equilibrium degree of coordination, i.e.  $\lambda = 1 - r$ , full transparency is always optimal:

$$\sigma_\phi^{2*}|_{\rho=0, \lambda=1-r} = \max[0, (r-1)\sigma_\mu^2 - \sigma_\epsilon^2] = 0,$$

This conforms to the result of Hellwig (2005). The corresponding expected welfare is given by

$$\mathbb{E}(W|_{\rho=0, \lambda=1-r, \sigma_\phi^{2*}=0}) = -\frac{(1-r)\sigma_\epsilon^2\sigma_\mu^2}{\sigma_\epsilon^2 + (1-r)\sigma_\mu^2}.$$

### 3.1.2 Action and communication

In the second operational framework, the central bank can both take an action and disclose information, as in James and Lawler (2011). First the optimal stabilisation policy of the central bank when  $(\sigma_\epsilon^2, \sigma_\mu^2, \sigma_\phi^2, r, \lambda)$  are fixed is obtained by differentiating (10) with respect to  $\rho$ . This yields the optimal policy action

$$\rho^* = -\frac{(\sigma_\epsilon^2 + (2 - 2r - \lambda)\sigma_\mu^2 + \sigma_\phi^2)\sigma_\epsilon^2}{(\sigma_\epsilon^2 + \lambda\sigma_\mu^2)\sigma_\phi^2 + (\sigma_\epsilon^2 + (1-r)\sigma_\mu^2)^2}.$$

In the remaining of the analysis, we always consider that the central bank implements the optimal policy action  $\rho^*$ .

Second, the communication strategy is chosen to maximise welfare. We calculate the welfare function at the optimal policy action by plugging  $\rho^*$  in (10), which yields:

$$\mathbb{E}(W|_{\rho^*}) = -\frac{(\lambda(\sigma_\epsilon^2 + \sigma_\phi^2) + (1-r)^2\sigma_\mu^2)\sigma_\epsilon^2\sigma_\mu^2}{(\sigma_\epsilon^2 + \lambda\sigma_\mu^2)\sigma_\phi^2 + (\sigma_\epsilon^2 + (1-r)\sigma_\mu^2)^2}.$$

Differentiating this expression with respect to  $\sigma_\phi^2$  yields:

$$\frac{\partial \mathbb{E}(W|_{\rho^*})}{\partial \sigma_\phi^2} = \frac{(1-r-\lambda)^2\sigma_\epsilon^4\sigma_\mu^4}{\left((\sigma_\epsilon^2 + \lambda\sigma_\mu^2)\sigma_\phi^2 + (\sigma_\epsilon^2 + (1-r)\sigma_\mu^2)^2\right)^2} > 0, \quad (12)$$

which is always positive. For any parameter value, it is welfare improving for the central

bank to increase the noise in the semi-public signal, and thus full opacity is optimal.

Under full opacity, i.e.  $\sigma_\phi^2 \rightarrow \infty$ , optimal central bank's action is given by

$$\rho^*|_{\sigma_\phi^2 \rightarrow \infty} = -\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + \lambda\sigma_\mu^2}, \quad (13)$$

and expected welfare writes

$$\mathbb{E}(W|_{\rho^*, \sigma_\phi^2 \rightarrow \infty}) = -\frac{\lambda\sigma_\epsilon^2\sigma_\mu^2}{\sigma_\epsilon^2 + \lambda\sigma_\mu^2}.$$

This result corroborates that of James and Lawler (2011) when  $\lambda = 1$ : public disclosure of central bank's information always deteriorates welfare whenever the central bank takes an action. Even when the central bank has some information of very high quality, it is optimal not to communicate this information.

When the welfare function is such that the efficient and equilibrium degree of coordination coincide, i.e.  $\lambda = 1 - r$ , the partial derivative (12) equals zero, indicating that communication is irrelevant. This means that when  $\lambda = 1 - r$  and when central bank's action is optimal, social welfare does not depend on the communication policy because there is no conflict between the objective of the central bank and that of any agent  $i$ .

### 3.1.3 Signaling action

While in the previous section action and communication were not directly linked, we now consider a third more realistic operational framework, such that taking action also signals what the central bank believes about the state of the economy. Indeed, although the central bank may not explicitly communicate about its beliefs, its action is always observable and, thereby, reveals its beliefs about the economic fundamental, as highlighted in Baeriswyl and Cornand (2010).

