Endogenous Central Bank Information and the Optimal Degree of Transparency*

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As a policymaker, the central bank both observes and shapes the economy. The central bank scrutinizes market activity to assess the state of the economy, and its policy strongly shapes market outcomes. When transparency allows the central bank to shape the economy more effectively, it may also cause the informational role of the economic aggregate to deteriorate. This paper presents a simple model to capture the endogenous nature of central bank information and to address welfare issues. First, accounting for the endogeneity of information highlights the detrimental effects of transparency. A model with endogenous information always calls for a lower degree of transparency than a model with exogenous information. Second, the optimal degree of transparency for endogenous information is unrelated to the accuracy of firms' private information.

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1. Introduction

As a policymaker, the central bank both observes and influences the economy. On the one hand, the central bank observes market activity to assess the state of the economy and to decide the course of its policy. In practice, a central bank devotes extensive resources to collecting data on economic agents' behavior to estimate aggregate economic outcomes. For example, to make its policy decisions, a

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central bank will predict price levels to estimate potential economic imbalances. In a prominent article, Hayek (1945) emphasized the informational role of prices and argued that prices are not only an exchange rate between goods but also an information aggregator. He pointed out that the prices determined by decentralized markets are an essential source of information because they aggregate the "dispersed bits of incomplete and frequently contradictory knowledge, which all the separate individuals possess."

On the other hand, the policy that is implemented by the central bank influences the economy, particularly private-sector expectations. Indeed, the shaping of market expectations plays a key role in the conduct of monetary policy. Woodford (2005) pointed out, "for [monetary policy to be most effective] not only do expectations about policy matter, but [...] very little else matters."

However, the ambivalent role of the central bank—as an observer and as a shaper—causes a dilemma concerning 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 reliably market outcomes serve as indicators of the state of the economy. Although market outcomes would reflect the true state of the economy in the absence of central bank interventions (i.e., if the central bank were an observer only), they nevertheless partly reflect the central bank's expectation because it intervenes in economic development. As soon as the central bank's estimation errors cause it to misread the state of the economy, these errors will be reflected in market outcomes. This dilemma raises the question of the desirability of central bank transparency.

Although the current paper discusses the theoretical possibility that central bank transparency spoils the informational content of economic aggregates, some empirical analyses highlight the plausibility of the mechanism.[1] For instance, in their analysis of U.S. data, Ehrmann and Fratzscher (2005) showed 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

[1]See Geithner (2006) for a general discussion on central bank uncertainty and transparency.

"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 policy, the Federal Reserve has less such information available." Transparency standards in central banking have improved in recent decades, as Geraats (2009) documented, and therefore this argument should have become more relevant.

This paper aims to develop a simple model with strategic complementarities under imperfect common knowledge that captures the endogenous nature of central bank information. Central bank information is endogenous in the sense that its accuracy is a function of the disclosure strategy of the central bank itself.[2] In this context, increasing the level of ambiguity in the central bank's disclosure also increases the accuracy of its information. Moreover, increasing the level of ambiguity in the central bank's disclosure may even increase the accuracy of firms' information.

The feedback effect between the central bank and the private sector, which arises from endogenous information, is reminiscent of the case made by Bernanke and Woodford (1997). They addressed the existence and uniqueness of a rational expectations equilibrium when the central bank observes and responds to private-sector forecasts. In particular, they showed that a central bank cannot infer the value of the state variable by observing private-sector forecasts and simultaneously stabilize the economy fully. This situation arises because if inflation equals the target in equilibrium, then the information of the private forecasters is not revealed. It was the stabilizing action of the central bank that rendered the private-sector forecasts uninformative in Bernanke and Woodford's paper, but, in the present analysis, it is the noisy announcement of the central bank that makes the aggregated price level less informative.

[2]The endogeneity of central bank information is to be distinguished from the endogeneity of central bank release. The information released by the action of the central bank to the private sector is endogenous in the sense that it depends on the central bank's preferences and economic assessment. However, this does not imply that the information of the central bank is endogenous. For instance, Walsh (2007) or Baeriswyl and Cornand (2010) analyze the conduct of monetary policy when the central bank release is endogenous but its information is exogenous.

From a normative point of view, this paper contributes to the ongoing debate on the welfare effects of central bank transparency and emphasizes that the deterioration of central bank information (and disclosure) is a potentially detrimental effect. This argument resonates with that of Morris and Shin (2002) (hereafter M-S). In their seminal beauty-contest paper on exogenous information, they highlighted the potentially detrimental effect of noisy public information. In an environment of strategic complementarities, central bank disclosure is given too much weight relative to its face value because it serves as a focal point. Higher-order expectations are mainly driven by public disclosures, and therefore the response to a noisy public disclosure, exacerbated by the coordination motive, may destabilize the economy. Thus, reducing the degree of transparency improves welfare because it reduces the extent of common knowledge about the disclosure and the weight assigned to it for higher-order expectations.

Moreover, endogenous information addresses the detrimental effect of transparency to the accuracy of central bank disclosure and thereby of firms' information. M-S focuses on the large weight assigned to public disclosures for higher-order expectations, which are exacerbated by coordination, but the present model of endogenous information emphasizes the negative accuracy effect of transparency for both first- and higher-order expectations.

Two conclusions can be drawn with respect to the optimal degree of transparency. First, accounting for the endogeneity of information reinforces the detrimental effect of transparency. A model with endogenous information always calls for a lower degree of transparency than a model with exogenous information. Second, the optimal degree of transparency for endogenous information is unrelated to the accuracy of firms' private information. This conclusion contrasts with M-S's model for exogenous information, in which a decrease in the accuracy of firms' private information increased the optimal degree of transparency.

Section 2 describes the economy such that the Keynesian beauty contest, formalized by M-S, is interpreted as the price-setting problem of monopolistically competitive firms.[3] Section 3 presents the

[3]See also Amato, Morris, and Shin (2002), Hellwig (2005), or Hellwig and Veldkamp (2009) for an application of M-S to price-setting decisions by firms.

model for exogenous central bank information and replicates M-S's analysis as a benchmark. Section 4 derives the model for endogenous information and discusses the effects of transparency on central bank information and disclosure. While sections 3 and 4 address the welfare effects of transparency on a broad range of welfare functions, section 5 focuses on microfounded welfare, which highly weights coordination at the social level. The conclusions are presented in section 6.

