# Why Adopt Transparency?
# The Publication of Central Bank Forecasts*

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**Abstract**

Recently, several central banks have abandoned the usual secrecy in monetary policy and become very transparent. This paper provides an explanation for this puzzling fact, focussing on the disclosure of central bank forecasts. It shows that transparency reduces the inflationary bias and gives the central bank greater flexibility to respond to shocks in the economy. Furthermore, it makes it easier for a central bank to build reputation. To achieve these benefits of transparency it is generally necessary to publish the conditional central bank forecasts for both inflation and output.

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# 1 Introduction

Central banks have long been associated with secrecy. Recently, however, several central banks, including the Bank of England, the Sveriges Riksbank and the Reserve Bank of New Zealand, have emphatically embraced transparency in several aspects, including the disclosure of internal forecasts. The move towards transparency coincided with other significant changes in their institutional or policy design, in an apparent attempt to break with relatively high inflation in the past. This is puzzling in light of the many theoretical arguments in favor of secrecy in monetary policy. One advantage of transparency is that it improves democratic accountability. However, it is not clear whether transparency has any economic benefits. This paper presents a formal argument how transparency could be beneficial for central banks and enhance their reputation. It focuses on a specific aspect of transparency, the publication of central bank forecasts.

Intuitively, the advantage of opaqueness about economic forecasts is that it limits loss of reputation for a weak central bank that prefers inflationary policy, because it obscures its true intent. However, lack of transparency could be harmful for the reputation of a strong central bank that is averse to inflation. For example, suppose the European Central Bank (ECB) reduces interest rates to stimulate the economy in response to signs of slacking demand in the euro zone. If the market is unsure of the true cause, it may interpret this as a sign of inflationary policy, destroying the ECB's incipient reputation. As a result, despite the usual secretiveness in monetary policy, transparency could be useful and improve the central bank's ability to gain reputation.

The model in this paper is in the tradition of the discretionary monetary policy games first described by Kydland and Prescott (1977) and later formalized by Barro and Gordon (1983). It is a simple two-period model with a Phillips relation and an implicit inflation target for the central bank. However, it distinguishes itself from most previous models in two respects. There is an explicit distinction between a regime of opaqueness and transparency, where the latter corresponds to the publication of conditional central bank forecasts for inflation and output. In addition, the model features a real interest rate transmission mechanism, so the nominal interest rate acts as both the policy instrument and a signal of the central bank's intentions.

The central bank's reputation, measured by the public's inflation expectations, plays a salient role. The reputation effects are based on rational updating by the public based on the central bank's actions, like Backus and Driffill (1985) and Barro

(1986). The public uses the interest rate to infer the central bank's inflation target. In the case of opaqueness, this signal is noisier and the market's inflation expectations are less responsive to the central bank's attempts to establish a reputation. When there is an inflationary bias, the central bank has an incentive to build reputation through higher interest rates. Since the market pays less attention to signals from opaque central banks, they invest less in reputation which leads to higher inflation. As a result, the public prefers transparency. Since transparency has the effect of revealing the central bank's type, weak central banks would rather have opaqueness.

When the central bank cares about the variability of output, transparency has another advantage. It gives the central bank greater flexibility to respond to shocks in the economy. The reason is that the central bank is better off when the public correctly anticipates its inflation target. So, a central bank operating under opaqueness limits its stabilization efforts to make the interest rate a better signal of its type. It is forced to engage in interest rate 'smoothing' to prevent undesired effects on people's inflation expectations. As a result, opaque central banks no longer fully offset demand shocks, adding to volatility in the economy.

The conclusions of previous research related to information disclosure, or transparency, in monetary policy are mixed. Most provide explanations for secrecy, but a few have recently started to advocate openness. However, transparency is a multifaceted concept, so I propose to distinguish the following five aspects: (i) openness about policy objectives, like explicit inflation targets, ('political transparency'), (ii) disclosure of economic data, models and central bank forecasts ('economic transparency'), (iii) information about the monetary policy strategy and internal policy deliberations, for instance through the release of minutes and voting records ('procedural transparency'), (iv) communication of policy decisions, like changes in the interest rate, and statements about likely future actions ('policy transparency'), and (v) openness about the implementation of policy decisions, market interventions and control errors ('operational transparency', or more generally, 'market transparency'). These aspects of transparency are illustrated in figure 1. Each of them gives rise to different motives and incentives for transparency.