Consider the case where central bank's action is perfectly observable by agents, i.e.  $\sigma_\phi^2 \rightarrow 0$ . Differentiating (10) with respect to  $\rho$  yields the central bank's optimal action

$$\rho^*|_{\sigma_\phi^2 \rightarrow 0} = -\frac{(\sigma_\epsilon^2 + (2 - 2r - \lambda)\sigma_\mu^2)\sigma_\epsilon^2}{(\sigma_\epsilon^2 + (1 - r)\sigma_\mu^2)^2}, \quad (14)$$

and the expected welfare writes

$$\mathbb{E}(W|_{\rho^*, \sigma_\phi^2 \rightarrow 0}) = -\frac{(\lambda\sigma_\epsilon^2 + (1 - r)^2\sigma_\mu^2)\sigma_\epsilon^2\sigma_\mu^2}{(\sigma_\epsilon^2 + (1 - r)\sigma_\mu^2)^2}.$$

Note that when  $\sigma_\phi^2 = 0$  the optimal action is indeterminate, as any (common knowledge) policy coefficient yields the same optimal welfare. The central bank's action (14) is the optimal action as the degree of opacity  $\sigma_\phi^2$  converges toward zero.

When the welfare function is such that the efficient and the equilibrium degree of

for $\lambda \neq 1 - r$	$\sigma_\phi^2$	$\rho$	$\mathbb{E}(W)$
No CB	$\infty$	0	$-\sigma_\epsilon^2$
PC if $(2\lambda - 3 + 3r)\sigma_\mu^2 \leq \sigma_\epsilon^2$	0	0	$-\frac{(\lambda\sigma_\epsilon^2 + (1-r)^2\sigma_\mu^2)\sigma_\epsilon^2\sigma_\mu^2}{(\sigma_\epsilon^2 + (1-r)\sigma_\mu^2)^2}$
otherwise	$(2\lambda - 3 + 3r)\sigma_\mu^2 - \sigma_\epsilon^2$	0	$-\sigma_\epsilon^2 + \frac{\sigma_\epsilon^4}{4(\lambda-1+r)\sigma_\mu^2}$
AC	$\infty$	$-\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + \lambda\sigma_\mu^2}$	$-\frac{\lambda\sigma_\epsilon^2\sigma_\mu^2}{\sigma_\epsilon^2 + \lambda\sigma_\mu^2}$
SA	0	$-\frac{(\sigma_\epsilon^2 + (2-2r-\lambda)\sigma_\mu^2)\sigma_\epsilon^2}{(\sigma_\epsilon^2 + (1-r)\sigma_\mu^2)^2}$	$-\frac{(\lambda\sigma_\epsilon^2 + (1-r)^2\sigma_\mu^2)\sigma_\epsilon^2\sigma_\mu^2}{(\sigma_\epsilon^2 + (1-r)\sigma_\mu^2)^2}$
for $\lambda = 1 - r$	$\sigma_\phi^2$	$\rho$	$\mathbb{E}(W)$
No CB	$\infty$	0	$-\sigma_\epsilon^2$
PC	0	0	$-\frac{(1-r)\sigma_\epsilon^2\sigma_\mu^2}{\sigma_\epsilon^2 + (1-r)\sigma_\mu^2}$
AC	indeterminate	$-\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1-r)\sigma_\mu^2}$	$-\frac{(1-r)\sigma_\epsilon^2\sigma_\mu^2}{\sigma_\epsilon^2 + (1-r)\sigma_\mu^2}$
SA	0	$-\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1-r)\sigma_\mu^2}$	$-\frac{(1-r)\sigma_\epsilon^2\sigma_\mu^2}{\sigma_\epsilon^2 + (1-r)\sigma_\mu^2}$

Table 2: Expected welfare in various operational frameworks

coordination coincide, i.e.  $\lambda = 1 - r$ , the optimal action is given by

$$\rho^*|_{\sigma_\phi^2 \rightarrow 0, \lambda=1-r} = -\frac{\sigma_\epsilon^2}{\sigma_\epsilon^2 + (1-r)\sigma_\mu^2},$$

and the expected welfare is

$$\mathbb{E}(W|_{\rho^*, \sigma_\phi^2 \rightarrow 0, \lambda=1-r}) = -\frac{(1-r)\sigma_\epsilon^2\sigma_\mu^2}{\sigma_\epsilon^2 + (1-r)\sigma_\mu^2}.$$

After having derived the optimal behavior of the central bank in three different operational frameworks, the next section compares these frameworks at their respective optimum.

