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Transparency, the Opacity Bias, and Optimal Flexible Inflation Targeting

Carl E. Walsh*

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Abstract

In this paper, I revisit an old question in the analysis of monetary policy that was first studied by Rogoff (1985) – should central banks pursue objectives that differ systematically from social welfare? I investigate how the answer to this question is affected by the degree of transparency that characterizes monetary policy. When the policy regime is one of discretion and the central bank is opaque, changes in the policy instrument have informational effects that distort the central bank’s incentives and generate policy biases. Directing the central bank to place more weight on inflation stabilization, i.e., to implement a less flexible inflation targeting policy, can offset this distortion and lead to lower social loss. In contrast, the objectives of a transparent central bank should coincide with those of society. However, outcomes under transparency may be dominated by those produced by an opaque and conservative (i.e., less flexible) central bank

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1 Introduction

Central bank statements and policy actions are often scrutinized for signals about policy makers' outlook for the economy. For example, after the August 10, 2010 press statement of the Federal Reserve's Open Market Committee contained language indicating the Fed had downgraded its forecast for the U.S. economy, many commentators treated this as new information calling for a more pessimistic assessment of the economy¹. In more normal times, a policy rate hike designed to ensure inflation remains on target can be interpreted as a signal of the central bank's concerns about future inflation, causes inflation expectations to rise rather than remain anchored. Or, a large interest rate cut, like the one that occurred in the U.S. on January 22, 2008 when the Fed reduced its funds rate target by 75 basis points, may be interpreted by private agents as signaling that the central bank's forecast of future economic activity has deteriorated.²

If policy actions or announcements convey (or are thought to convey) information that affects private sector expectations, these effects will influence the impact the policy actions have on inflation and the real economy. These informational effects alter the central bank's decisions, resulting in a bias – an opacity bias – by distorting the central bank's response to shocks.

In the presence of an opacity bias, should central banks pursue objectives that differ systematically from social welfare? Rogoff (1985) showed that assigning objectives to the central bank that gave more weight to inflation stabilization than called for by social welfare could reduce the average inflation bias associated with discretionary monetary policy. Clarida, Galí, and Gertler (1999) showed that even in the absence of the average inflation bias that was central to Rogoff's analysis, a stabilization bias arises under discretion in a forward-looking new Keynesian model (Yun 1996, Wood-

¹As reported in the *Financial Times* on September 22, 2010, "Fed officials openly say their communications in August.... was a failure" because "markets feared the Fed had some secret information that suggested the economy was collapsing." (FT, "Fed clears decks for further easing," 9/22/2010).

²For example, after the Fed's policy action *U.S. News and World Reports* posted an article with the title, "Stocks Down After Surprise Fed Rate Cut: The central bank's dramatic move, signaling increased fears of recession, is its largest cut since 1984."

ford 2003a). When cost shocks are serially correlated, this bias could be reduced through the appointment of a conservative central banker. In the modern analysis of inflation targeting, the weight placed on real output gap stabilization (relative to inflation stabilization) reflects the degree of policy flexibility. Thus, in a discretionary policy regime with an average inflation bias, society prefers a central bank that is less flexible in pursuing its inflation objectives. Similarly, under discretion when agents are forward looking and cost shocks are positively serially correlated, society is better off with a less flexible inflation targeter. In the absence of serially correlated cost shocks or an average inflation bias, however, the standard new Keynesian model implies that welfare is maximized if the central bank's objectives are aligned with those of society. Central bankers should not be conservative but should reflect the preferences of the representative agent.

This earlier analysis assumed either that the private sector could not use the central bank's policy actions to update their expectations about the economy (Rogoff) or that there was complete transparency so that the central bank and the public shared the same information (Clarida, Galí, and Gertler). Neither assumption captures the case in which policy actions are very public, but information may be asymmetric so that agents use observations on the central bank's actions to infer the policy maker's outlook for the economy.

When the public updates its expectations based on the central bank's policy actions, I show that a less flexible (more conservative) inflation targeter, can partially offset the opacity bias. Thus, even in the absence of an average inflation bias or a stabilization bias due to serially correlated disturbances, opacity generates a policy bias that may require a central bank to be less flexible in the way it implements inflation targeting. Transparency eliminates this bias, implying that the objectives of a transparent central bank should coincide with those of society. However, because transparency can make expectations more volatile, it need not be the case that full transparency is optimal. In fact, for a calibrated version of the model, an opaque and conservative central bank may deliver better outcomes than a transparency central bank that shares society's preferences.

That a lack of transparency can affect the central bank's incentives is a common feature of models with asymmetric information (e.g., Cukierman and Meltzer 1986, Faust and Svensson 2002, Geraats 2005, and the survey by Geraats 2002). Employing a model in which the central bank prefers more output to less so that there is no role for stabilization policies, Geraats (2007) shows that even when the public can observe the central bank's actions prior to forming expectations, a lack of transparency results in an average inflation bias because the policy action does not fully reveal the central bank's information about the economy. She shows how transparency about the central bank's information can eliminate this bias. I study a model in which the central bank is concerned about stabilizing inflation and the output gap, so an average inflation bias does not arise. Stabilization policy is distorted by the opacity bias, and I focus on how opacity affects the optimal degree of policy flexibility.

In Geraats (2007), the public's only information about underlying shocks comes from observing the central bank's action unless the central bank fully reveals its information. Private agents all share the same information set and have no independent information about the shocks. In contrast, I analyze the opacity bias in a model that incorporates heterogeneous information among private firms as well as information asymmetries between the private sector and the central bank. A fraction of firms adjust prices each period, and these firms must forecast demand and cost conditions, but, because they care about their relative price, they must also forecast what other firms are doing. This introduces the need to form expectations about what others are expecting along the lines analyzed by Morris and Shin (2002). The role of heterogeneous information has been explored by Woodford (2003b), Hellwig (2004), Amato and Shin (2003), Svensson (2006), Fukunaga (2007), and Walsh (2007, 2008). In contrast to the analysis of transparency in Walsh (2007, 2008), the focus in the present paper is on the role asymmetric information plays in affecting the optimal degree of flexibility under a regime of inflation targeting. In addition, an innovation of the present paper is the introduction of a way to distinguish between the role of heterogeneous private sector information that is emphasized by Morris and Shin and the

role of asymmetric information between the central bank and the private sector that is the focus of Geraats (2002, 2007).

Relative to the earlier literature on central bank transparency which primarily studied issues of transparency about objectives in models based on a Lucas supply equation in which only surprises mattered for real output and that assumed homogeneous information among private agents, I employ a new Keynesian framework in which systematic policy is crucial, focus on asymmetric information about real economic disturbances, and allow for informational heterogeneity among private firms. Finally, since the welfare costs of inflation volatility depends on the dispersion of relative prices, I incorporate the dispersion that arises from inflation heterogeneity when comparing outcomes under opacity and transparency and focus on the optimal degree of flexibility.³

The next section provides a simple example designed to highlight the intuition behind the opacity bias. A more general model is developed in section 3. Equilibrium with an opaque central bank is analyzed in section 4. Section 5 addresses the issue of whether an opaque central bank should be less flexible and focus more on stabilizing inflation. Outcomes under the opaque policy regimes are compared to those achieved when the central bank is transparent in section 6. Section 7 concludes.

2 A simple example

In this section, a simple example is used to illustrate the bias that arises with discretionary policy when the central bank is opaque.