2. The Economy

The economy is populated by a representative household, a *continuum* of monopolistic competitive firms, and a central bank. We abstract from the microfounded market interactions since they are very standard and focus on the optimal behavior of firms.[4]

2.1 Firms

In an economy where the representative household consumes a composite good à la Dixit-Stiglitz and where goods are imperfect substitutes, the optimal pricing rule of firm i is given by

$$p_i = \mathbb{E}_i[p + \xi c], \tag{1}$$

where $\mathbb{E}_i$ is the expectation operator of firm i conditional on its information, p is the overall price level, and c is the real output gap. The pricing rule (1) says that each firm sets its price according to both its own belief about the real output gap and its belief about the overall price level. We assume that the nominal aggregate demand defined as $c + p$ is determined by a stochastic demand shock $g \in \mathbb{R}$. So, one can write the pricing rule as

$$p_i = \mathbb{E}_i[(1 - \xi)p + \xi g]. \tag{2}$$

The parameter ξ captures the impact of the real output gap on prices (through wages). A large ξ means that the representative household is highly risk averse and that output gaps imply large variations in

[4]See Adam (2007) for a full derivation of the microfoundations.

wages and therefore in prices. We shall assume in this paper that $0 < \xi < 1$, which implies that prices are strategic complements, meaning that firms tend to raise their price whenever they expect the others to do so. This assumption seems very natural and captures the concept of beauty contest introduced by Keynes: firms base their decision not only on their own expectations of fundamentals but also on the so-called higher-order expectations, i.e., on their expectation of others' expectations of fundamentals.

Substituting successively the average price level with higher-order expectations about the demand shock, the pricing rule becomes

$$\begin{aligned} p_i &= \mathbb{E}_i[(1-\xi)p + \xi g] \\ &= \mathbb{E}_i\Big[\xi g + (1-\xi)\left[\bar{\mathbb{E}}[\xi g + (1-\xi)[\bar{\mathbb{E}}[\xi g + \ldots]]]\right]\Big]. \end{aligned} \tag{3}$$

Using the fact that with heterogeneous information the law of iterated expectations fails since expectations of higher order do not collapse to the average expectation of degree one,[5] the pricing rule can be rewritten as

$$p_i = \xi \sum_{k=0}^{\infty} (1-\xi)^k \mathbb{E}_i[\bar{\mathbb{E}}^{(k)}(g)],$$

and averaging over firms, we get

$$p = \xi \sum_{k=0}^{\infty} (1-\xi)^k [\bar{\mathbb{E}}^{(k+1)}(g)], \tag{4}$$

where k is the degree of higher-order iteration, and $\bar{\mathbb{E}}$ is the population average expectation operator such that $\bar{\mathbb{E}}(.) = \int_i \mathbb{E}_i(.)di$. We use the following notation of higher-order expectations: $\bar{\mathbb{E}}^{(0)}(x) = x$ is the expected variable x itself, $\bar{\mathbb{E}}^{(1)}(x) = \bar{\mathbb{E}}(x)$ is the average expectation of x, $\bar{\mathbb{E}}^{(2)}(x) = \bar{\mathbb{E}}\bar{\mathbb{E}}^{(1)}(x) = \bar{\mathbb{E}}\bar{\mathbb{E}}(x)$ is the average expectation of the average expectation of x, and so on.

To take its pricing decision, each firm receives two signals. First, each firm gets a private signal about the demand shock. The private

[5]See Morris and Shin (2002).

signal is centered on the true value of g and has a normally distributed error term:

$$g_i = g + \varepsilon_i \quad \text{with } \varepsilon_i \sim N(0, \sigma_\varepsilon^2), \tag{5}$$

where ε_i are identically and independently distributed across firms.

Second, the central bank provides firms with its viewpoint about the demand shock. The central bank communicates its information D with more or less ambiguity. We capture this ambiguity with the degree of transparency of its disclosure. Generally speaking, transparency refers to the case where the central bank shares its information with the private sector (symmetric information).[6] Imperfect transparency is commonly interpreted in terms of noise variance that induces uncertainty to the private sector on the central bank's assessment.[7] With heterogenous information, transparency is interpreted as the degree of common knowledge among private agents. Heinemann and Illing (2002) propose to control the degree of common knowledge by introducing idiosyncratic noise in central bank disclosure.

The signal disclosed by the central bank and received by firm i is written as

$$D_i = D + \phi_i \quad \text{with } \phi_i \sim N(0, \sigma_\phi^2). \tag{6}$$

The dispersion of individual noises σ_ϕ^2 determines the degree of transparency of the central bank. Under transparency, every firm gets the same univocal signal ($\sigma_\phi^2 = 0$). Then, the central bank disclosure D is a public signal that is common knowledge among firms. Under opacity, the individual signal gotten by each firm has an infinite idiosyncratic noise ($\sigma_\phi^2 \to \infty$). The central bank disclosure thus does not contain any valuable information.

[6] According to the classification of Geraats (2002), the transparency discussed in this paper is economic transparency since the only uncertainty in the economy is the value of the fundamental shock g.

[7] For instance, Cukierman and Meltzer (1986) interpret transparency as the noise variance of monetary control or Faust and Svensson (2002) as the noise variance of information on monetary control errors. See Geraats (2002) for an overview.