### 3.2 Optimal operational framework

Table 2 summarises the optimal central bank's behavior under pure communication (PC), action and communication (AC), and signaling action (SA). The first line also shows the welfare when the central bank neither talks nor takes any action (no CB). In this section we compare these operational frameworks.

When the efficient degree of coordination coincides with the equilibrium degree of coordination, i.e. when  $\lambda = 1 - r$ , the operational framework is irrelevant for the social welfare. Moreover, this welfare is always superior to the case where the central bank neither talks nor takes any action:

$$\mathbb{E}(W|_{\rho=0, \sigma_\phi^{2*}=0, \lambda=1-r}) = \mathbb{E}(W|_{\rho^*, \sigma_\phi^{2*} \rightarrow \infty, \lambda=1-r}) = \mathbb{E}(W|_{\rho^*, \sigma_\phi^2 \rightarrow 0, \lambda=1-r}) > \mathbb{E}(W|_{\rho=0, \sigma_\phi^2 \rightarrow \infty}).$$

When the efficient degree of coordination does not coincide with the equilibrium degree

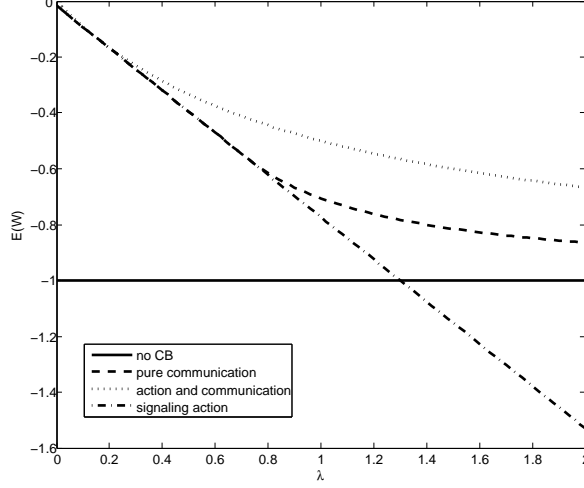


Figure 1: Expected welfare as a function of  $\lambda$  for  $\sigma_\epsilon^2 = 1$ ,  $\sigma_\mu^2 = 1$  and  $r = 0.85$

of coordination, i.e. when  $\lambda \neq 1 - r$ , the operational framework matters for social welfare. Three results hold. Figure 1 illustrates these results for the parameter configuration  $\sigma_\epsilon^2 = 1$ ,  $\sigma_\mu^2 = 1$  and  $r = 0.85$ .

First, choosing simultaneously an optimal action and full opacity (AC) yields a higher welfare than under the pure communication and signaling action frameworks:

$$\begin{aligned} \mathbb{E}(W|_{\rho^*, \sigma_\phi^{2*} \rightarrow \infty}) &\geq \mathbb{E}(W|_{\rho=0, \sigma_\phi^{2*}=0}) = \mathbb{E}(W|_{\rho^*, \sigma_\phi^2 \rightarrow 0}), \\ \mathbb{E}(W|_{\rho^*, \sigma_\phi^{2*} \rightarrow \infty}) &\geq \mathbb{E}(W|_{\rho=0, \sigma_\phi^{2*}=(2\lambda-3+3r)\sigma_\mu^2-\sigma_\epsilon^2}). \end{aligned}$$

Second, when partial transparency is optimal under the pure communication framework, i.e. when  $(2\lambda - 3 + 3r)\sigma_\mu^2 > \sigma_\epsilon^2$  or  $\lambda > 0.725$  on Figure 1, pure communication is superior to taking a signaling action. When full transparency is optimal under the pure communication framework, i.e.  $(2\lambda - 3 + 3r)\sigma_\mu^2 \leq \sigma_\epsilon^2$  or  $\lambda \leq 0.725$  on Figure 1, pure communication and signaling action are equivalent:

$$\begin{aligned} \mathbb{E}(W|_{\rho=0, \sigma_\phi^{2*}=(2\lambda-3+3r)\sigma_\mu^2-\sigma_\epsilon^2}) &> \mathbb{E}(W|_{\rho^*, \sigma_\phi^2 \rightarrow 0}) && \text{if } (2\lambda - 3 + 3r)\sigma_\mu^2 > \sigma_\epsilon^2, \\ \mathbb{E}(W|_{\rho=0, \sigma_\phi^{2*}=0}) &= \mathbb{E}(W|_{\rho^*, \sigma_\phi^2 \rightarrow 0}) && \text{if } (2\lambda - 3 + 3r)\sigma_\mu^2 \leq \sigma_\epsilon^2. \end{aligned}$$