Consider a central bank that acts under discretion to minimize a quadratic loss function of the form

$$L = \left(\frac{1}{2}\right) [\pi_t^2 + \lambda(x_t - e_t^u)] \quad (1)$$

³Geraats (2007) examines an extension to issues of stabilization with a new Keynesian Phillips curve but her focus is on imperfect information about the central bank's inflation target rather on the way opacity about the state of the economy biases stabilization policies. She also assumes homogenous private information and does not examine the role of policy flexibility.

where π is the inflation rate, x is the output gap, and e^u is a shock to target output. I will assume that (1) also gives social loss, so e^u should be thought of as a stochastic shock to the wedge between the flexible price output gap and the welfare maximizing output gap.

Let θ_t denote the central bank's instrument and assume

$$x_t = \theta_t + e_t^v, \quad (2)$$

where e^v is a demand shock. Both e^u and e^v are taken to be white noise, independently and normally distributed processes with variances σ_v^2 , and σ_u^2 . The central bank observes e^u and e^v prior to setting its instrument.

Inflation is driven by firms's marginal cost, which in turn depends on the output gap. However price setting firms must set prices before observing the shocks e^u and e^v . They are, however, able to condition on the policy instrument:

$$\pi_t = \kappa \mathbb{E}_\theta x_t = \kappa (\theta_t + \mathbb{E}_\theta e_t^v), \quad (3)$$

where \mathbb{E}_θ denotes expectations conditional on θ . Private sector beliefs about the central bank's actions, which will be consistent with actual policy behavior in equilibrium, are described by

$$\theta_t = \delta_1 e_t^v + \delta_2 e_t^u. \quad (4)$$

The variance of the policy instrument is $\sigma_\theta^2 = \delta_1^2 \sigma_v^2 + \delta_2^2 \sigma_u^2$, and

$$\mathbb{E}_\theta v_t = \delta_1 \left(\frac{\sigma_v^2}{\sigma_\theta^2} \right) \theta_t.$$

This implies that (3) becomes

$$\pi_t = \kappa \left[1 + \delta_1 \left(\frac{\sigma_v^2}{\sigma_\theta^2} \right) \right] \theta_t = \kappa (1 + \Phi) \theta_t, \quad (5)$$

where $\Phi \equiv \delta_1 (\sigma_v^2 / \sigma_\theta^2)$. The impact of policy on inflation operates through two channels: the direct impact of θ on the output gap for given expectation about the demand shock (given by $\kappa \theta_t$), and the indirect effect arising from

the response of firms' expectations about the demand shock that occurs when firms observe θ (given by $\kappa\Phi\theta_t$).

As will be shown shortly, $\Phi < 0$. Therefore, $\kappa(1 + \Phi) < \kappa$; opacity reduces the impact of the policy instrument on inflation. A rise in θ_t cause private agents to infer that the central bank expects a negative output gap. This leads them to reduce their forecast of the future output gap, tending to dampen inflation. Thus, the net effect of the rise of θ on inflation is partially offset.

The central bank's decision problem involves minimizing (1) subject to (2) and (5). The optimal discretionary policy is given by

$$\theta_t = - \left(\frac{\lambda}{\lambda + \kappa^2 (1 + \Phi)^2} \right) (e_t^v - e_t^u). \quad (6)$$

Comparing this to private sector beliefs given by (4) shows that

$$\delta_1 = -\delta_2 = - \left(\frac{\lambda}{\lambda + \kappa^2 (1 + \Phi)^2} \right) < 0. \quad (7)$$

Hence, letting $\phi \equiv \sigma_v^2 / (\sigma_v^2 + \sigma_u^2)$, the equilibrium value of Φ satisfies⁴

$$0 \leq \left(\frac{\kappa^2 \phi}{\lambda} \right) (1 + \Phi)^2 + (1 + \Phi) = (1 - \phi) \leq 1. \quad (8)$$

There are two solutions to (8). Both solutions are negative; one satisfies $-1 < \Phi_1 < -\phi < 0$, the other is greater than one in absolute value, $\Phi_2 < -1$. Assuming a policy expansion (a rise in θ) does not cause a more than proportionate drop in private sector expectations about v so that inflation falls, Φ_1 is the relevant solution.

In contrast to the case of opacity, it is straightforward to show that when private firms also observe v and u (i.e., with a regime of transparency) the

⁴The equilibrium condition for Ω is obtained by substituting the expression for δ_1 in (7) into the definition of Ω and rearranged.

optimal policy under discretion is

$$\theta_t = -e_t^v + \left(\frac{\lambda}{\lambda + \kappa^2} \right) e_t^u. \quad (9)$$

Comparing (6) and (9) shows how opacity biases the central bank's responses to the two shocks. Under opacity, the public infers from a rise in θ that the central bank is forecasting a negative shock to demand ($E_\theta v_t = \delta_1 (\sigma_v^2 / \sigma_\theta^2) \theta_t$ and $\delta_1 < 0$). This dampens the inflation effects of the policy action. Hence, because the effect of θ on inflation is $\kappa(1 + \Phi) < \kappa$, the central bank perceives that the inflationary consequences of reacting to u shocks are smaller than in the fully transparent case. This leads the central bank to over-respond to these shocks:

$$\frac{\lambda}{\lambda + \kappa^2 (1 + \Phi)^2} > \frac{\lambda}{\lambda + \kappa^2}.$$

To obtain the optimal response to e^u shocks, society would need to assign a degree of flexibility λ^{cb} to the central bank such that

$$\frac{\lambda^{cb}}{\lambda^{cb} + \kappa^2 (1 + \Phi)^2} = \frac{\lambda}{\lambda + \kappa^2} \Rightarrow \lambda^{cb} = \lambda (1 + \Phi)^2 < \lambda.$$

Thus, in the face of welfare gap shocks, it is optimal to have an opaque central bank implement a less flexible inflation targeting policy, or, in Rogoff's terms, to appoint a more conservative central banker.

However, the desirability of a less flexible inflation targeter can depend on the nature of the shocks. While over-reacting to e^u shocks, the central bank under-reacts to e^v shocks, failing to fully insulating the economy from demand shocks as called for when the private sector has full information (see 9):

$$\frac{\lambda}{\lambda + \kappa^2 (1 + \Phi)^2} = 1 - \left(\frac{\kappa^2 (1 + \Phi)^2}{\lambda + \kappa^2 (1 + \Phi)^2} \right) < 1.$$

Because movements of θ are attributed partially as a response to e^u shocks, a change in θ designed to offset a e^v shock still affects firms' expectations

about the output gap, thereby leading to movements in inflation. From the central bank’s perspective, this reaction of expectations raises the cost of responding to demand shocks. Thus, the informational effects of policy actions in an opaque policy regime distort the central bank’s responses to shocks. To achieve the optimal response to e^v shocks would require that the central bank focus only on stabilizing the welfare gap (i.e., $\lambda^{cb} \rightarrow \infty$), but this is, in part, because demand shocks have no direct impact on inflation in this example (only expected demand shocks matter for inflation).

The purpose of this simple example has been to illustrate that a policy bias arises in an opaque policy regime. Policy actions convey information to the public, and the presence of this informational affect alters the incentives of the central bank and biases policy responses. As the example also showed, the opacity bias may require the central bank to be a less flexible inflation targeter or a more flexible targeter, depending on the nature of shocks.