This paper focuses on the effect of economic transparency. It assumes that there is some political uncertainty and the procedures can simply be described as discretionary monetary policy by a single central banker. In addition, there is complete policy and operational transparency as the policy instrument, the interest rate, is observed by the public and there are no control errors.

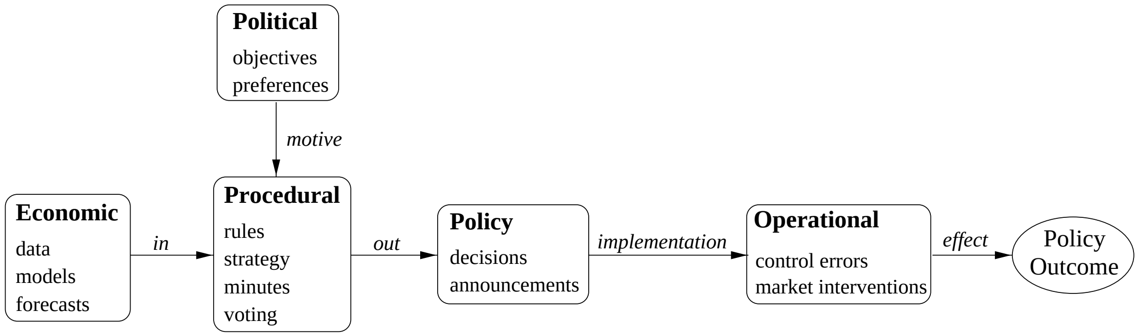


Figure 1: A conceptual framework for transparency.

Political transparency is analyzed by Nolan and Schaling (1996). They show that less uncertainty about the central bank's preferences can have a beneficial effect and reduce the inflation bias. Procedural and policy transparency, in particular the publication of minutes, voting records and policy directives, are discussed by Goodfriend (1986) , Buiter (1999) and Issing (1999). The disclosure of individual voting records is formally analyzed by Gersbach and Hahn (2000). There are several models on operational transparency. In a seminal paper, Cukierman and Meltzer (1986) provide a motivation for operational ambiguity and show that a central bank chooses to obfuscate shifts in its preferences through control errors. Using a variation on their model, Faust and Svensson (1998) make an important contribution by introducing a theoretical distinction between imperfect monetary control and (operational) transparency. Transparency is modeled as the extent to which a central bank discloses the monetary control errors which obscure its unobservable, shifting objectives, thus ultimately providing a measure of (ex post) political transparency. Through simulations, they find that increased transparency generally improves social welfare, but Faust and Svensson (1999) argue that minimum transparency is a likely outcome in practice. Thus, they are not able to explain the deliberate choice for greater openness by an increasing number of central banks. In a model similar to Faust and Svensson (1998) but with a New-Keynesian instead of the standard Phillips curve, Jensen (2000) finds that greater transparency could actually reduce social welfare, thus reviving the argument in favor of secrecy.

There are a few other papers on economic transparency. Gersbach (1998) and Cukierman (1999) are similar to this paper in the sense that the publication of central bank forecasts removes an information asymmetry about economic shocks. They consider a model with a monetary transmission mechanism and find that the disclosure of central bank forecasts reduces welfare. The reason is that the central bank loses the ability to stabilize output as supply shocks revealed by the forecasts are incorporated in inflation expectations. Cukierman (1999) also considers a model that features a real interest rate channel like this paper. Although secrecy is no longer needed to achieve output stabilization, the publication of central bank forecasts has a negative effect if social welfare is decreasing in the variability of interest rates. These conclusions against economic transparency, however, hinge on the assumption that there is perfect information about the central bank's preferences.

Instead, this paper assumes that there is some uncertainty about the intentions of the central bank, reflecting the credibility problem that is inherent to unobservable preferences, and it provides formal arguments in favor of economic transparency.

Tarkka and Mayes (1999) consider a completely different type of economic transparency by focusing on (mutual) uncertainty about expectations. In their model, the public is not only uncertain about the central bank's preferences, but also about the central bank's assessment of the public's inflation expectations. The publication of central bank forecasts removes these uncertainties and leads to greater predictability of monetary policy.

These papers, including the present one, all assume that central bank forecasts are truthful and that people are able to interpret them correctly. Winkler (1999) argues that effective communication is not trivial; he proposes to view transparency in terms of openness, clarity, honesty and common understanding. Garfinkel and Oh (1995) assume that central bank forecasts are unverifiable and show how a central bank could partially reveal its private information through noisy forecasts. However, forecasts could in principle be verified. After all, the data collection, modeling and forecasting activities performed by central bank staff members could be delegated to an independent agency that reports to both the public and monetary policymakers. When the forecasts used for decision making deviate from staff forecasts and reflect policymakers' judgement, an independent monitor could attend all policy meetings and release minutes with the arguments underlying the adjustments, thereby exposing fudging of the forecasts. Thus, credibility is not a fundamental issue for economic transparency. This is in contrast to political transparency, which concerns preferences that can never be directly observed.