Third, when  $(\lambda - 2 + 2r)\sigma_\mu^2 - \sigma_\epsilon^2 > 0$  or  $\lambda > 1.3$  in Figure 1, taking a signaling action yields a lower welfare than doing nothing:

$$\mathbb{E}(W|_{\rho=0, \sigma_\phi^2 \rightarrow \infty}) > \mathbb{E}(W|_{\rho^*, \sigma_\phi^2 \rightarrow 0}) \quad \text{if } (\lambda - 2 + 2r)\sigma_\mu^2 > \sigma_\epsilon^2.$$

Under this parameter combination, unconditional expected welfare is higher when the central bank refrains from influencing the economy than when it takes an action which is perfectly observable.

## 4 Endogenous information

The endogenous information set-up departs from the unrealistic assumption that the central bank directly observes economic fundamentals. Rather, the central bank infers the fundamental from its observation of the average decision of agents, that is from the market outcome. In reality, the central bank has no direct source of information about economic fundamentals but observes the aggregate economic activity to assess the state of the economy.

We postulate that the central bank receives a signal  $\Omega$  on the average decision  $\bar{a}$  with some noise  $\eta$

$$\Omega = \bar{a} + \eta, \quad \eta \sim \mathcal{N}(0, \sigma_\eta^2).$$

Using (9) and the fact that  $\gamma_1 + \gamma_2 = 1 + \rho$ , we can express the information of the central bank as

$$\begin{aligned} \Omega &= \gamma_1 \theta + \gamma_2 \frac{\Omega}{1 + \rho} + \eta \\ &= (1 + \rho) \theta + \frac{1 + \rho}{\gamma_1} \eta. \end{aligned}$$

It is important to stress that the central bank cannot infer the true fundamental  $\theta$  from its observation of the aggregate decision  $\Omega$ , even if the central bank knows which signal it discloses to agents because its observation contains an unknown error  $\eta$ . Therefore the central bank's best estimate of the fundamental, which is conditional on its observation, is the observation itself up to the instrument  $\rho$ :  $\mathbb{E}(\theta | \Omega) = \frac{\Omega}{1 + \rho} = y$ . According to the definition of (5), the variance of central bank's expectation error under endogenous information becomes

$$\text{Var}[\mathbb{E}(\theta | \Omega) - \theta] = \frac{\sigma_\eta^2}{\gamma_1^2} \equiv \sigma_\mu^2. \quad (15)$$

The precision of central bank's information is a function of the equilibrium response of agents  $\gamma_1$ , which depends on the action and communication strategy of the central bank, as shown in Baeriswyl (2011).

In the following subsections, we extend on the consequences of endogenous central bank's information in terms of agents' and central bank's information quality on welfare for our three operational frameworks. We derive welfare for each operational framework before comparing these operational frameworks at their respective optimum.

### 4.1 Optimal central bank's behavior

Solving analytically the optimisation problem of the central bank is not straightforward under endogenous information because the relationship between the variance of central bank's expectation error (15) and agents' response  $\gamma_1$  is non-linear. We thus apply nu-

merical procedures.<sup>6</sup>

#### 4.1.1 Pure communication

Let us consider the first operational framework, in which the central bank discloses information but implements no action ( $\rho = 0$ ). Under endogenous information, central bank transparency affects the accuracy of the average decision of agents as an indicator of the economic fundamental. The information value of the average decision  $\bar{a}$  is evaluated as the variance of the error of fundamental expectations conditional on the average decision:

$$\text{Var} [\mathbb{E}(\theta|\bar{a}) - \theta] = \text{Var} \left[ \mathbb{E} \left( \theta \mid \theta + \frac{\gamma_2}{\gamma_1} \eta \right) - \theta \right] = \frac{\gamma_2^2}{\gamma_1^2} \sigma_\eta^2.$$

The effect of central bank's communication on the information value of the average decision is illustrated in Figure 2 in the case of pure communication. The information about the fundamental contained in the average decision decreases with central bank transparency. The more effectively the central bank influences the decision of agents through more transparency, the less accurately the average decision reflects the fundamental. When the central bank is completely opaque, i.e. when  $\sigma_\phi^2 \rightarrow \infty$ , agents do not react to the central bank disclosure and the average decision becomes a perfect indicator for the fundamental  $\theta$ . The degree of strategic complementarities  $r$  drives the overreaction of agents to the central bank's disclosure and, thereby, affects the information contained in the average decision. A higher degree of strategic complementarities reduces the information value of the average decision as agents react more to the central bank's disclosure.