2.2 Welfare

In an economy characterized by monopolistic competition, the welfare of the representative household is decreasing in both the dispersion of prices across firms $\int_i (p_i - p)^2 di$ and the variability of the output gap $c = g - p$. Therefore, we define the social loss as

$$L = \int_i (p_i - p)^2 di + \lambda (g - p)^2, \tag{7}$$

where λ is the weight assigned to the output-gap variability. As Angeletos and Pavan (2007) stressed, demand shocks create inefficiencies only when information is incomplete.[8]

The welfare function used in the transparency debate of M-S is a controversial matter because the detrimental effect of transparency is driven by the relative relevance of coordination (dispersion) and stabilization (distortion) at the social level. However, the application of the M-S argument to different welfare functions may lead to different conclusions. For example, Hellwig (2005) and Woodford (2005) showed that when coordination is socially highly valuable, transparency improves welfare because it helps to coordinate firms' price setting. We leave λ unspecified in sections 3 and 4 to discuss the M-S argument in an environment where coordination is not particularly socially valuable and to emphasize the effect of endogenous information in this context. We show in section 3.2 that the welfare in M-S given by $-\int_i (p_i - g)^2 di$ can be expressed by (7) with the parameter $\lambda = 1$. Thus, the welfare function in M-S gives equal weight to coordination and stabilization at the social level. Then, in section 5, following Hellwig (2005) and Woodford (2005), we consider the welfare function that is consistent with a microfounded economy.

2.3 The Central Bank

The central bank seeks to minimize the unconditional expected loss (7) by disclosing information to firms about the fundamental

[8]Indeed, with perfect information, $p_i = p = g$ ensures that the loss (7) is zero.

demand shock g.[9] We will discuss the welfare effect of the central bank's disclosure in two informational cases.

First, we consider the case where the central bank directly observes the stochastic demand shock g with some noise. The precision of central bank information is then exogenously determined and independent of its disclosure strategy (section 3). Second, we assume that the central bank cannot directly observe the demand shock g but instead watches market activity to evaluate the state of the economy. In this case, we show that the precision of central bank information is endogenous because it depends upon its disclosure strategy (section 4).

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

$$\mathrm{Var}[\mathbb{E}(g|D) - g] \equiv \sigma_\mu^2. \tag{8}$$

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

2.4 Equilibrium

This section derives the perfect Bayesian equilibrium behavior of firms. To determine the optimal price rule (4), we build the first- and higher-order expectations of firm i about the demand shock g conditional on its information. Given firms' information (5), (6), and (8), the expectation of degree one about the demand shock $\mathbb{E}_i(g)$ yields

$$\mathbb{E}(g|g_i, D_i) = \frac{\sigma_\mu^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + \sigma_\mu^2 + \sigma_\phi^2} g_i + \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \sigma_\mu^2 + \sigma_\phi^2} D_i = \Omega_{11} g_i + \Omega_{12} D_i. \tag{9}$$

[9] Note that the central bank does not implement any monetary instrument to stabilize the economy because the instrument would be indeterminate since the price level does not enter the loss function as defined in section 2.2. See Baeriswyl and Cornand (2010) for an analysis that accounts for the interaction between the monetary instrument and the disclosure of the central bank.

The best estimate of the demand shock by firm i is an average of both its signals whose weighting depends upon 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 $\mathbb{E}_i(D)$. This delivers

$$\mathbb{E}(D|g_i, D_i) = \frac{\sigma_\phi^2}{\sigma_\varepsilon^2 + \sigma_\mu^2 + \sigma_\phi^2} g_i + \frac{\sigma_\varepsilon^2 + \sigma_\mu^2}{\sigma_\varepsilon^2 + \sigma_\mu^2 + \sigma_\phi^2} D_i = \Omega_{21} g_i + \Omega_{22} D_i. \tag{10}$$

Note that under transparency (when $\sigma_\phi^2 = 0$), the central bank's disclosure is univocal and $\Omega_{21} = 0$, which means that the private signal g_i does not help in guessing D (since $D_i = D$). Under opacity, when the idiosyncratic noise is infinite ($\sigma_\phi^2 \to \infty$), the central bank's disclosure is of no use to estimate the demand shock g and the best estimate is the private signal g_i itself ($\Omega_{11} = 1$).

Using these results, we can express the higher-order expectation of degree k as

$$\bar{\mathbb{E}}^{(k)} \begin{pmatrix} g \\ D \end{pmatrix} = \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{pmatrix}^k \begin{pmatrix} g \\ D \end{pmatrix}.$$

Plugging this into the price rule (4), we get

$$p = \begin{pmatrix} \xi & 0 \end{pmatrix} \sum_{k=0}^{\infty} (1-\xi)^k \begin{pmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{pmatrix}^{k+1} \begin{pmatrix} g \\ D \end{pmatrix}. \tag{11}$$

The price rule is a linear combination of the demand shock and the central bank's average disclosure:

$$\begin{aligned} p &= \gamma_1 g + \gamma_2 D \quad \text{with} \\ \gamma_1 &= \frac{(1-\xi)\Omega_{21}\gamma_2 + \xi\Omega_{11}}{1-(1-\xi)\Omega_{11}} = \frac{\xi\sigma_\mu^2 + \sigma_\phi^2}{\sigma_\varepsilon^2 + \xi\sigma_\mu^2 + \sigma_\phi^2} \\ \gamma_2 &= \frac{(1-\xi)\Omega_{12}\gamma_1 + \xi\Omega_{12}}{1-(1-\xi)\Omega_{22}} = \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \xi\sigma_\mu^2 + \sigma_\phi^2}. \end{aligned} \tag{12}$$

γ_1 and γ_2 sum up to 1. The equilibrium firms' action can be interpreted as a weighted average of the fundamental g and the average

disclosure D. The weight assigned to the central bank's disclosure is larger in the equilibrium action (12) than in the best estimate of g given in (9): $\gamma_2 > \Omega_{12}$. This discrepancy arises because of the coordination motive in the pricing rule. While ε_i and ϕ_i are idiosyncratic noises, the central bank noise with variance σ_μ^2 is commonly observed by all firms through the disclosure D_i. The weight assigned to the central bank's error (and thereby to D_i) increases as the coordination motive strengthens; strategic complementarities raise the firms' incentives to coordinate their actions around the central bank's disclosure. When the degree of strategic complementarities $1 - \xi$ increases, the weight assigned to the private signal g_i declines ($\frac{\partial \gamma_1}{\partial \xi} > 0$), and the weight assigned to the central bank's disclosure increases ($\frac{\partial \gamma_2}{\partial \xi} < 0$). When the degree of transparency increases (σ_ϕ^2 falls), the weight given to the central bank's disclosure D_i increases because firms can interpret it less ambiguously and better guess the actions of others ($\frac{\partial \gamma_1}{\partial \sigma_\phi^2} > 0$ and $\frac{\partial \gamma_2}{\partial \sigma_\phi^2} < 0$). Signals are also given a higher weight when their precision increases: $\frac{\partial \gamma_1}{\partial \sigma_\varepsilon^2} < 0$ and $\frac{\partial \gamma_2}{\partial \sigma_\mu^2} < 0$.