3 The model with heterogeneous information

To investigate the opacity bias further, a more general model is developed in this section. The model incorporates nominal rigidities through a standard Calvo-type model of price setting by monopolistic competitive firms and informational asymmetries, both among private sector firms and between the private sector and the central bank. The specification allows for the effects of asymmetric information and heterogeneous information among private agents to be separately studied. The model also incorporates explicitly the welfare costs of opacity on the dispersion of relative prices across firms. I focus on differing assessments of the underlying state of the economy by the central bank and private firms. These differences could arise if private agents and the central bank have different information about the economy, but they could also arise from differences in the models used to generate forecasts or simply from the role of judgement factors that influence both the central bank’s and the private sector’s assessment of future economic developments.

Relative to the simple example of the previous section, the model devel-

oped in this section incorporates a cost shock in addition to demand and welfare gap shocks, provides for private agents as well as the central bank to have noisy signals on the shocks, allows for heterogeneity in information sets across firms, and takes explicit account of the welfare costs of relative price dispersion that result both from inflation variability and from informational heterogeneity.

Since the information aspects of the model are critical, I describe them first. There are a continuum of differentiated firms operating in an environment characterized by monopolistic competition. Each firm receives private information on the fundamental shocks. The information on the time $t + 1$ realization of shock i received by firm j at time t is denoted by $e_{j,t+1}^i$. This signal is related to the true realization of the shock e_{t+1}^i by

$$e_{j,t+1}^i = e_{t+1}^i + (1 - \alpha)\phi_{t+1}^i + \alpha\phi_{j,t+1}^i, \quad (10)$$

where ϕ_{t+1}^i is a shock-specific measurement error common to all firms and $\phi_{j,t+1}^i$ is a firm j idiosyncratic error. If $\alpha = 1$, we have the Morris and Shin (2002) case; the noise in the firm's signal is firm-specific, private information. If $\alpha = 0$, private information is common, and the only informational asymmetry is that between the private sector and the central bank.

Similar to firms, the central bank receives information about the shocks:

$$e_{cb,t+1}^i = e_{t+1}^i + \phi_{cb,t+1}^i. \quad (11)$$

The signal $e_{cb,t+1}^i$ is private information to the central bank. All shocks and noise terms are assumed to be normally and independently distributed with zero means and no serial correlation.

For later use, the signal-to-noise ratio for firm j and shock i is

$$\gamma_j^i = \frac{\sigma_i^2}{\sigma_i^2 + \sigma_{i,j}^2},$$

where σ_i^2 is the variance of e^i and $\sigma_{i,j}^2 \equiv (1 - \alpha)var(\phi^i) + \alpha^2 var(\phi_j^i)$. Similarly for the central bank, define the central bank's signal-to-noise ratio for shock

i as

$$\gamma_{cb}^i = \frac{\sigma_i^2}{\sigma_i^2 + \sigma_{cb,i}^2},$$

where $\sigma_{cb,i}^2$ is the variance of ϕ_{cb}^i . Then, the central bank's forecast of e_{t+1}^i is

$$\mathbb{E}_t^{cb} e_{t+1}^i = \gamma_{cb}^i e_{cb,t+1}^i.$$

Standard assumptions of rational expectations presume private agents know the quality of the central bank's information (i.e., they know γ_{cb}^i). Hence, while transparency will be interpreted as the release of the central bank's signals, we could equivalently talk about the central bank releasing its forecast of future economic developments.

Firms adjust prices according to the Calvo model of sticky prices, with a fixed fraction of firms randomly selected to adjust each period. Those firms that are able to adjust set their price for period $t + 1$ based on time t information and the new information they receive about $t + 1$ shocks. Define $\pi_{j,t+1}^* \equiv p_{j,t+1}^* - p_t$ as the optimal price set by firm j relative to the time t price level. Then the optimal adjustment by firm j is given by

$$\pi_{j,t+1}^* = (1 - \omega) \mathbb{E}_t^j \bar{\pi}_{t+1}^* + (1 - \omega\beta) \left(\kappa \mathbb{E}_t^j x_{t+1} + \mathbb{E}_t^j e_{t+1}^s \right) + \left(\frac{\omega\beta}{1 - \omega} \right) \mathbb{E}_t^j \pi_{t+2}, \quad (12)$$

where $\bar{\pi}_{t+1}^*$ is the average price adjustment across all firms allowed to reset their prices in period t (see Walsh 2007). The parameter ω is the fraction of non-adjusting firms, and β is the discount factor. Information sets may differ; thus, the operator \mathbb{E}^j reflects expectations conditional on firm j 's information. The firm's optimal price depends on its forecasts of other firms' forecasts of inflation $\mathbb{E}_t^j \bar{\pi}_{t+1}^*$, of the output gap, $\mathbb{E}_t^j x_{t+1}$, of the cost shock $\mathbb{E}_t^j e_{t+1}^s$, and of future aggregate inflation $\mathbb{E}_t^j \pi_{t+2}$. Aggregate inflation is equal to

$$\pi_{t+1} = (1 - \omega) \int \pi_{j,t+1}^* dj = (1 - \omega) \bar{\pi}_{t+1}^*. \quad (13)$$

In the standard, common information framework, $\pi_{j,t+1}^* = \bar{\pi}_{t+1}^*$ for all j as all firms are identical. Note that in this case, (12) and (13) reduce to a

standard new Keynesian Phillips curve with Christiano, Eichenbaum, and Evans (2005) timing.

To keep the demand side of the model simple, let

$$x_{t+1} = \theta_t + e_{t+1}^v, \quad (14)$$

where θ is the central bank's instrument and e^v is a demand shock.

The model is completed with a specification of social loss and the policy regime. In the standard new Keynesian model with monopolistic competition and staggered price adjustment, inflation volatility generates an inefficient dispersion of relative prices across firms. Similarly, differences in information also causes relative prices to differ across firms, and this is socially inefficient since the informational heterogeneity is due solely to noise. Social loss is therefore approximated by

$$\left(\frac{1}{2}\right) \mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \left[\pi_{t+k}^2 + \lambda_z z_{t+k}^2 + \lambda_x (x_{t+k} - e_{t+k}^u)^2 \right], \quad (15)$$

where the shock e^u reflects stochastic variation in the welfare gap between the flexible-price equilibrium level of output and the efficient level respectively, and the term z_{t+k}^2 is a measure of the variance of prices across firms due to heterogeneous information. It reflects the welfare costs associated with heterogeneous noisy information.

The policy regime is one of “constrained discretion” (Bernanke 2003, King 2004) in the sense that I assume the decision to make announcements (or not make them) is one the central bank must commit to, but the choice of the policy instrument θ_t is made each period under discretion to minimize the expectation of (15), where the expectation is taken with respect to the central bank's information set.

The basic timing is as follow: 1) At the end of period t , the central bank observes signals about $t + 1$ shocks and sets its policy instrument θ_t ; 2) Firms observe π_t , x_t , and θ_t as well as individual specific signals about $t + 1$ shocks. Firms may also observe announcements made by the central bank; 3) Those firms that can adjust their price set prices for $t + 1$; and 4)

Period $t + 1$ actual shocks occur and π_{t+1} and x_{t+1} are realized.

4 Equilibrium with an opaque central bank

When the central bank is opaque, it makes no announcements. Private agents must base their inferences about the central bank's outlook for the economy by observing the current setting of the policy instrument. They forecast what other firms are expecting, as well as the output gap and the cost shock by combining their own private information with the information that can be gleaned from observing θ_t .