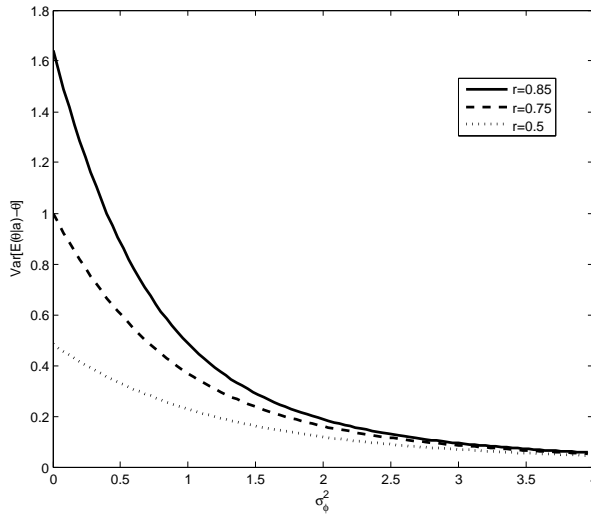


Figure 2: Informative value of average decision for  $\sigma_\epsilon^2 = 1$ ,  $\sigma_\eta^2 = 1$ , and  $\rho = 0$

Central bank's transparency exerts a dual effect on the accuracy of agents' information. On the one hand, an increase in transparency reduces the idiosyncratic noise of the central

<sup>6</sup>Matlab codes for solving the model under endogenous information are available from the authors upon request.

bank's disclosure  $\sigma_\phi^2$ , which improves the accuracy of agents' information. On the other hand, an increase in transparency reduces the informative value of the average decision, which deteriorates the accuracy of central bank's information and disclosure. Overall, transparency exerts an ambiguous effect on the accuracy of agents' information. This is evaluated by the variance of the error of fundamental expectations conditional on both the private signal  $x_i$  and the central bank's disclosure  $y_i$ :

$$\begin{aligned} \text{Var} [\mathbb{E}(\theta|x_i, y_i) - \theta] &= \text{Var} \left[ \mathbb{E}(\theta|\theta + \epsilon_i, \theta + \frac{\eta}{\gamma_1} + \phi_i) - \theta \right] \\ &= \text{Var} \left[ \frac{(\sigma_\eta^2/\gamma_1^2 + \sigma_\phi^2)(\theta + \epsilon_i) + \sigma_\epsilon^2(\theta + \eta/\gamma_1 + \phi_i)}{\sigma_\epsilon^2 + \sigma_\eta^2/\gamma_1^2 + \sigma_\phi^2} - \theta \right] \\ &= \frac{(\sigma_\eta^2/\gamma_1^2 + \sigma_\phi^2)\sigma_\epsilon^2}{\sigma_\epsilon^2 + \sigma_\eta^2/\gamma_1^2 + \sigma_\phi^2}. \end{aligned}$$

The effect of central bank's communication on the accuracy of agents' information is illustrated in Figure 3. When the degree of strategic complementarities is low ( $r = 0.5$ ), reducing transparency deteriorates the accuracy of agents' information. By contrast, for a higher degree of strategic complementarities ( $r = 0.75$  and  $r = 0.85$ ), reducing transparency does not unambiguously deteriorate the accuracy of agents' information. Below a certain threshold, reducing transparency improves the accuracy of agents' information: the rise in the information value of the average decision overcomes the rise in the idiosyncratic noise.

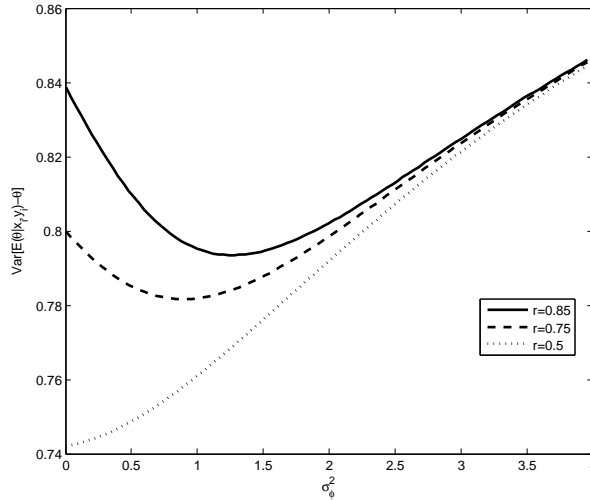


Figure 3: Informative value of firms' information for  $\sigma_\epsilon^2 = 1$ ,  $\sigma_\eta^2 = 1$ , and  $\rho = 0$