The remainder of this paper is organized as follows. The model is presented in section 2. First, the transparency regime is analyzed in section 2.1. Subsequently, the consequences of opaqueness are derived in section 2.2 and compared to those of transparency in section 2.3. The subtle difference between the publication of conditional versus unconditional forecasts is explained in section 2.4. Extensions to the basic model are described in section 3. Asymmetric information about the structure of the economy is addressed in section 3.1. Section 3.2 provides an argument how market discipline could induce all central banks to be transparent when the regime is endogenous. The model is analyzed for a quadratic central bank objective function in section 3.3 and it is shown that opaqueness induces interest rate 'smoothing'. Incentives for secrecy that may explain why many central banks shun greater openness are discussed in section 3.4. Finally, section 5 concludes.

# 2 Model

The central banker is in office for two periods and maximizes the objective function

$$U = W_1 + \delta W_2, \tag{1}$$

where $\delta$ is the subjective discount factor ($0 < \delta < 1$), and

$$W_t = -\frac{1}{2}\alpha\left(\pi_t - \pi^*\right)^2 + \beta\left(y_t - \bar{y}\right), \tag{2}$$

where $\pi_t$ is inflation; $y_t$ is the level of aggregate real output; $\pi^*$ is the implicit inflation target, drawn from the (nondegenerate) normal distribution: $\pi^* \sim N\left(\tau, \sigma_\tau^2\right)$ with $\sigma_\tau^2 > 0$; $\bar{y}$ equals the natural rate of output; $\alpha$ is the importance of the inflation target ($\alpha > 0$); $\beta$ is the weight on output stimulation ($\beta > 0$); and the subscript $t$ denotes the time period, $t \in \{1, 2\}$. The economy is described by two equations. The demand for output is given by the IS relationship

$$y_t = \bar{y} - a\left(i_t - \pi_t^e - \bar{r}\right) + \varepsilon_t^d, \tag{3}$$

where $i_t$ is the nominal interest rate; $\pi_t^e$ denotes the market's inflation expectations; $\varepsilon_t^d$ is a white noise demand shock: $\varepsilon_t^d \sim N\left(0, \sigma_d^2\right)$; $\bar{r}$ is the long-run, ex ante real interest rate; and, $a$ is the sensitivity of output to the ex ante real interest rate ($a > 0$). The supply of output is given by the aggregate supply relation $y_t = \bar{y} + b\left(\pi_t - \pi_t^e\right) + \varepsilon_t^s$, or equivalently, the price adjustment equation

$$\pi_t = \pi_t^e + \frac{1}{b}\left(y_t - \bar{y}\right) - \frac{1}{b}\varepsilon_t^s, \tag{4}$$

where the inverse of $b$ is the extent to which excess output leads to demand-pull inflation ($b > 0$), and $\varepsilon_t^s$ is a white noise supply shock: $\varepsilon_t^s \sim N\left(0, \sigma_s^2\right)$. Assume that $\varepsilon_t^s$, $\varepsilon_t^d$ and $\pi^*$ are independent.

The monetary policy instrument is the nominal interest rate $i_t$, following the actual practice of most central banks. The public fixes its inflation expectations $\pi_t^e$, so the central bank is able to influence the ex ante real interest rate $i_t - \pi_t^e$. As a result, monetary policy has real effects. Inflation can be indirectly controlled through the output gap $y_t - \bar{y}$.

The timing is as follows. Before the first period, a regime of transparency ($T$) or opaqueness ($O$) is announced and the central bank commits to it. With transparency, the public has the same information about the shocks $\varepsilon_t^d$ and $\varepsilon_t^s$ as the central bank. Under opaqueness, the public remains ignorant about the central bank's forecasts of $\varepsilon_t^d$ and $\varepsilon_t^s$. Next, the inflation target $\pi^*$ is realized, but only known to the central bank. In addition, the public forms its inflation expectations $\pi_1^e$. In the first period, the central bank observes $\pi_1^e$ and the economic disturbances $\varepsilon_1^d$ and $\varepsilon_1^s$, and subsequently sets the nominal interest rate $i_1$. At the end of the first period, the public forms inflation expectations $\pi_2^e$, using the interest rate $i_1$ (and under transparency, $\varepsilon_1^d$ and $\varepsilon_1^s$) to update its prior on $\pi^*$. At the beginning of the second period, the levels of inflation $\pi_1$ and output $y_1$ are observed. The central bank perceives $\pi_2^e$ and the shocks $\varepsilon_2^d$ and $\varepsilon_2^s$, and determines the interest rate $i_2$. After this last period, inflation $\pi_2$ and output $y_2$ are known.