The model is solved using the method of undetermined coefficients under the assumption of rational expectation. If $\Omega_{j,t+1} = [e_{j,t+1}^u, e_{j,t+1}^s, e_{j,t+1}^v]'$ denotes the vector of private signals observed by firm j , then the equilibrium strategy of a price-adjusting firm is a linear function of $\Omega_{j,t+1}$ and θ_t :

$$\pi_{j,t+1}^* = A\Omega_{j,t+1} + B\theta_t.$$

Aggregate inflation will equal

$$\pi_{t+1} = (1 - \omega)\bar{\pi}_{t+1}^* = (1 - \omega)(A\Omega_{t+1} + B\theta_t),$$

where $\Omega_{t+1} = \int \Omega_{j,t+1} dj$.

Let the 3×1 vector $E^j \Omega_\theta$ denote the impact observing θ_t has on firm j 's expectations of the aggregate information received by all firms and let $E^j Z_\theta$ denote the impact observing θ_t has on firm j 's expectations of the vector of fundamental shocks. If $\alpha = 1$ so that the measurement error across firms is uncorrelated, $E^j \Omega_\theta = E^j Z_\theta$. The elasticity of inflation with respect to the instrument of monetary policy can then be written as

$$\frac{\partial \pi_{t+1}}{\partial \theta_t} \equiv (1 - \omega)B = \delta_1 + \delta_2,$$

where

$$\delta_1 = \frac{(1 - \omega)(1 - \omega\beta)\kappa}{\omega}$$

is the direct impact of the policy instrument on expected output and inflation, and

$$\delta_2 = \frac{(1 - \omega)^2}{\omega} AE^j \Omega_\theta + \delta_1 DE^j Z_\theta$$

is the informational effect, where A and D are 1×3 vectors of coefficients (see the appendix). The parameter δ_1 is the elasticity of inflation with respect to the output gap in a standard new Keynesian model. The second term, δ_2 , captures the informational effects of policy actions. This, in turn, consists of two components. The first captures the impact of θ on inflation arising from the adjustment of firms' expectations about the signals received by other firms (and so about the expectations of the other firms). The second captures the effect of θ on firms' expectations about the underlying shocks. The presence of a non-zero value of δ_2 , by altering the impact of policy on inflation, affects policy incentives and will lead to an opacity bias, much as Φ did in the example of section 2.

4.1 Optimal policy

I employ a calibrated version of the model to investigate the role informational asymmetries play in distorting policy responses. Standard parameter values are used; these are given in Table 1. The discount rate is set at 0.99, appropriate for quarterly data. Micro evidence on the Calvo parameter that governs the degree of nominal rigidity suggests a value of around 0.5, while time series macro estimates are generally much higher, closer to 0.8. I choose an intermediate value and set $\omega = 0.65$. In a standard new Keynesian model, the parameter κ is the sum of the coefficient of relative risk aversion and the inverse of the wage elasticity of labor supply. I set the first of these equal to 1 (log utility) and the second to 0.8, yielding $\kappa = 1.8$. For the baseline case, I assume equal weight on inflation and output gap volatility in the loss function so that, expressed in terms of quarterly inflation rates, $\lambda_x = 1/16 = 0.0625$. Walsh (2008) shows that when the coefficient on π^2 in the loss function is normalized to one, the coefficient on relative price dispersion created by information heterogeneity is $\lambda_z = (1 - \omega)^2/\omega = 0.1885$. Initially, I set the variances of all three shocks equal to 1.

Table 1: Parameter values

β	0.99
ω	0.65
κ	1.8
λ_z	0.1885
λ_x	0.0625

Tables 2a and 2b show the optimal policy responses to the central bank's forecast of each shock when policy is conducted under discretion in an opaque regime. The responses are shown for various combinations of the quality of private sector information, measured by the signal to noise ratio γ_j , and the quality of the central bank's information, measured by γ_{cb} . Also shown under the column headed $\delta_1 + \delta_2$ is the elasticity of inflation with respect to the policy instrument θ . Table 2a is based on $\alpha = 0$, the case of common private information; Table 2b is based on $\alpha = 1$; the case of idiosyncratic private information. Row (1) of each table reports the optimal policy responses for the case of perfect information on the part of the private sector (a signal to noise ratio of one). In this case, there is no informational value in observing θ and $\delta_2 = 0$. Policy responses in this case are independent of the quality of the central bank's information, reflecting the certainty equivalence that Svensson and Woodford (2002) show holds in this case. Since $\delta_1 = 0.3455$ and is independent of informational quality, changes in $\delta_1 + \delta_2$ as γ_{cb} and γ_j vary reflect variations in δ_2 .

Table 2a: Optimal policy responses to shock forecasts: $\alpha = 0$

$\sigma_s^2 = \sigma_v^2 = \sigma_u^2 = 1$						
	γ_{cb}	γ_j	$\delta_1 + \delta_2$	$E^{cb}e^s$	$E^{cb}e^v$	$E^{cb}e^u$
1)	—	1	0.3455	-0.3647	-1.0	0.3436
2)	0.4	0.4	0.1591	-0.1320	-0.9127	0.6750
3)		0.6	0.1951	-0.2088	-0.9568	0.5809
4)		0.8	0.2539	-0.2901	-0.9871	0.4649
5)	0.6	0.4	0.1442	-0.1227	-0.9132	0.6924
6)		0.6	0.1718	-0.1926	-0.9548	0.6082
7)		0.8	0.2281	-0.2750	-0.9855	0.4905
8)	0.8	0.4	0.1268	-0.1114	-0.9150	0.7146
9)		0.6	0.1410	-0.1688	-0.9533	0.6495
10)		0.8	0.1829	-0.2442	-0.9832	0.5436

Table 2b: Optimal policy responses to shock forecasts: $\alpha = 1$

	$\sigma_s^2 = \sigma_v^2 = \sigma_u^2 = 1$					
	γ_{cb}	γ_j	$\delta_1 + \delta_2$	e^s	e^v	e^u
1)	—	1	0.3455	-0.3647	-1.0	0.3436
2)	0.4	0.4	0.1474	-0.0975	-0.8877	0.7122
3)		0.6	0.2365	-0.1670	-0.9349	0.6244
4)		0.8	0.2277	-0.2585	-0.9773	0.5120
5)	0.6	0.4	0.1983	-0.0917	-0.8898	0.7247
6)		0.6	0.2212	-0.1539	-0.9342	0.8571
7)		0.8	0.2608	-0.2413	-0.9754	0.5410
8)	0.8	0.4	0.1865	-0.0853	-0.8922	0.7387
9)		0.6	0.2010	-0.1371	-0.9342	0.6873
10)		0.8	0.2319	-0.2114	-0.9725	0.5919

Several conclusions can be drawn from Tables 2a and 2b. First, as the quality of private sector information rises (i.e., as γ_j increases), holding γ_{cb} constant, the marginal impact of policy actions on inflation also increases in absolute value, as shown in the column labeled $\delta_1 + \delta_2$. To understand this effect, recall that firms are using θ_t to infer something about the central bank's information. A rise in the policy instrument could arise because the central bank believes the efficient level of output has risen ($e^u > 0$), because it expects demand to fall ($e^v > 0$), or because it expects a negative inflation shock ($e^s < 0$). Under an opaque regime when these shocks are equally volatile, the net effect of a rise in θ_t is to actually lower private sector forecasts of output.⁵ This acts to reduce the impact of the rise in θ_t on inflation. This effect is smaller, the higher is the quality of the firms' own

⁵The January 22, 2008 interest rate cut (corresponding to a rise in θ in the model) offers an example of an expansionary shift in policy that was interpreted by markets as evidence the Fed was expecting a worsening of the recession.

information. So δ_2 falls in absolute value as γ_j rises.