We now turn to the effect of endogenous central bank's information on welfare. Figure 4 plots the expected welfare as a function of opacity for  $\sigma_\epsilon^2 = 1$ ,  $\sigma_\eta^2 = 1$ ,  $\lambda = 0.75$ , and  $\rho = 0$ . It shows that, depending on the degree of strategic complementarities, transparency may (or not) be preferable to opacity and that there is an interior optimal degree of opacity.



The optimal degree of opacity is given by

$$\sigma_\phi^{2*} = \max[0, (2\lambda - 3(1 - r))\sigma_\eta^2/\gamma_1^2].$$

It increases with the degree of strategic complementarities. As illustrated by the case where  $r = 0.25$  on Figure 4, when the efficient degree of coordination coincides with the equilibrium degree of coordination (i.e. when  $\lambda = 1 - r$ ), full transparency is optimal. This recalls the analysis under exogenous information in section 3.1.1 which shows that full transparency is also optimal when the efficient and equilibrium degree of coordination coincide.

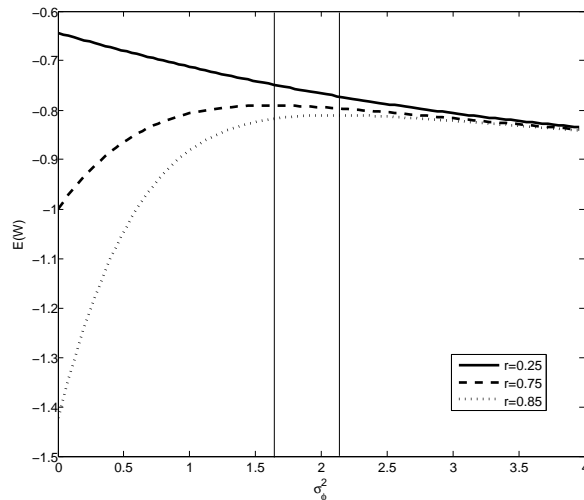


Figure 4: Expected welfare with pure communication as a function  $\sigma_\phi^2$  for  $\sigma_\epsilon^2 = 1$ ,  $\sigma_\eta^2 = 1$ ,  $\lambda = 0.75$  and  $\rho = 0$

Figure 5 compares the optimal degree of opacity under endogenous and exogenous informational set-ups, as a function of the degree of strategic complementarities  $r$  for  $\sigma_\epsilon^2 = 1$ . While in both cases, there is an interior optimal degree of opacity, it shows that under endogenous information, greater opacity is required to compensate for the deterioration in central bank's information quality. Increasing the degree of opacity improves the accuracy of the average decision as an aggregator of information. The difference between the optimal degree of opacity under endogenous information and that under exogenous information is  $\sigma_\epsilon^2$ , as in Baeriswyl (2011).

#### 4.1.2 Action and communication

We now focus on the second operational framework, in which the central bank implements a policy action in addition to disclosing information. Figure 6 represents the expected welfare when the central bank implements an optimal action  $\rho^*$  as a function of the degree of opacity  $\sigma_\phi^2$  for different parameter values. Full opacity is optimal when an optimal action is implemented. This result corroborates that of James and Lawler (2011) under exogenous

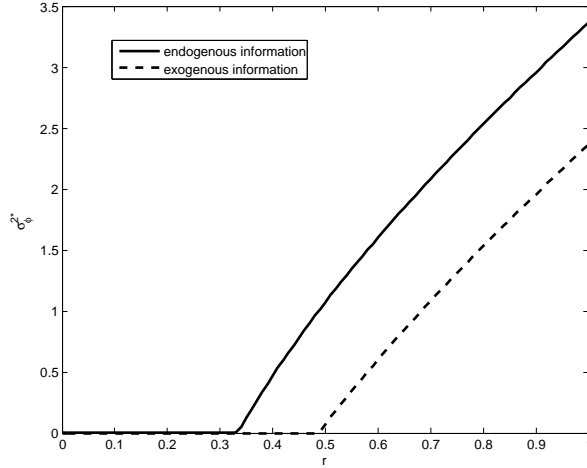


Figure 5: Optimal degree of opacity with pure communication as a function  $r$  for  $\sigma_\epsilon^2 = 1$ ,  $\sigma_\eta^2 = 1$ ,  $\lambda = 1$  and  $\rho = 0$

information and, in this respect, acknowledging the endogenous nature of central bank's information does not alter their conclusion. Nevertheless, the optimal degree of opacity is not indeterminate under endogenous information when  $\lambda = 1 - r$  (opacity is optimal), contrary to exogenous information.