For simplicity, the model assumes that the central bank is able to forecast the economic shocks $\varepsilon_t^d$ and $\varepsilon_t^s$ perfectly. It is straightforward to extend the model to allow for forecast errors, but this does not affect any of the qualitative results.

Clearly, there is asymmetric information in the model. The public does not observe the central bank's inflation target $\pi^*$. In addition, it does not know the shocks $\varepsilon_t^d$ and $\varepsilon_t^s$ when it forms its inflation expectations $\pi_t^e$. But, under transparency, the public gets all the information that is available to the central bank when it sets the interest rate $i_t$, except for its implicit inflation target $\pi^*$. It is assumed that the public has rational expectations.

The public uses the interest rate $i_1$ to infer the central bank's inflation target. Due to the timing in the model, information on inflation $\pi_1$ and output $y_1$ is not available when the public forms its inflation expectations $\pi_2^e$. This reflects (implicit) lags in monetary policy; changes in the policy instrument only take effect after a substantial lag. Meanwhile, people adjust their expectations, which sets the stage for the next policy decision.

The problem can be solved by backwards induction. In period two, the central bank maximizes $W_2$ with respect to $i_2$ subject to (4) and (3), and given $\pi_2^e$, $\varepsilon_2^d$ and

$\varepsilon_2^s$. The first order condition implies

$$i_2 = \bar{r} + \pi_2^e - \frac{b}{a}\left(\pi^* + \frac{\beta b}{\alpha} - \pi_2^e\right) + \frac{1}{a}\left(\varepsilon_2^d - \varepsilon_2^s\right). \tag{5}$$

The nominal interest rate $i_2$ (and the ex ante real interest rate $i_2 - \pi_2^e$) is increasing in the market's inflation expectations $\pi_2^e$ and the demand shock $\varepsilon_2^d$, but decreasing in the supply shock $\varepsilon_2^s$. Substituting (5) into (3) and (4) yields

$$y_2 = \bar{y} + b\left(\pi^* + \frac{\beta b}{\alpha} - \pi_2^e\right) + \varepsilon_2^s \tag{6}$$

$$\pi_2 = \pi^* + \frac{\beta b}{\alpha}. \tag{7}$$

So, output $y_2$ is decreasing in inflation expectations $\pi_2^e$ and increasing in the output supply shock $\varepsilon_2^s$. The demand shock $\varepsilon_2^d$ is completely offset by monetary policy. Since the objective function is linear in output, the supply shock $\varepsilon_2^s$ does not affect the level of inflation $\pi_2$ and there is an inflationary bias ($\pi_2 > \pi^*$) of discretionary monetary policy. Substituting (7) and (6) into (2) gives

$$W_2 = \frac{\beta^2 b^2}{2\alpha} + \beta b\left(\pi^* - \pi_2^e\right) + \beta\varepsilon_2^s. \tag{8}$$

This shows that the central bank benefits from lower inflation expectations $\pi_2^e$. Thus, it has an incentive to improve its reputation through its actions in period one.

In the first period, the central bank maximizes the expected value of $U$ with respect to $i_1$ subject to (4) and (3), given $\pi_1^e$, $\varepsilon_1^d$ and $\varepsilon_1^s$, and taking into account the effect of $i_1$ on $W_2$ through $\pi_2^e$. Assume that people use the following rule to update their inflation expectations and form $\pi_2^e$ based on $i_1$:

$$\pi_2^e = u + v i_1. \tag{9}$$

It will be shown below that this rule is consistent with a rational expectations equilibrium. Then, the first order condition with respect to $i_1$ implies

$$i_1 = \bar{r} + \pi_1^e - \frac{b}{a}\left(\pi^* + \frac{\beta b}{\alpha} - \pi_1^e\right) + \frac{1}{a}\left(\varepsilon_1^d - \varepsilon_1^s\right) - \frac{\delta\beta b^3}{\alpha a^2}v. \tag{10}$$

The expression for the nominal interest rate is similar to the one for the second period, except for the last term on the right-hand side. This term reflects the reputation effect of the interest rate on inflation expectations in the next period.