3. Exogenous Central Bank Information

This section analyzes the welfare effect of central bank disclosure when the central bank directly observes the demand shock. The aim of this section is to illustrate M-S's much-debated conclusion where central bank information is exogenous. The present section should be seen as a benchmark case that replicates M-S's results and allows a better comparison with the endogenous case in section 4.

We describe the information structure and discuss the optimal information disclosure for two cases. We first examine the case when the central bank chooses between full transparency and full opacity (i.e., the central bank either perfectly reveals its opinion or totally withholds it) and, second, the case when the central bank can choose its optimal degree of transparency (i.e., the central bank makes announcements with some ambiguity).

3.1 Information Structure

Under exogenous information, the central bank directly (but imperfectly) observes the demand shock g. According to the definition

of the error term of central bank information (8), we assume that the central bank receives a signal D on the demand shock that is centered on its true value g and contains an error term μ:

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

The precision of central bank information σ_μ^2 is exogenous.

3.2 Welfare

Given the equilibrium behavior of firms (12) and the central bank information as described in the previous section, the unconditional expected social loss (7) can be written as

$$\mathbb{E}(L) = \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\phi^2 + \lambda\gamma_2^2\sigma_\mu^2 = \frac{\sigma_\varepsilon^2(\lambda\sigma_\mu^2 + \sigma_\phi^2) + (\xi\sigma_\mu^2 + \sigma_\phi^2)^2}{(\sigma_\varepsilon^2 + \xi\sigma_\mu^2 + \sigma_\phi^2)^2}\sigma_\varepsilon^2. \tag{13}$$

The welfare considered in M-S is given by $-\int_i (p_i - g)^2 di$. We write the corresponding loss as

$$\mathbb{E}(L_{MS}) = \mathbb{E}\left(\int_i (p_i - g)^2 di\right) = \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\phi^2 + \gamma_2^2\sigma_\mu^2.$$

This implies that the welfare in M-S is a particular case of our general formulation (13) where $\lambda = 1$. This means that the model of M-S equally weights coordination and stabilization at the social level.

3.3 Transparency versus Opacity

3.3.1 Opacity

The welfare is now computed when the central bank withholds its information, i.e., $\sigma_\phi^2 \to \infty$. Under opacity, firms set their price equal to their private signal g_i, i.e., $\gamma_1 = 1$ and $\gamma_2 = 0$. The resulting expected loss is

$$\mathbb{E}(L_O) = \mathbb{E}\left(\int_i (\gamma_1(g + \varepsilon_i) - \gamma_1 g)^2 di + \lambda(g - \gamma_1 g)^2\right) = \sigma_\varepsilon^2.$$

The overall price level p is equal to the fundamental g, which implies an output gap of zero. The price dispersion across firms is given by the variance of the idiosyncratic noise ε_i.

3.3.2 Transparency

Under transparency, the disclosure of the central bank is common knowledge ($\sigma_\phi^2 = 0$) and the pricing rule of firms becomes

$$p = \frac{\xi\sigma_\mu^2}{\sigma_\varepsilon^2 + \xi\sigma_\mu^2} g + \frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \xi\sigma_\mu^2} D,$$

which yields the expected loss

$$\mathbb{E}(L_T) = \left(\frac{\xi\sigma_\mu^2}{\sigma_\varepsilon^2 + \xi\sigma_\mu^2} \right)^2 \sigma_\varepsilon^2 + \lambda \left(\frac{\sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \xi\sigma_\mu^2} \right)^2 \sigma_\mu^2.$$

Transparency improves welfare when the loss under opacity L_O is larger than the loss under transparency L_T. When the precision of central bank information is exogenous, full transparency is preferable to opacity when

$$\lambda - 2\xi < \psi, \tag{14}$$

where $\psi = \frac{\sigma_\varepsilon^2}{\sigma_\mu^2}$ is the relative inaccuracy of private and central bank information. Transparency is detrimental to welfare when public information is too noisy relative to private information, when the degree of strategic complementarities is relatively high, and when the weight assigned to coordination is relatively low.

The general framework developed in this paper shows the extent to which the welfare effect of transparency is related to the social value of coordination. In the case of M-S, as $\lambda = 1$, private information must be more accurate than public information ($\psi < 1$) for transparency to be detrimental. Geraats (2002) and Svensson (2006) argue that the detrimental effect of transparency emphasized in M-S's beauty-contest framework arises under unrealistic conditions because the information held by public institutions (e.g., a central bank) is typically more accurate than the information that is privately available.[10] However, if the social value of coordination

[10] For instance, in an empirical analysis on U.S. data, Romer and Romer (2000) show that the Federal Reserve better forecasts the output and inflation than any single private commercial bank.

is smaller than in M-S ($\lambda > 1$), opacity may be preferable even when public information is more accurate than private information ($\lambda - 2\xi > 1$).

3.4 Optimal Degree of Transparency

In the previous section, the central bank could either disclose its noisy information with perfect precision or withhold it. In reality, however, central bankers are known for their ambiguous mumblings. Central bank disclosures are, therefore, open to interpretation. The more equivocally a central bank discloses information, the higher the uncertainty surrounding both the interpretation of the disclosure (fundamental uncertainty) and its interpretation by others (strategic uncertainty). When full transparency is detrimental to welfare relative to opacity, reducing transparency may improve welfare. However, even when full transparency is preferable to opacity, partial transparency may still yield a superior outcome.[11]