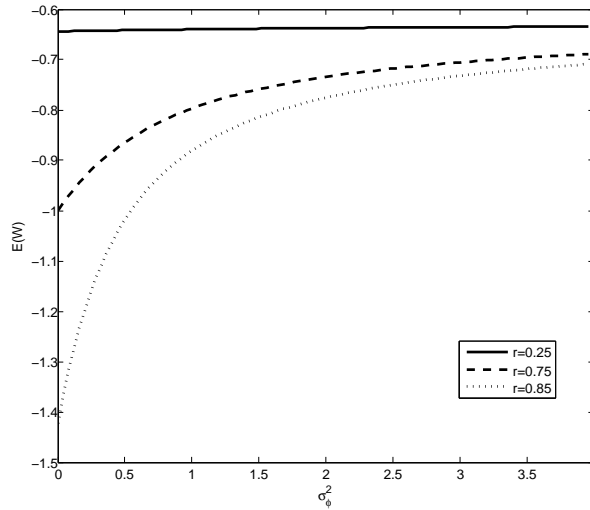


Figure 6: Expected welfare with optimal action  $\rho^*$  as a function of  $\sigma_\phi^2$  for  $\sigma_\epsilon^2 = 1$ ,  $\sigma_\eta^2 = 1$ ,  $\lambda = 0.75$

Under full opacity, the optimal action is independent of the degree of strategic complementarities because there is no public information. Figures 7 and 8 plot the optimal action under full opacity for different parameter values. In absence of public information, the exogenous and endogenous set-ups coincide. The distinction between exogenous and endogenous information comes about when the agents' reaction to central bank's disclosure deteriorates the informative value of the average decision and, thereby, the precision

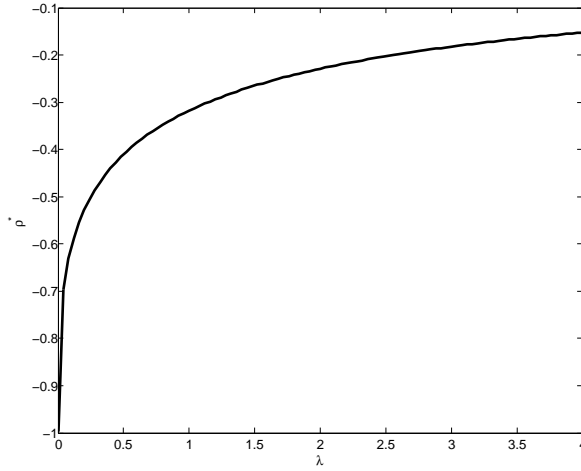


Figure 7: Optimal action  $\rho^*$  under full opacity as a function of  $\lambda$  for  $\sigma_\epsilon^2 = 1$  and  $\sigma_\eta^2 = 1$

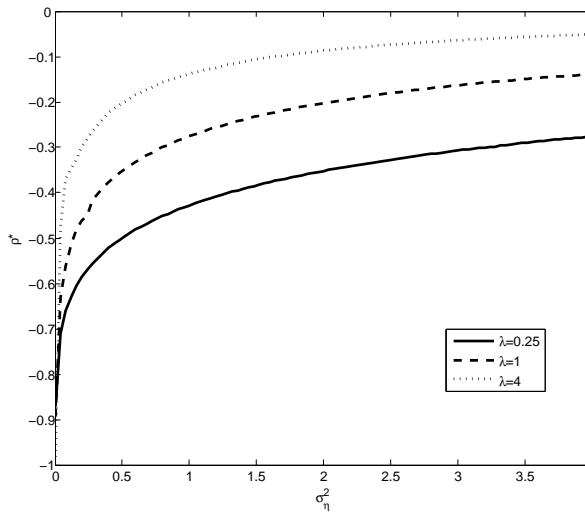


Figure 8: Optimal action  $\rho^*$  under full opacity as a function of  $\sigma_\eta^2$  for  $\sigma_\epsilon^2 = 1$

of central bank's information. However, when the central bank is fully opaque (what is optimal), the average decision of agents is unbiased by any public disclosure and reveals the fundamental. The set-up of endogenous information thus conforms to that of exogenous information.