To show that the updating equation for inflation expectations (9) is rational, and to compute the values of $u$ and $v$, it is necessary to distinguish between the regimes of transparency and opaqueness. In principle, economic transparency obtains when the public has access to the same economic information that is available to the central bank when it sets the interest rate $i_t$, with the exception of the level of the unobservable inflation target $\pi^*$. Thus, people are able to infer the central bank's type from its actions. The role of conditional central bank forecasts in economic transparency is to provide information on the economic disturbances $\varepsilon_t^d$ and $\varepsilon_t^s$ that affect the central bank's behavior.

More precisely, let $i^C$ denote the interest rate that is used for the conditional forecast. Then the public can use the conditional forecast for output $y_t^C$, its inflation expectations $\pi_t^e$ and (3) to deduce the demand shock $\varepsilon_t^d$. Similarly, the supply shock $\varepsilon_t^s$ follows from the conditional forecast for inflation $\pi_t^C$, $y_t^C$, $\pi_t^e$ and (4). Note that it is generally necessary to disclose central bank forecasts for both output and inflation to achieve economic transparency. Perhaps surprisingly, the publication of unconditional forecasts does not necessarily have the same effect as that of conditional forecasts; this will be discussed in section 2.4. So, for the remainder of the paper, (economic) transparency corresponds to the publication of conditional central bank forecasts for inflation and output.

Formally, the information set available to the public when it forms its inflation expectations $\pi_1^e$ equals $\mathcal{T} \equiv \{T, \Omega\}$ under transparency and $\mathcal{O} \equiv \{O, \Omega\}$ under opaqueness, where $\Omega \equiv \{\alpha, \beta, a, b, \bar{y}, \bar{r}, \tau, \sigma_\tau^2, \sigma_d^2, \sigma_s^2\}$ summarizes the structure and parameters of the model. When the public forms its inflation expectations $\pi_2^e$, the available information set equals $\{i_1, \varepsilon_1^d, \varepsilon_1^s, \mathcal{T}\}$ under transparency and $\{i_1, \mathcal{O}\}$ under opaqueness. For notational convenience, denote the information sets at the end of period one excluding the interest rate by $\mathcal{T}_1 \equiv \{\varepsilon_1^d, \varepsilon_1^s, \mathcal{T}\}$ and $\mathcal{O}_1 \equiv \mathcal{O}$. Comparing transparency with opaqueness, the only difference is that in the case of transparency the public observes the economic disturbances to which the central bank reacts.

In both regimes $R \in \{T, O\}$, rational expectations imply $(\pi_2^e)^R = \mathrm{E}[\pi_2 | i_1, \mathcal{R}_1]$, where $\mathcal{R}_1 \in \{\mathcal{T}_1, \mathcal{O}_1\}$. Using (7) and the fact that $i_1$ in (10) is normally distributed because it depends on $\pi^*$ (and under opaqueness, on the unobserved $\varepsilon_1^d$ and $\varepsilon_1^s$) gives

$$(\pi_2^e)^R = \mathrm{E}[\pi^* | \mathcal{R}_1] + \frac{\mathrm{Cov}\{\pi^*, i_1 | \mathcal{R}_1\}}{\mathrm{Var}[i_1 | \mathcal{R}_1]} \left(i_1^R - \mathrm{E}[i_1 | \mathcal{R}_1]\right) + \frac{\beta b}{\alpha}. \tag{11}$$

The outcome under transparency will be derived first.

## 2.1 Transparency

Under a regime of transparency, indicated by superscript $T$, the public knows $i_1$, $\varepsilon_1^d$ and $\varepsilon_1^s$ when it forms its inflation expectations $\pi_2^e$. It can therefore infer the inflation target $\pi^*$ (ex post) from (10). So, using rational expectations and (7),

$$\left(\pi_2^e\right)^T = \pi^* + \frac{\beta b}{\alpha}. \tag{12}$$

Substituting (12) into (5), (6) and (7) gives the interest rate, output and inflation in the second period:

$$\begin{aligned} i_2^T &= \bar{r} + \pi^* + \frac{\beta b}{\alpha} + \frac{1}{a}\left(\varepsilon_2^d - \varepsilon_2^s\right) && (13) \\ y_2^T &= \bar{y} + \varepsilon_2^s && (14) \\ \pi_2^T &= \pi^* + \frac{\beta b}{\alpha}. && (15) \end{aligned}$$