To determine the optimal degree of transparency σ_ϕ^2, we minimize the loss (13) with respect to σ_ϕ^2 and set it equal to zero:

$$\begin{aligned}\frac{\partial \mathbb{E}(L)}{\partial \sigma_\phi^2} &= 2\gamma_1\sigma_\varepsilon^2\frac{\partial \gamma_1}{\partial \sigma_\phi^2} + \gamma_2^2 + 2\gamma_2\sigma_\phi^2\frac{\partial \gamma_2}{\partial \sigma_\phi^2} + 2\lambda\gamma_2\sigma_\mu^2\frac{\partial \gamma_2}{\partial \sigma_\phi^2} \\ &= \frac{(\sigma_\varepsilon^2 + (3\xi - 2\lambda)\sigma_\mu^2 + \sigma_\phi^2)\sigma_\varepsilon^4}{(\sigma_\varepsilon^2 + \xi\sigma_\mu^2 + \sigma_\phi^2)^3} \\ &= 0 \quad \Leftrightarrow \quad \sigma_\phi^2 = (2\lambda - 3\xi)\sigma_\mu^2 - \sigma_\varepsilon^2. \end{aligned} \tag{15}$$

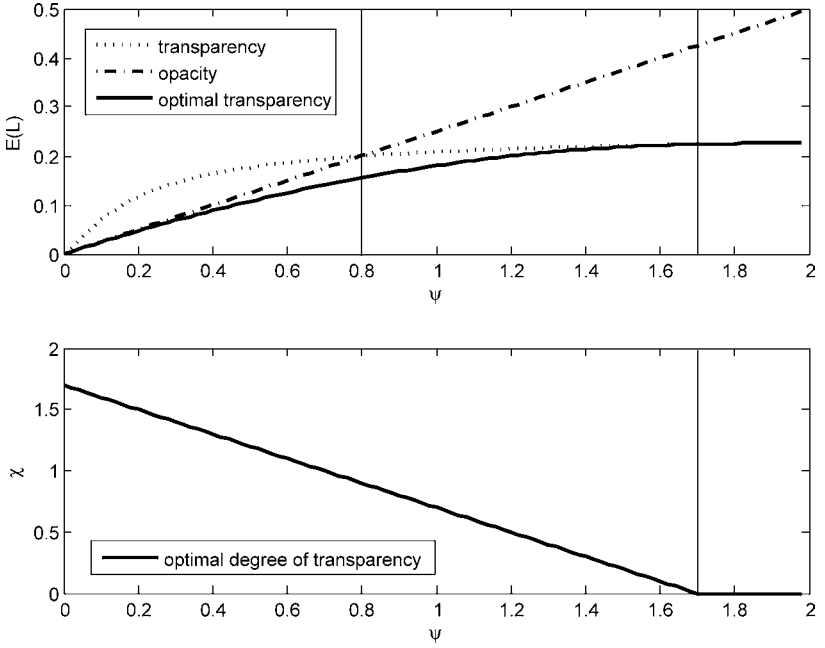
Since the variance of idiosyncratic noise is non-negative, the optimal degree of transparency is described by

$$\chi_{\text{exo}} = \max[0; 2\lambda - 3\xi - \psi], \tag{16}$$

where $\chi_{\text{exo}} = \frac{\sigma_\phi^2}{\sigma_\mu^2}$ is the relative variance of idiosyncratic and fundamental noise of the central bank's disclosure. This analysis calls for

[11] This idea goes back to Cornand and Heinemann (2008), who show that reducing the degree of common knowledge is welfare improving. However, they propose to reduce the degree of common knowledge by disclosing a public signal to a fraction of firms only (partial publicity) instead of introducing idiosyncratic noise (partial transparency).

Figure 1. Unconditional Expected Loss and Optimal Degree of Transparency



partial transparency when coordination is not very valuable at the social level (λ large), when the degree of strategic complementarities is high (ξ small), and when the relative accuracy of private and central bank information ψ is small.

Figure 1 illustrates the unconditional expected loss under transparency (dotted line), under opacity (dashed line), and under optimal degree of transparency (solid line). The parameter values are $\xi = 0.1$, $\lambda = 1$, and $\sigma_\mu = 0.25$. As (14) shows, full opacity is superior to full transparency when $\psi < \lambda - 2\xi = 0.8$. The optimal degree of transparency is represented in the lower graph shown in figure 1. As (16) states it, reducing the degree of transparency is optimal when $\psi < 2\lambda - 3\xi = 1.7$.

Interestingly, there is a linear negative relation between the relative idiosyncratic private noise ψ and the relative idiosyncratic noise of the central bank's disclosure χ_{exo}. Expression (16) shows that the

optimal idiosyncratic relative noise of the central bank's disclosure χ_{exo} declines as the idiosyncratic relative noise of firms' private information ψ increases. The expression $2\lambda - 3\xi$ can be interpreted as the optimal minimal idiosyncratic relative noise, which depends on the preference and structure of the economy.

The distribution of the idiosyncratic noise across ψ and χ is, however, not irrelevant for welfare. The derivation $\frac{\partial \mathbb{E}(L)}{\partial \psi} = 0 \Leftrightarrow \psi = \max[0; -\frac{(\xi+\chi)^2}{2\lambda-\xi+\chi}]$ shows that increasing the relative inaccuracy of firms' private information ψ is detrimental to welfare unless the weight assigned to stabilization λ, the degree of complementarity $1-\xi$, and the idiosyncratic relative noise of the central bank's disclosure χ are all low $(2\lambda - \xi + \chi < 0)$. This derivation confirms the finding of Hellwig (2005) that increasing the accuracy of firms' private information does not always improve welfare when coordination is significant because more accurate private information would exacerbate dispersion.[12]

Reducing the degree of transparency can be interpreted as the central bank's attempt to control the equilibrium level of coordination.[13] If the central bank could choose the degree of complementarity $1-\xi$ that drives the coordination motive in the equilibrium pricing rule (12), it would solve $\frac{\partial \mathbb{E}(L)}{\partial \xi} = 0 \Leftrightarrow \xi = \lambda$. The optimal degree of coordination decreases with social aversion to distortion. For instance, when the degree of complementarity is larger than the optimal level for the central bank, i.e., $\xi < \lambda$, the central bank could shape the equilibrium response of firms γ_1 and γ_2 in (12) through the idiosyncratic noise of its disclosure σ_ϕ^2 in the same way that it would by directly influencing ξ. However, the idiosyncratic noise entails a detrimental dispersion effect that mitigates the central bank's incentive to reduce the equilibrium degree of coordination. Therefore, the central bank will reduce the equilibrium degree of coordination less by varying σ_ϕ^2, as it would by varying ξ. From (16), it follows that the central bank will never reduce the degree of transparency when $\xi > \frac{2}{3}\lambda$.