Second, imperfect private and central bank information reduces the optimal policy response to a signal on the cost shock e^s . This effect can be large. When $\gamma_{cb} = 0.8$ and $\gamma_j = 0.4$, the optimal response to e^s is -0.1114 when $\alpha = 0$ and -0.0853 when $\alpha = 1$, compared to -0.3647 in the $\gamma_j = 1$ case. Because $\delta_1 + \delta_2$ is smaller with imperfect information, the central bank must accept greater output volatility to achieve any given degree of inflation volatility. This causes the optimal response to involve less inflation stabilization in the face of cost shocks.

Third, the central bank does not fully insulate the economy from demand shocks under imperfect information; the response to e^v is less than 1.0 in absolute value. A rise in θ designed to offset a negative forecast of e^v is interpreted partially as a sign the central bank is boosting output in reaction to a positive shock to the efficient level of output (which would raise expected inflation) or to offset a negative cost shock (which would lower expected inflation), the impact on inflation is ambiguous. For the calibrations used in Tables 2a and 2b, the net effect of a rise in θ in response to a negative demand shock is to cause expected inflation to rise; this tempers the central bank's reaction and the optimal response fails to sully insulate the output gap from demand shocks.

Fourth, under imperfect information, the optimal response to welfare gap shocks is larger than when $\gamma_j = 1.0$. Because of the information effects, the inflation costs of responding to welfare gap shocks is lower since the response is partially viewed as a reaction to a negative demand or cost shock. By reducing the inflation costs of responding to welfare gap shocks, the optimal reaction becomes stronger.

In general, the results are relative insensitive to variation in α . However, a rise in the quality of central bank information reduces the marginal impact of policy actions on inflation when $\alpha = 0$ but has ambiguous effects when $\alpha = 1$ (the Morris and Shin case).

Tables 2a and 2b were constructed under the assumption that the three fundamental shocks had equal variances. The basic conclusions from the table are robust to variations in the relative variances of the shocks, although

altering the variance of welfare gap shocks has the biggest impact on the optimal response coefficients. This is illustrated in Tables 3a and 3b which are based on setting σ_u^2 to a much smaller value than the other two variance ($\sigma_u^2 = 0.001$; the other two variances are left equal to one). The general conclusions from Tables 2a-b continue to hold for the parameterization of Tables 3a-b with one exception. With welfare gap shocks having a much smaller variance, the optimal response calls for a more than one-for-one response to expected demand shocks when private sector information is imperfect. When welfare gap shocks are very small, the model essentially has only two fundamental shocks – the cost shock and the aggregate demand shock. When the central bank adjusts θ to fully offset its forecast of the demand shock, part of the movement in the policy instrument is interpreted by the public as a reaction to a forecast of a cost shock. For example, suppose the central bank receives a positive signal e_{cb}^v . It lowers θ , but when private firms observe the cut in θ , they view this, in part, as evidence that the central bank is forecasting a positive cost shock. Firms therefore expect higher inflation. The central bank cuts θ more to help offset inflationary impact of this rise in expected inflation.

Table 3a: Optimal policy responses to shock forecasts: $\alpha = 0$

$\sigma_s^2 = \sigma_v^2 = 1, \sigma_u^2 = 0.001$						
	γ_{cb}	γ_j	$\delta_1 + \delta_2$	$E^{cb}e^s$	$E^{cb}e^v$	$E^{cb}e^u$
1)	—	1	0.3455	-0.3647	-1.0	0.3436
2)	0.4	0.4	0.0905	-0.0934	-1.0085	0.8404
3)		0.6	0.1539	-0.1901	-1.0123	0.6702
4)		0.8	0.2375	-0.2869	-1.0081	0.4917
5)	0.6	0.4	0.0652	-0.0703	-1.0053	0.8787
6)		0.6	0.1187	-0.1589	-1.0095	0.7243
7)		0.8	0.2042	-0.2657	-1.0076	0.5294
8)	0.8	0.4	0.0353	-0.0403	-1.0019	0.9294
9)		0.6	0.0690	-0.1041	-1.0050	0.8177
10)		0.8	0.1415	-0.2152	-1.0061	0.6188

Table 3b: Optimal policy responses to shock forecasts: $\alpha = 1$

$\sigma_s^2 = \sigma_v^2 = 1, \sigma_u^2 = 0.001$						
	γ_{cb}	γ_j	$\delta_1 + \delta_2$	$E^{cb}e^s$	$E^{cb}e^v$	$E^{cb}e^u$
1)	—	1	0.3455	-0.3647	-1.0	0.3436
2)	0.4	0.4	0.0655	-0.0551	-1.0048	0.9057
3)		0.6	0.1180	-0.1369	-1.0110	0.7647
4)		0.8	0.2024	-0.2509	-1.0104	0.5588
5)	0.6	0.4	0.0462	-0.0399	-1.0027	0.9309
6)		0.6	0.0873	-0.1078	-1.0077	0.8137
7)		0.8	0.1659	-0.2234	-1.0094	0.6072
8)	0.8	0.4	0.0244	-0.0218	-1.0009	0.9617
9)		0.6	0.0484	-0.0650	-1.0033	0.8863
10)		0.8	0.1056	-0.1659	-1.0063	0.7077

When private sector information is imperfect, Tables 2 and 3 show that the central bank will, in an opaque regime, respond less to its forecast of cost shocks and more to its forecast of welfare gap shocks than would be the case with perfect private sector information. Thus, again relative to the $\gamma_j = 1$ case, the welfare gap will be more stable and inflation less stable. By responding less to cost shock forecasts, output is made less volatile, but the cost shocks have a larger impact on inflation. By responding more to welfare gap shocks, these shocks have a smaller impact on the welfare gap, but the greater volatility of output leads to more inflation volatility. This result suggests that, when policy is opaque, requiring the central bank to increase its focus on inflation stabilization will move policy closer to the perfect information case. This suggestion is examined in the next section.

5 The optimal weight on inflation objectives

In this section, I consider whether central banks should place more weight on stabilizing inflation than implied by the social welfare function. That is, should the central bank be a less flexible inflation targeter when transparency is incomplete? While the results of the previous section suggested that assigning a larger weight to inflation would move policy closer to the outcomes under perfect private information, this does not necessarily mean that the net effect will be to increase welfare.

Suppose that the central bank is assigned the following loss function:

$$\left(\frac{1}{2}\right) \mathbb{E}_t^{cb} \sum_{k=0}^{\infty} \beta^k \left[\pi_{t+k}^2 + \lambda_z z_{t+k}^2 + (1 + \tau) \lambda_x (x_{t+k} - e_{t+k}^u)^2 \right], \quad (16)$$

which differs from social loss as specified in (15) if $\tau \neq 0$. For $\tau < 0$, the central bank places less weight on output gap stabilization (more weight on inflation stabilization) than society does.⁶ Rogoff (1985) showed that the optimal τ is less than zero when there is an average inflation bias under discretionary policy. Clarida, Galí, and Gertler (1999) showed that even in the absence of an inflation bias, the optimal τ is less than zero if cost shocks are positively serially correlated. In the present model, there is no average inflation bias and shocks are serially uncorrelated. Thus, the standard rationale for giving more weight to inflation stabilization have been eliminated. However, the optimal τ may still differ from zero because of the opacity bias created by imperfect information and a lack of transparency.