To get the outcomes in the first period, the reputation coefficient $v$ must be computed. Under transparency, solving (10) for $\pi^*$, substituting into (12) and matching coefficients with (9) yields[1,2]

$$v^T = -\frac{a}{b}. \tag{16}$$

Thus, it is established that this is indeed a rational expectations equilibrium.[3] The negative value of $v^T$ indicates that the central bank can invest in reputation by increasing $i_1$ to reduce $\pi_2^e$. The first-period outcomes are obtained by substituting $v^T$ into (10), using (3) and (4), and imposing rational expectations, $\left(\pi_1^e\right)^T = \mathrm{E}\left[\pi_1|\mathcal{T}\right]$. This produces

$$\begin{aligned} i_1^T &= \bar{r} + \mathrm{E}\left[\pi^*|\mathcal{T}\right] - \frac{b}{a}\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{T}\right]\right) + (1-\delta)\frac{\beta b}{\alpha} + \frac{1}{a}\left(\varepsilon_1^d - \varepsilon_1^s\right) && (17) \\ y_1^T &= \bar{y} + b\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{T}\right]\right) + \varepsilon_1^s && (18) \\ \pi_1^T &= \pi^* + (1-\delta)\frac{\beta b}{\alpha}. && (19) \end{aligned}$$

The first period is different from the second period for two reasons: There is a reputation effect in period one, and transparency yields $\mathrm{E}\left[\pi^*|\mathcal{T}_1\right] = \pi^*$ in period two.

[1] For completeness, $u^T = \frac{a+b}{b}\left(\pi_1^e\right)^T + \frac{a}{b}\bar{r} + \frac{\delta\beta b}{\alpha} + \frac{1}{b}\left(\varepsilon_1^d - \varepsilon_1^s\right)$.

[2] Equation (12) may give the impression that $v^T = 0$ is also a solution. However, $\pi^*$ is not directly observable; it can only be inferred indirectly from $i_1$, $\varepsilon_1^d$ and $\varepsilon_1^s$. Alternatively, one can use (10) and (11) to compute $v^T$.

[3] Multiple rational expectations equilibria may exist. However, this is the only one that satisfies the McCallum (1983) criterion to employ a minimal set of state variables in the updating equation.

Regarding the latter, the uncertainty about the central bank's inflation target makes the level of output in the first period dependent on the central bank's type. A higher inflation target $\pi^*$ reduces the interest rate and thereby increases output in period one.

The effect of reputation is to decrease both the nominal interest rate and inflation in period one. The effect on the interest rate may seem counter-intuitive. However, for a given level of inflation expectations $\pi_1^e$, the central bank chooses a higher (nominal and ex ante real) interest rate, and thereby lower output and lower inflation, in period one to reduce inflation expectations in period two. The lower level of inflation in period one is anticipated and reduces inflation expectations $\pi_1^e$. This decreases the (nominal and ex ante real) interest rate. Rational expectations ensure that the negative effect on output in period one is completely offset, so there is no net effect on the ex ante real interest rate. As a result, lower inflation expectations give rise to a lower nominal interest rate in period one. The effect of reputation on inflation is more familiar. Although the ex ante real interest rate is the same, the lower level of inflation expectations $\pi_1^e$ reduces the level of inflation, at least partly eliminating the inflationary bias of discretionary monetary policy: $\pi^* \leq \pi_1^T < \pi_2^T$.

Substituting (12) into (8), and using (19) and (18), the expected payoff to the central bank in the case of transparency equals

$$\mathrm{E}\left[U|\pi^*, \mathcal{T}\right] = -\left(1-\delta+\delta^2\right)\frac{\beta^2 b^2}{2\alpha} + \beta b\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{T}\right]\right). \tag{20}$$

It shows that the central bank's expected payoff is decreasing in the inflation target expected by the public, $\mathrm{E}\left[\pi^*|\mathcal{T}\right]$.