[12]Section 5 discusses the case with microfounded preferences.

[13]See Angeletos and Pavan (2007).

4. Endogenous Central Bank Information

In this section, we drop the assumption that the central bank directly observes the exogenous aggregate shock g that underlies the economy. The central bank has no direct source of information about stochastic aggregate economic conditions, and therefore it must observe the aggregate activity of firms to infer the demand shock. In reality, a central bank learns about aggregate shocks by collecting data from the aggregate economic outcome, not by observing an exogenous fundamental process.[14] The model developed in the current section accounts for the insight that the central bank gains on economic conditions from watching the economy itself. However, the central bank, as a policymaker, also strongly shapes market expectations and thereby drives the course of economic activity. The dual role of the central bank causes a dilemma: the better the central bank succeeds in influencing economic activity, the more the economy reflects the central bank's assessments. Thus, aggregate economic outcomes become less accurate indicators of imbalances.

The next sections describe the information structure and discuss the effect of the central bank's disclosure on the accuracy of its information and of that of firms. Finally, we examine the optimal disclosure strategy and compare it with the case of exogenous information.

4.1 Information Structure

The central bank has no direct access to information on the underlying economic shock. In particular, it cannot observe the aggregate demand shock g. Instead, the central bank bases its estimation of the demand shock on its observations of the overall price level. As Hayek (1945) pointed out, prices play a crucial informational role because they aggregate individual information. By observing the average action of firms, the central bank obtains information about the state of the economy.

[14] In this sense, the realism of the exogenous information structure discussed in section 3 is limited since the signal received by the central bank about economic conditions is independent from the existence or behavior of firms.

We postulate that the central bank receives a signal D on the price level p with some noise η

$$D = p + \eta, \quad \text{with } \eta \sim N(0, \sigma_\eta^2).$$

Using the price-setting rule (12) and the fact that $\gamma_1 + \gamma_2 = 1$, we can express the information of the central bank as

$$D = \gamma_1 g + \gamma_2 D + \eta = g + \frac{\eta}{\gamma_1}.$$

It is important to stress here that the central bank cannot infer the true demand shock g from its observation of the price level D, even if the bank knows which signal it discloses to firms (i.e., D itself), because its observation contains an unknown error η. Therefore, the best central bank estimate of the demand shock, which is conditional on its observation, is the observation itself because the demand shock is improperly distributed: $\mathbb{E}(g|D) = D$.

According to the definition (8), the variance of the central bank expectation error under endogenous information becomes

$$\text{Var}[\mathbb{E}(g|D) - g] \equiv \sigma_\mu^2 = \frac{\sigma_\eta^2}{\gamma_1^2}. \tag{17}$$

As it is immediately visible, the precision of central bank information is a function of the equilibrium response of firms γ_1, which depends—as shown in (12)—upon the disclosure strategy of the central bank.

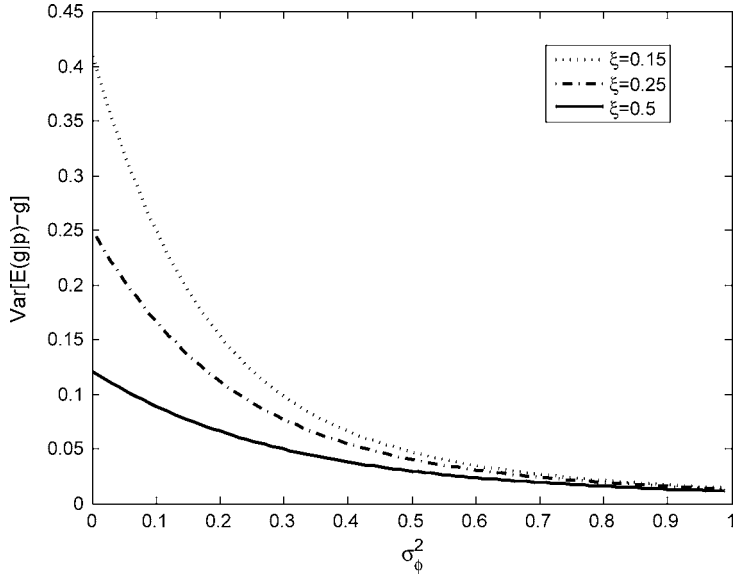
4.2 Information Value of Prices

Figure 2 illustrates the accuracy of the price level as an indicator of economic conditions. The computation is done with $\sigma_\eta^2 = \sigma_\varepsilon^2 = 0.25$. The information value of prices is evaluated as the variance of the error of demand shock expectations conditional on the price level p. The information value of the price level p is given by

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

The figure shows that the information about the state of the economy that is contained in the price level decreases with the degree of

Figure 2. Informative Value of Prices

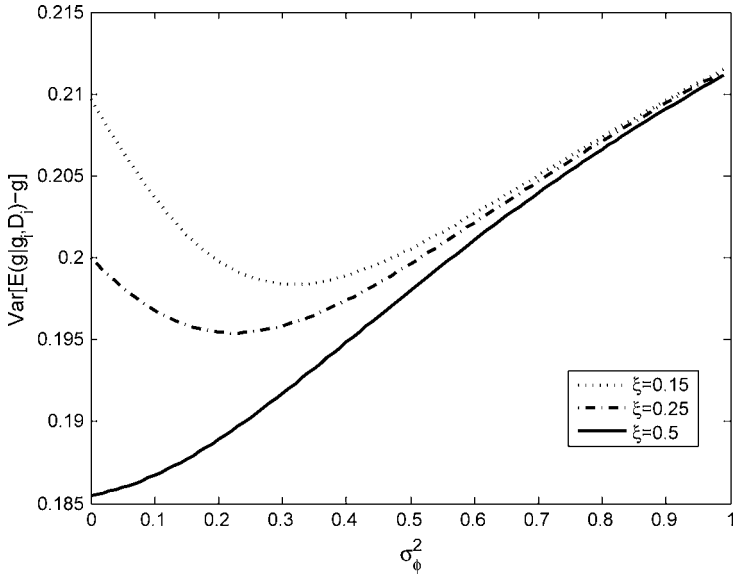


central bank transparency. This relationship clearly highlights the endogenous nature of central bank information. The more effectively the central bank influences the pricing behavior of firms (γ_2 large), the less accurately price levels indicate economic conditions. At the limit of opacity, γ_2 converges to zero (i.e., firms do not react to the disclosure), and the price level becomes a perfect indicator for the demand shock g. The degree of strategic complementarities affects the information value of prices because it drives the overreaction to the central bank's disclosure. When complementarities are high (ξ small), the central bank's disclosure is given a lot of weight in the pricing rule, and this response increases the impact of the noise η on the price level.