Table 4 shows the optimal τ and the percent reduction in loss at the optimal τ for various combinations of the quality of central bank and private sector information. The top part of the table is constructed for the case of $\alpha = 0$ – all private sector information is common – while the bottom section shows the $\alpha = 1$ case – all private sector information is idiosyncratic. When

⁶The weight λ_z has been left unchanged as this arises from the same distortions that cause inflation volatility to be costly. Thus, the focus here is on whether the central bank should place more or less weight on reducing the distortions created by relative price dispersion.

private sector information is perfect ($\gamma_j = 1$), the optimal τ is equal to zero, regardless of the quality of the central bank's information. This is because policy actions have no informational content in this case, so policy responses are not distorted.

Table 4: Optimal τ and percent reduction in loss

		$\sigma_s^2 = \sigma_v^2 = \sigma_u^2 = 1$				
$\alpha = 0$		γ_j				
		0.4	0.6	0.8	1	
1)		0.4	-0.45(2.47%)	-0.62(2.48%)	-0.39(0.70%)	0
2)	γ_{cb}	0.6	-0.31(3.08%)	-0.65(5.64%)	-0.45(2.03%)	0
3)		0.8	-0.16(2.61%)	-0.29(5.28%)	-0.57(6.82%)	0
$\alpha = 1$						
4)		0.4	-0.34(1.71%)	-0.63(3.25%)	-0.49(1.31%)	0
5)	γ_{cb}	0.6	-0.25(2.32%)	-0.42(4.30%)	-0.56(3.44%)	0
6)		0.8	-0.16(2.51%)	-0.19(3.33%)	-0.56(9.01%)	0

In all cases, the optimal τ is negative; making the central bank more accountable for inflation stabilization mutes the distortions introduced by imperfect information. This conclusion does not depend on whether private information is common ($\alpha = 0$) or idiosyncratic ($\alpha = 1$). With $\tau < 0$, the central bank will react more (in absolute value) to cost shocks under discretion, reducing their impact on inflation. With $\tau < 0$, the central bank will react less to welfare gap shocks.

Table 5 repeats the calculations of Table 4 for the case of a small variance of the welfare gap shocks. This case corresponds to the more standard situation in which only demand and cost shocks are present. The optimal values for τ are larger (in absolute value) than those in Table 4, particularly when private information is poor. Comparing the policy responses to cost shocks in Tables 2 (when $\sigma_u^2 = 1$) and 3 (when $\sigma_u^2 = 0.001$) reveals that the

central bank engages in less inflation stabilization when welfare gap shocks are small. Because the impact of the instrument on inflation is smaller when σ_u^2 is smaller (compare $\delta_1 + \delta_2$ in Tables 2 and 3), the central bank must generate more output gap volatility to stabilize inflation when welfare gap shocks are small. Thus, the optimal τ rises in absolute value to ensure the central bank places more weight on its inflation objective.

Table 5: Optimal τ and percent reduction in loss

		$\sigma_s^2 = \sigma_v^2 = 1, \sigma_u^2 = 0.001$				
$\alpha = 0$		γ_j				
		0.4	0.6	0.8	1	
1)		0.4	-0.77(2.47%)	-0.65(1.47%)	-0.40(0.32%)	0
2)	γ_{cb}	0.6	-0.78(3.08%)	-0.71(4.46%)	-0.47(1.15%)	0
3)		0.8	-0.84(2.61%)	-0.80(15.15%)	-0.62(6.37%)	0
$\alpha = 1$						
4)		0.4	-0.77(2.44%)	-0.74(2.27%)	-0.51(0.67%)	0
5)	γ_{cb}	0.6	-0.81(4.96%)	-0.78(6.06%)	-0.58(2.28%)	0
6)		0.8	-0.85(7.94%)	-0.82(15.27%)	-0.72(10.50%)	0

To conclude this section, in an opaque and discretionary policy regime with asymmetric and imperfect information, the central bank should be structured to give more weight to inflation stabilization than society does, that is it should be a less flexible inflation targeter.

6 Transparency versus Opaqueness

The previous section showed that when policy lacks transparency, the central bank should be tasked to place more weight on inflation stabilization (and less on welfare gap stabilization) than society does. Social welfare can be improved when the central bank's objective function is distorted relative to

the social loss function. Under a fully transparent regime, the optimal τ is always zero – a transparency central bank should share society’s preferences over inflation and real objectives. In that sense, transparency allows an inflation targeting central bank to be more flexible by giving more weight to stabilizing real objectives. In this section, social loss under three regimes – opaque policy, opaque policy with an optimal τ , and transparent policy – are compared. While an opaque policy regime with an optimal τ clearly is always at least as good as an opaque policy that minimizes social loss, whether a transparent regime will dominant turns out to depend on the relative quality of the central bank’s information.

To compare the three regimes, I report the percent difference in social loss between the two opaque regimes and the fully transparent regime. Thus, a positive value indicates the regime is dominated by transparency (loss is higher under the opaque regime) while a negative value indicates the opaque regime achieves a lower value of the loss function than is obtained under transparency. To focus on the role played by the central bank’s information, I set the quality of private information γ_j^i equal to 0.6 for all of the shocks while varying γ_{cb}^s and γ_{cb}^v , with γ_{cb}^u fixed, first at 0.4 and then at 0.8. Because findings were similar for $\alpha = 0$ and $\alpha = 1$, only the latter results corresponding to the Morris-Shin heterogeneous information case are reported.

Table 6: Loss relative to transparency (%)

$\alpha = 1, \gamma_j^i = 0.6, \sigma_i^2 = 1, i = s, v, u$							
γ_{cb}^s							
		0.4		0.6		0.8	
		$\tau = 0$	$\tau = \tau^*$	$\tau = 0$	$\tau = \tau^*$	$\tau = 0$	$\tau = \tau^*$
		(1)	(2)	(3)	(4)	(5)	(6)
$\gamma_{cb}^u = 0.4$	0.4	1.27	-2.02	0.96	-2.53	-0.10	-3.36
γ_{cb}^v	0.6	1.94	-2.01	1.71	-2.22	0.56	-3.22
	0.8	1.98	-1.89	1.97	-1.82	0.79	-2.85
$\gamma_{cb}^u = 0.8$	0.4	2.11	-2.29	1.79	-2.52	0.64	-3.27
γ_{cb}^v	0.6	5.58	-1.42	3.33	-1.52	2.10	-2.02
	0.8	4.91	0.58	4.97	0.81	3.67	0.40

When the central bank minimizes the social loss function under discretion (columns 1, 3, and 5 for $\tau = 0$), transparency dominates opaqueness for all combinations of the quality of central bank and private sector information except in one case (when $\gamma_{cb}^s = 0.8$ and $\gamma_{cb}^u = \gamma_{cb}^v = 0.4$). The one exception occurs when the central bank has very good information on the cost shock but poor information on the other shocks. Even in this case, however, outcomes under the two regimes are virtually the same. Since $\alpha = 1$ in Table 6, the environment corresponds to the heterogenous information situation in which Morris and Shin have argued transparency might lower welfare by making expectations sensitive to central bank forecast errors. Here, transparency dominates opaqueness, consistent with Svensson (2006).

When transparency is compared to an opaque regime in which the central bank implements a less flexible policy (i.e., when $\tau = \tau^*$), the advantage of transparency disappears (columns 2, 4, and 6). The exceptions occur when the central bank has relatively good information on aggregate demand and welfare gap shocks, as shown in the last row of the table. Transparency allows the central bank to fully insulate both output and inflation from these shocks. If the potential gains from stabilizing the economy from demand

shocks is large (because the central bank's forecast errors are small), then transparency is the dominate policy regime.