## 2.2 Opaqueness

To appreciate the benefits of transparency it is important to look at the case of opaqueness as well. Under a regime of opaqueness, indicated by superscript $O$, using (10) and matching coefficients between (11) and (9) yields[4]

$$v^O = -\frac{b^2\sigma_\tau^2}{b^2\sigma_\tau^2 + \sigma_d^2 + \sigma_s^2}\frac{a}{b} = -\lambda\frac{a}{b}, \tag{21}$$

where $\lambda \equiv \frac{b^2\sigma_\tau^2}{b^2\sigma_\tau^2+\sigma_d^2+\sigma_s^2}$ can be interpreted as a signal-to-noise ratio. Note that $0 < \lambda < 1$, so compared with transparency, $\left|v^O\right| < \left|v^T\right|$. A lower interest rate has a smaller

[4]For completeness, $u^O = \lambda\left(\frac{a+b}{b}\left(\pi_1^e\right)^O + \frac{a}{b}\bar{r} + \lambda\delta\frac{\beta b}{\alpha}\right) + (1-\lambda)\left(\mathrm{E}\left[\pi^*|\mathcal{O}\right] + \frac{\beta b}{\alpha}\right)$.

effect on $\pi_2^e$ under opaqueness because people cannot tell whether it reflects a weak central bank (high $\pi^*$), or either a negative demand shock (low $\varepsilon_1^d$) or positive supply shock (high $\varepsilon_1^s$). The signal $i_1$ is noisier so the optimal response to it is smaller. In the limiting case $(\sigma_d^2 + \sigma_s^2) \to 0$, it follows that $\lambda \to 1$; the absence of uncertainty about the disturbances $\varepsilon_1^d$ and $\varepsilon_1^s$ in period two gives the same outcome for $v$ as under transparency.[5]

Using (10), (11) amounts to

$$(\pi_2^e)^O = \pi^* + \frac{\beta b}{\alpha} - (1-\lambda)\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{O}\right]\right) - \lambda \frac{1}{b}\left(\varepsilon_1^d - \varepsilon_1^s\right). \tag{22}$$

This shows that a positive net demand shock has a beneficial effect on reputation under opaqueness, because rational agents partly attribute the rise in interest rates to a low inflation target $\pi^*$ and reduce their inflation expectations correspondingly. In addition, the central bank enjoys lower inflation expectations $\pi_2^e$ when its inflation target is higher than expected, because the public believes that the lower level of interest rates is due to negative net demand shocks instead.

The first-period outcomes are obtained by substituting $v^O$ into (10), using (3) and (4), and imposing rational expectations, $(\pi_1^e)^O = \mathrm{E}\left[\pi_1|\mathcal{O}\right]$. This produces

$$i_1^O = \bar{r} + \mathrm{E}\left[\pi^*|\mathcal{O}\right] - \frac{b}{a}\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{O}\right]\right) + (1-\lambda\delta)\frac{\beta b}{\alpha} + \frac{1}{a}\left(\varepsilon_1^d - \varepsilon_1^s\right) \tag{23}$$

$$y_1^O = \bar{y} + b\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{O}\right]\right) + \varepsilon_1^s \tag{24}$$

$$\pi_1^O = \pi^* + (1-\lambda\delta)\frac{\beta b}{\alpha}. \tag{25}$$

These expressions are similar to those under transparency, (17), (18) and (19), except that under opaqueness the discount factor is effectively reduced from $\delta$ to $\lambda\delta$. To facilitate comparison, use the fact that $\mathrm{E}\left[\pi^*|\mathcal{O}\right] = \mathrm{E}\left[\pi^*|\mathcal{T}\right]$ because the regime is exogenous and independent of the central bank's type. Then, the nominal interest rate in period one is higher than under transparency ($i_1^O > i_1^T$), but monetary policy is more expansionary in the sense that it leads to higher inflation ($\pi_1^O > \pi_1^T$). These seemingly contradictory results are due to the higher level of inflation expectations $\pi_1^e$ under opaqueness. For given initial inflation expectations, $(\pi_1^e)^T = (\pi_1^e)^O$, the nominal (and ex ante real) interest rate is lower ($i_1^O < i_1^T$) and output is higher ($y_1^O > y_1^T$) under opaqueness. The reason is that higher interest rates do not reduce inflation

[5]Notice that $\lambda \to 1$ is not sufficient to get the same expression for $u^O$, and thereby $(\pi_2^e)^O$, as under transparency. This is due to a difference in the information sets at the end of the first period: $\mathrm{E}\left[\varepsilon_1^d|\mathcal{O}_1\right] = \mathrm{E}\left[\varepsilon_1^s|\mathcal{O}_1\right] = 0$, whereas $\mathrm{E}\left[\varepsilon_1^d|\mathcal{T}_1\right] = \varepsilon_1^d$ and $\mathrm{E}\left[\varepsilon_1^s|\mathcal{T}_1\right] = \varepsilon_1^s$.