4.3 Firms' Information

We now turn to the accuracy of individual firms' information. Although opacity increases the precision of the central bank's observation and thereby of the average disclosure D, it simultaneously increases the idiosyncratic noise (σ^2_ϕ). Opacity therefore has an

Figure 3. Precision of Firms' Information



ambiguous impact, overall, on the accuracy of the disclosure that is received by an individual firm i. On one hand, a rise in opacity increases the precision of the central bank's observation and average disclosure. This increase in precision also tends to increase the precision of individual disclosure D_i. On the other hand, a rise in opacity induces a larger idiosyncratic noise ϕ_i that reduces the precision of the individual disclosure. Increasing idiosyncratic noise, which always reduces the precision of firms' information in the case of exogenous information, may, in contrast, increase the precision of firms' information with endogenous information.

The precision of firms' information is interpreted as the variance of the error of expectations for demand shock, conditional on both the private signal g_i and the central bank's disclosure D_i. This is given by

$$\mathrm{Var}[\mathbb{E}(g|g_i, D_i) - g] = \frac{\sigma_\varepsilon^2[\gamma_1^{-2}\sigma_\eta^2 + \sigma_\phi^2]}{\sigma_\varepsilon^2 + \gamma_1^{-2}\sigma_\eta^2 + \sigma_\phi^2}.$$

Figure 3 illustrates this variance for three degrees of strategic complementarities as a function of the degree of transparency. The

solid line shows that when complementarities are low, reducing the degree of transparency always decreases firms' information. This decrease occurs because transparency does not significantly distort central bank information when the coordination motive is weak. The increased idiosyncratic noise of opacity is not overcome by the increased precision of the central bank's information.

The dotted and dashed lines show that, when the degree of transparency is high and complementarities are strong, reducing the degree of transparency increases the precision of firms' information. The rise in the precision of central bank information overcomes the rise in idiosyncratic noise as long as transparency is sufficiently high. Below a certain threshold of transparency, lowering transparency further reduces the precision of firms' information. The case of endogenous information highlights a new effect of transparency on the first-order expectation of firms.

4.4 Welfare

Given the definition of the variance of the central bank expectation error under endogenous information (17) and the equilibrium behavior of firms (12), the unconditional expected social loss (7) can be written as

$$\mathbb{E}(L) = \gamma_1^2\sigma_\varepsilon^2 + \gamma_2^2\sigma_\phi^2 + \lambda\gamma_2^2\frac{\sigma_\eta^2}{\gamma_1^2}. \tag{18}$$

4.5 Optimal Degree of Transparency

This section derives the optimal degree of transparency under endogenous information and compares it with the case of exogenous information discussed in section 3.4.

To determine the optimal degree of transparency σ_ϕ^2, we derive the loss (18) with respect to σ_ϕ^2 and set it equal to zero:

$$\frac{\partial\mathbb{E}(L)}{\partial\sigma_\phi^2} = 2\gamma_1\sigma_\varepsilon^2\frac{\partial\gamma_1}{\partial\sigma_\phi^2} + \gamma_2^2 + 2\gamma_2\sigma_\phi^2\frac{\partial\gamma_2}{\partial\sigma_\phi^2} + 2\lambda\gamma_2\frac{\sigma_\eta^2}{\gamma_1^2}\frac{\partial\gamma_2}{\partial\sigma_\phi^2}\underbrace{-2\lambda\gamma_2^2\frac{\sigma_\eta^2}{\gamma_1^3}\frac{\partial\gamma_1}{\partial\sigma_\phi^2}}_{\text{endog. spec.}}$$

$$= 0. \tag{19}$$

The last term of this equation captures the endogenous specific impact that the central bank's transparency has on the accuracy of firms' information. Solving this optimization problem analytically is not straightforward because the equilibrium pricing rule (12) is characterized by non-linear equations under endogenous information. However, it is easy to recognize two properties of the optimal degree of transparency for endogenous information, which is interpreted as the optimal relative variance of idiosyncratic and fundamental noise associated with the central bank's disclosure $\chi_{\text{endo}} = \frac{\sigma_\phi^2 \gamma_1^2}{\sigma_\eta^2}$. First, the optimal degree of transparency under exogenous information χ_{exo} converges to that under endogenous information χ_{endo} when the relative inaccuracy of private and central bank information ψ approaches zero.[15] Second, the optimal degree of transparency under endogenous information χ_{endo} is unrelated to the relative inaccuracy of private and central bank information ψ. These observations allow us to analytically express[16] the optimal degree of transparency under endogenous information as