7 Conclusions

In the face of asymmetric information about economic shocks, an opaque central bank should put more weight on achieving inflation objectives than society does. Reducing the flexibility of policy in this manner helps offset the distortions introduced by asymmetric information. These distortions arise because the information conveyed by policy actions alters the incentives the central bank faces when setting optimal policy under discretion, thereby creating an opacity bias in policy. Thus, a regime of relatively strict inflation targeting may be particularly relevant for central banks that are not transparent, while a fully transparent central bank can implement a more flexible policy of inflation targeting. And only transparent central banks should maximize social welfare. However, while it is inefficient to distort a transparent central bank's objectives by having it focus more on inflation, an opaque but conservative central bank may deliver better outcomes than a transparent central bank in a discretionary policy environment.

One argument for transparency is that it helps align private sector expectations with the central bank's projection for inflation. This role is absent in the present model, which might account for why the opaque regime with an optimal τ^* tends to produce better outcomes than a regime of full transparency. One way to introduce such a channel would be to allow for a stochastic target for inflation as in Geraats (2007). Greater transparency would then allow the central bank to achieve better control of the inflation gap – inflation minus the target rate – by ensuring private sector expectations of inflation were more consistent with the central bank's assessment of the desired target rate of inflation.

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Appendix (not for publication): Solving the basic model

Firm j 's price setting strategy is given by

$$\begin{aligned}\pi_{j,t+1}^* &= (1 - \omega)E_t^j \bar{\pi}_{t+1}^* + (1 - \omega\beta) \left(\kappa E_t^j x_{t+1} + E_t^j e_{t+1}^s \right) \\ &\quad + \left(\frac{\omega\beta}{1 - \omega} \right) E_t^j \pi_{t+2}.\end{aligned}\tag{17}$$

In the absence of central bank announcements, firm j 's new information is given by

$$\begin{bmatrix} \Omega_{j,t+1} \\ \theta_t \end{bmatrix},$$

where $\Omega_{j,t+1}$ is the 3×1 vector of signals received by the firm. Assume firms' beliefs about monetary policy are given by

$$\theta_t = \gamma' \Gamma_{cb} \Omega_{cb,t+1},$$

where $\Omega_{cb,t+1}$ is the vector of the central bank's signals and Γ_{cb} is the diagonal matrix of the bank's signal to noise ratios. Let the 3×1 vector of fundamental shocks be denoted by Z_{t+1} and the aggregate signal across firms be Ω_{t+1} . Then one can write firm j 's expectation of Z_{t+1} as

$$E_t^j Z_{t+1} = \Theta_1^o \Omega_{j,t+1} + \Theta_2^o \theta_t$$

and

$$E^j \Omega_{t+1} = \Psi_1^o \Omega_{j,t+1} + \Theta_2^o \theta_t.$$

Firm j 's strategy will take the form

$$\pi_{j,t+1}^* = A \Omega_{j,t+1} + B \theta_t$$

In forming expectations about the pricing behavior of other firms ad-

justing in the current period, firm j 's expectation of $\bar{\pi}_{t+1}^*$ is given by

$$\begin{aligned} E_t^j \bar{\pi}_{t+1}^* &= AE_{t+1}^j \Omega_{t+1} + BF\theta_t \\ &= A \left[\Psi_1^o \Omega_{j,t+1} + \Psi_2^o \tilde{\theta}_t \right] + B\theta_t \\ &= A\Psi_1^o \Omega_{j,t+1} + (A\Psi_2^o + B) \theta_t. \end{aligned}$$

Since

$$\pi_{t+1} = (1 - \omega) \bar{\pi}_{t+1}^*,$$

and all shocks are serially uncorrelated, it follows that

$$\begin{aligned} E_t^j \pi_{t+2} &= (1 - \omega) E_t^j \bar{\pi}_{t+2}^* \\ &= (1 - \omega) E_t^j [A\Psi_1^o \Omega_{j,t+2} + (A\Psi_2^o + B) \theta_{t+1}] \\ &= 0. \end{aligned}$$

Defining ι_i as a 1×3 vector with a 1 in the i^{th} place and zeros elsewhere, we can write (17) for a price-adjusting firm's price change as

$$\begin{aligned} \pi_{j,t+1}^* &= (1 - \omega) E_t^j \bar{\pi}_{t+1}^* + (1 - \omega\beta) \kappa \theta_t \\ &\quad + (1 - \omega\beta) (\iota_1 + \kappa \iota_2) (\Theta_1^o \Omega_{j,t+1} + \Theta_2^o \theta_t) \\ &= (1 - \omega) [A\Psi_1^o \Omega_{j,t+1} + (A\Psi_2^o + B) \theta_t] + (1 - \omega\beta) \kappa \theta_t \\ &\quad + (1 - \omega\beta) (\iota_1 + \kappa \iota_2) (\Theta_1^o \Omega_{j,t+1} + \Theta_2^o \theta_t). \end{aligned}$$

Collecting terms,

$$\begin{aligned} \pi_{j,t+1}^* &= [(1 - \omega)A\Psi_1^o + (1 - \omega\beta) (\iota_1 + \kappa \iota_2) \Theta_1^o] \Omega_{j,t+1} \\ &\quad + [(1 - \omega\beta) \kappa + (1 - \omega) (A\Psi_2^o + B) + (1 - \omega\beta) (\iota_1 + \kappa \iota_2) \Theta_2^o] \theta_t. \end{aligned}$$

Equating coefficients with the proposed solution yields

$$A = [(1 - \omega\beta) (\iota_1 + \kappa \iota_2)] \Theta_1^o [I_4 - (1 - \omega) \Psi_1^o]^{-1},$$

and

$$B = \frac{(1 - \omega\beta)\kappa}{\omega} + \left(\frac{1}{\omega}\right) [(1 - \omega)A\Psi_2^o + (1 - \omega\beta)(\iota_1 + \kappa\iota_2)\Theta_2^o].$$

Equilibrium inflation is given by

$$\pi_{t+1} = (1 - \omega)\bar{\pi}_{t+1}^* = (1 - \omega)(A\Omega_{t+1} + B\theta_t).$$

The impact of the policy instrument on inflation is $(1 - \omega)B$. Letting $E^j\Omega_\theta = \Psi_2^o$, $E^j Z_\theta = \Theta_2^o$, and $D = (1/\kappa)(\iota_1/\kappa + \iota_2)$ yields the expressions for δ_1 and δ_2 given in the text.

The optimal policy under discretion involves minimizing

$$\left(\frac{1}{2}\right) E_t^{cb} \left[\pi_{t+1}^2 + (1 + \tau)\lambda_x (x_{t+i} - e_{t+1}^u)^2 \right]$$

The first order condition for the central bank decision problem under discretion is

$$(1 - \omega)BE_t^{cb}\pi_{t+1} + (1 + \tau)\lambda_x \left(\theta_t + E_t^{cb}e_{t+1}^v - E_t^{cb}e_{t+1}^u \right) = 0.$$

Using the fact that

$$\begin{aligned} E_t^{cb}\pi_{t+1} &= (1 - \omega)AE_t^{cb}\Omega_{t+1} + (1 - \omega)B\theta_t \\ &= (1 - \omega)A\Gamma_{cb}\Omega_{cb,t+1} + (1 - \omega)B\theta_t \end{aligned}$$