#### 4.1.3 Signaling action

We now turn to the third operational framework, in which the action taken by the central bank signals to agents its information on the fundamental state of the economy. Figure 9 plots the expected welfare as a function of  $\lambda$ . Welfare decreases with the weight assigned to the distortion of the average decision from the fundamental. As equation (10) shows, an increase in  $\lambda$  lowers welfare.

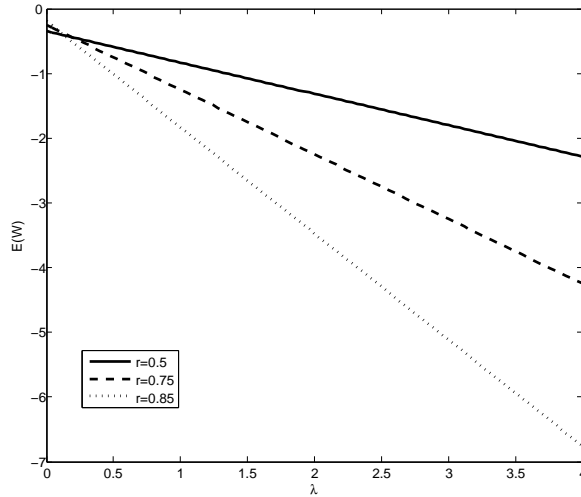


Figure 9: Expected welfare with signaling action as a function of  $\lambda$  for  $\sigma_\epsilon^2 = 1$  and  $\sigma_\eta^2 = 1$

## 4.2 Optimal operational framework

We compare our three operational frameworks under endogenous information at their respective optimum before comparing these outcomes to those obtained under exogenous information (in section 3.2). Figure 10 compares welfare for the different frameworks under endogenous information. We observe the same ranking for the different operational frameworks as under exogenous information. Indeed, the action and communication framework yields the highest welfare when the central bank is fully opaque.

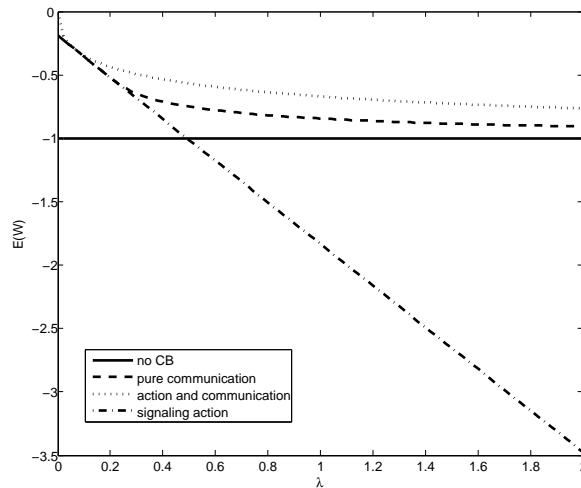


Figure 10: Expected welfare as a function of  $\lambda$  for  $\sigma_\epsilon^2 = 1$ ,  $\sigma_\eta^2 = 1$  and  $r = 0.85$

However, it seems rather unrealistic that the central bank takes an action that would be unobservable (as assumed in James and Lawler (2011)). Instead, if the central bank implements an action that is observed (signaling action), the comparison between Figure

1 and Figure 10 shows that the range of parameter values for which the absence of central bank policy yields a higher welfare is much larger under endogenous information rather than under exogenous information. Accounting for the endogenous nature of central bank's information gives rise to a detrimental effect of a signaling action on the precision of the average decision as an aggregator of information.

## 5 Conclusion

Although the central bank observes the market to assess economic fundamentals, the literature has typically ignored that central bank's information depends on market outcomes, which the central bank aims at influencing through its policy. The central bank plays a dual role as observer and shaper of the market: the more the central bank shapes market outcomes, the less reliably market outcomes serve as an indicator of economic fundamentals, thereby deteriorating the quality of central bank's information.

The novelty of this paper is to present a model that accounts for the impact of central bank's endogenous information under three operational frameworks proposed in the literature: pure communication, action and communication, and signaling action. Although acting optimally while being fully opaque yields the highest welfare, it seems rather unrealistic that a central bank may hide its action from market participants. In the realistic case, where central bank's action is observable and signals its information on the fundamentals to the public, we show that the attempt to stabilise the economy does not always improve welfare, as central bank's information deteriorates. Accounting for the role of the market as aggregator of information points out some limits of central bank's intervention.

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