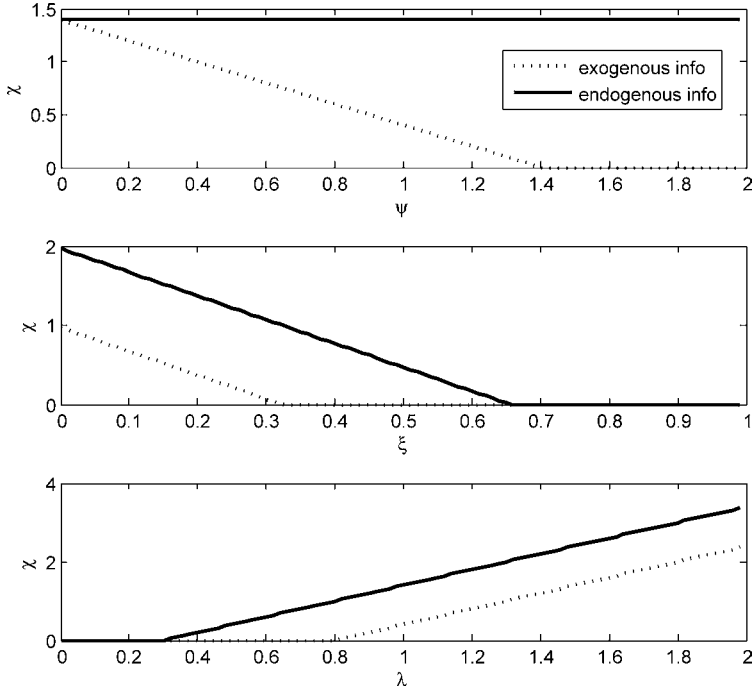
$$\chi_{\text{endo}} = \max[0; 2\lambda - 3\xi]. \tag{20}$$

Reducing transparency increases the accuracy of firms' average information under endogenous information, and therefore it is not surprising that the optimal degree of transparency under endogenous information is lower than it is under exogenous information: $\chi_{\text{endo}} \geq \chi_{\text{exo}}$ (compare with (16)). Contrary to exogenous information, the optimal degree of transparency under endogenous information is independent of the relative inaccuracy of private and central bank information ψ. The central bank does not find it optimal to increase the degree of transparency in response to less accurate firms' information because the accuracy of its information depends on firms' reaction to its disclosure. An increase in the inaccuracy of firms' private information makes the central bank's disclosure relatively more accurate, which would incite the central bank to become more transparent. However, a higher degree of transparency would decrease the accuracy of central bank disclosure. It turns out that

[15]More precisely, this occurs when $\psi_{\text{exo}} \equiv \frac{\sigma_\varepsilon^2}{\sigma_\mu^2} = \psi_{\text{endo}} \equiv \frac{\sigma_\varepsilon^2 \gamma_1^2}{\sigma_\eta^2}$ approaches zero.

[16]Numerical procedures unambiguously confirm this analytical expression.

Figure 4. Optimal Degree of Transparency for Exogenous and Endogenous Information



both effects perfectly offset each other. With endogenous information, the optimal minimal idiosyncratic relative noise $2\lambda - 3\xi$ exclusively impairs the central bank's disclosure and cannot be traded off against the idiosyncratic noise of firms' private information, as it is with exogenous information.

Figure 4 illustrates the optimal degree of transparency with exogenous (dotted line) and endogenous (solid line) central bank information. The parameter values set by default are $\psi = 1$, $\xi = 0.25$, and $\lambda = 1$. The first graph illustrates the impact of ψ, the relative accuracy of private and central bank information, on the optimal degree of transparency. Under exogenous information, an increase in the idiosyncratic relative noise of firms' private information ψ implies a reduction of the idiosyncratic relative noise of central bank disclosure χ (an increase in the degree of transparency). By contrast, an increase in ψ does not alter the optimal degree of

transparency under endogenous information. The second and third graphs illustrate the optimal degree of transparency as a function of the degree of complementarities $1 - \xi$ and the weight assigned to the output distortion λ, which determine the optimal minimal idiosyncratic relative noise.

5. Microfounded Welfare Preferences

This section examines the welfare effect of transparency when the weight assigned to output-gap deviation λ is consistent with the other parameters of the model. Adam (2007) derived the microfounded welfare of the representative household and showed that $\lambda = \frac{\xi}{\theta}$, where $\theta > 1$ is the price elasticity of demand in the Dixit-Stiglitz aggregator. The loss function (7) then becomes

$$L = \int_i (p_i - p)^2 di + \frac{\xi}{\theta}(g - p)^2. \tag{21}$$

The relative weight assigned to coordination is high because price dispersion reduces the utility of the representative household. This increases the welfare-improving effect of the central bank's disclosure because it helps to coordinate firms' pricing decisions. We may therefore expect the optimal degree of transparency to be higher than it is when coordination and stabilization are equally weighted, as in M-S ($\lambda = 1$).

Because the optimal minimal idiosyncratic relative noise $2\lambda - 3\xi = 2\frac{\xi}{\theta} - 3\xi < 0$ is negative with the microfounded weight λ, we conclude that full transparency is the best disclosure strategy under both exogenous and endogenous information.

It should be noted that the model with exogenous information confirms the study of Hellwig (2005), which analyzed the welfare effect of public disclosure in a fully microfounded model. Under exogenous information, the unconditional expected loss steadily increases with the inaccuracy of central bank information $\frac{\partial \mathbb{E}(L)}{\partial \sigma_\mu^2} > 0$. However, reducing the relative inaccuracy of private and central bank information ψ does not always improve welfare: $\frac{\partial \mathbb{E}(L)}{\partial \psi} > 0 \Leftrightarrow \psi > \frac{\xi\theta}{\theta - 2}$. Coordination is highly valuable for microfounded preferences; therefore, increasing the accuracy of firms' private information may reduce welfare because price dispersion will be exacerbated.

6. Concluding Remarks

This paper developed a model for endogenous central bank information that creates a trade-off between shaping market expectations and learning from them. As transparency increases the effect of central bank disclosure on firms' behavior, it reduces the accuracy of prices as an indicator for underlying shocks and thereby the accuracy of central bank information.

This study found that the endogeneity of central bank information entails an additional detrimental effect of transparency to that highlighted by Morris and Shin (2002). Their model of exogenous information underlined the potentially detrimental effect of transparency when higher-order expectations are given a large weight because of coordination. However, under endogenous information, transparency also decreases the accuracy of central bank information, which affects both the first- and higher-order expectations of firms.

We can draw two conclusions related to welfare. First, accounting for the endogeneity of information highlights the detrimental effect of transparency. The optimal degree of transparency is always lower under endogenous information than under exogenous information. Second, the optimal degree of transparency is unrelated to the relative accuracy of firms' private information under endogenous information. Thus, whether central bank information is more accurate than the information that is privately available in the economy is irrelevant to address central bank transparency questions. Instead, the optimal degree of transparency depends on the preference for coordination versus stabilization and the degree of complementarity in the economy.

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