(since $E_t^{cb}\Omega_{t+1} = E_t^{cb}Z_{t+1} = \Gamma_{cb}\Omega_{cb,t+1}$), the first order condition becomes

$$\begin{aligned} 0 &= (1 - \omega)B[(1 - \omega)A\Gamma_{cb}\Omega_{cb,t+1} + (1 - \omega)B\theta_t] \\ &\quad + (1 + \tau)\lambda_x \left(\theta_t + E_t^{cb}e_{t+1}^v - E_t^{cb}e_{t+1}^u \right) \end{aligned}$$

This in turn implies that

$$\begin{aligned} [(1 + \tau)\lambda_x + (1 - \omega)^2 B^2] \theta_t &= (1 + \tau)\lambda_x t_3 \Gamma_{cb} \Omega_{cb,t+1} \\ &\quad - (1 + \tau)\lambda_x t_2 \Gamma_{cb} \Omega_{cb,t+1} \\ &\quad - (1 - \omega)^2 B A \Gamma_{cb} \Omega_{cb,t+1}, \end{aligned}$$

so in terms of the individual coefficients, $\theta_t = \gamma_1 \mathbf{E}_t^{cb} e_{t+1}^u + \gamma_2 \mathbf{E}_t^{cb} e_{t+1}^s + \gamma_3 \mathbf{E}_t^{cb} e_{t+1}^v$ where

$$\gamma_1 = - \left[\frac{(1 - \omega)^2 B A_1}{(1 + \tau)\lambda_x + (1 - \omega)^2 B^2} \right] \quad (18)$$

$$\gamma_2 = - \left[\frac{(1 + \tau)\lambda_x + (1 - \omega)^2 B A_2}{(1 + \tau)\lambda_x + (1 - \omega)^2 B^2} \right] \quad (19)$$

$$\gamma_3 = \left[\frac{(1 + \tau)\lambda_x - (1 - \omega)^2 B A_3}{(1 + \tau)\lambda_x + (1 - \omega)^2 B^2} \right], \quad (20)$$

The following steps are involved in solving the model:

1. Start with guesses for γ_i .
2. Form Θ and Ψ .
3. Calculate A , and B .
4. Calculate new values for γ_i .
5. Iterate until the process converges.

Transparency: Under transparency, firms observe their own Ω_j as well as Ω_{cb} . Thus,

$$\mathbf{E}^j Z_{t+1} = \Theta^f \begin{bmatrix} \Omega_j \\ \Omega_{cb} \end{bmatrix} \text{ and } \mathbf{E}^j \Omega = \Psi^f \begin{bmatrix} \Omega_j \\ \Omega_{cb} \end{bmatrix}.$$

Firm j 's strategy takes the form

$$\pi_{j,t+1}^* = A \Omega_{j,t+1} + K \Omega_{cb,t+1} + B \theta_t$$

We can write a price-adjusting firm's price change as

$$\begin{aligned}
\pi_{j,t+1}^* &= (1 - \omega) \mathbb{E}_t^j \bar{\pi}_{t+1}^* + (1 - \omega\beta) \kappa \theta_t + (1 - \omega\beta) (\iota_1 + \kappa \iota_2) \mathbb{E}_t^j Z_{t+1} \\
&\quad + \left(\frac{\omega\beta}{1 - \omega} \right) \mathbb{E}_t^j \pi_{t+2} \\
&= (1 - \omega) \mathbb{E}_t^j \bar{\pi}_{t+1}^* + (1 - \omega\beta) \kappa \theta_t \\
&\quad + (1 - \omega\beta) (\iota_1 + \kappa \iota_2) \left(\Theta_1^f \Omega_{j,t+1} + \Theta_2^f \Omega_{cb,t+1} \right) + \left(\frac{\omega\beta}{1 - \omega} \right) \mathbb{E}_t^j \pi_{t+2}.
\end{aligned}$$

Following the same steps as employed to solve for the equilibrium under the opaque regime, one obtains

$$\begin{aligned}
A &= [(1 - \omega\beta) (\iota_1 + \kappa \iota_2)] \Theta_1^f \left[I_4 - (1 - \omega) \Psi_1^f \right]^{-1}, \\
K &= \left(\frac{1}{\omega} \right) \left[(1 - \omega) C \Psi_2^f + (1 - \omega\beta) (\iota_1 + \kappa \iota_2) \Theta_2^f \right] + \beta A \Theta_2^f,
\end{aligned}$$

and

$$B = \frac{(1 - \omega\beta) \kappa}{\omega}.$$

Equilibrium inflation is then

$$\pi_{t+1} = (1 - \omega) \bar{\pi}_{t+1}^* = (1 - \omega) (A \Omega_{t+1} + K \Omega_{cb,t+1} + B \theta_t).$$

Optimal policy under discretion involves minimizing

$$\left(\frac{1}{2} \right) \mathbb{E}_t^{cb} \left[\pi_{t+1}^2 + (1 + \tau) \lambda_x (x_{t+i} - e_{t+1}^u)^2 \right]$$

The first order condition for the central bank decision problem under discretion is

$$(1 - \omega) B \mathbb{E}_t^{cb} \pi_{t+1} + (1 + \tau) \lambda_x \left(\theta_t + \mathbb{E}_t^{cb} e_{t+1}^v - \mathbb{E}_t^{cb} e_{t+1}^u \right) = 0.$$

Since

$$\begin{aligned} \mathbf{E}_t^{cb} \pi_{t+1} &= (1 - \omega) A \mathbf{E}_t^{cb} \Omega_{t+1} + (1 - \omega) K \Omega_{cb,t+1} + (1 - \omega) B \theta_t \\ &= (1 - \omega) (A \Gamma_{cb} + K) \Omega_{cb,t+1} + (1 - \omega) B \theta_t, \end{aligned}$$

the first order condition becomes

$$\begin{aligned} 0 &= (1 - \omega) B [(1 - \omega) (A \Gamma_{cb} + K) \Omega_{cb,t+1} + (1 - \omega) B \theta_t] \\ &\quad - (1 - \omega) B \mathbf{E}_t^{cb} e_{t+1}^p + (1 + \tau) \lambda_x \left(\theta_t + \mathbf{E}_t^{cb} e_{t+1}^v - \mathbf{E}_t^{cb} e_{t+1}^u \right) \end{aligned}$$

This in turn implies that

$$\begin{aligned} [(1 + \tau) \lambda_x + (1 - \omega)^2 B^2] \theta_t &= (1 + \tau) \lambda_x t_3 \Gamma_{cb} \Omega_{cb,t+1} \\ &\quad - (1 + \tau) \lambda_x t_2 \Gamma_{cb} \Omega_{cb,t+1} \\ &\quad + (1 - \omega) B t_4 \Gamma_{cb} \Omega_{cb,t+1} \\ &\quad - (1 - \omega)^2 B (A + K \Gamma_{cb}^{-1}) \Gamma_{cb} \Omega_{cb,t+1}, \end{aligned}$$

so the individual coefficients in the policy rule are

$$\gamma_1 = - \left[\frac{(1 - \omega)^2 B (A_1 + K_1 / \gamma_{cb}^s)}{(1 + \tau) \lambda_x + (1 - \omega)^2 B^2} \right] \quad (21)$$

$$\gamma_2 = - \left[\frac{(1 + \tau) \lambda_x + (1 - \omega)^2 B (A_2 + K_2 / \gamma_{cb}^v)}{(1 + \tau) \lambda_x + (1 - \omega)^2 B^2} \right] \quad (22)$$

$$\gamma_3 = \left[\frac{(1 + \tau) \lambda_x - (1 - \omega)^2 B (A_3 + K_3 / \gamma_{cb}^u)}{(1 + \tau) \lambda_x + (1 - \omega)^2 B^2} \right], \quad (23)$$