expectations $\pi_2^e$ as much under opaqueness because the signal is considered noisier. So, the reputation effect $v$ of higher interest rates is diminished under opaqueness, giving rise to more expansionary monetary policy. People anticipate the higher level of inflation so that $(\pi_1^e)^O > (\pi_1^e)^T$. Thus, the central bank sets a higher level of the first-period (nominal and ex ante real) interest rate under opaqueness to contain inflation. Rational expectations ensure that the levels of output are constant across the (random) regimes, so the ex ante real interest rates are the same in both cases. Consequently, opaqueness brings about a higher first-period nominal interest rate. Although the ex ante real interest rate is the same in both cases, the higher level of inflation expectations exerts its influence. As a result, opaqueness leads to higher first-period inflation than transparency: $\pi^* < \pi_1^T < \pi_1^O < \pi_2^T = \pi_2^O$.[6]

The analogy with the reputation argument in section 2.1 is striking. It appears that the adoption of transparency and investment in reputation have a similar effect. Both reduce the inflation bias. Moreover, transparency makes investment in reputation more fruitful. It allows the public to identify the central bank's efforts to stabilize economic shocks, which produces a more accurate signal of the central bank's type. Thus, transparency makes it more enticing for the central bank to invest in reputation, resulting in lower inflation than under opaqueness.

The size of the inflation bias under opaqueness is decreasing in the signal-to-noise ratio $\lambda$. A reduction in the variance of economic shocks, $\sigma_d^2$ and $\sigma_s^2$, increases $\lambda$ by diminishing the severity of opaqueness, so it makes the inflation bias smaller. However, a reduction in the ex ante uncertainty about the central bank's inflation target $\sigma_\tau^2$ decreases the signal-to-noise ratio $\lambda$ and thereby increases the inflation bias. So, greater political transparency actually makes a situation of economic opaqueness worse. Intuitively, when the public faces less uncertainty about the central bank's type, it pays less attention to the interest rate, which reduces the payoff of investing in reputation and leads to higher inflation.[7]

[6]The result that opaqueness leads to higher inflation is very robust. A sufficient condition is that $v^T < v^O$ and it is independent of the way inflation expectations are formed.

[7]This result is in sharp contrast to Nolan and Schaling (1996) who find that greater preference transparency reduces the inflation bias in a static model with an objective function that is quadratic in output. However, it should be mentioned that their result is specific to the kind of preference uncertainty. They consider uncertainty about the inflation stabilization parameter ($\alpha$), which has a convex effect on inflation, so that greater transparency reduces inflation expectations and thereby the inflation bias. Less uncertainty about the output stabilization parameter ($\beta$), which has a concave effect on inflation, actually increases the inflation bias. Uncertainty about the inflation target ($\pi^*$), which enters additively in inflation, has no effect in a static context.

To complete the analysis of opaqueness, substitute (22) into (8), and use (25) and (24) to get the expected payoff for the central bank

$$\mathrm{E}\left[U|\pi^*,\mathcal{O}\right] = -\left(1-(2\lambda-1)\,\delta+\lambda^2\delta^2\right)\frac{\beta^2 b^2}{2\alpha}+\left(1+(1-\lambda)\,\delta\right)\beta b\left(\pi^*-\mathrm{E}\left[\pi^*|\mathcal{O}\right]\right). \tag{26}$$

Again, the expected payoff is decreasing in the expected inflation target $\mathrm{E}\left[\pi^*|\mathcal{O}\right]$.

## 2.3 Comparison

The analysis of opacity above shows that inflation is lower under transparency ($\pi_1^T < \pi_1^O$) but independent of economic shocks in both cases, and that the expected value of output conditional on the regime is equal ($\mathrm{E}\left[y_1^T|\mathcal{T}\right] = \mathrm{E}\left[y_1^O|\mathcal{O}\right]$). This suggests that the public would prefer transparency. For simplicity, assume that society shares the central bank's objective function. This means that there is no principal-agent problem and that (2) can be interpreted as a social welfare function. Using (20) and (26), the expected payoffs for the public, which is ignorant of the central bank's inflation target $\pi^*$, equal

$$\begin{aligned}\mathrm{E}\left[U|\mathcal{T}\right] &= -\left(1-\delta+\delta^2\right)\frac{\beta^2 b^2}{2\alpha}\\ \mathrm{E}\left[U|\mathcal{O}\right] &= -\left(1-(2\lambda-1)\,\delta+\lambda^2\delta^2\right)\frac{\beta^2 b^2}{2\alpha}.\end{aligned}$$

It follows that $\mathrm{E}\left[U|\mathcal{T}\right] > \mathrm{E}\left[U|\mathcal{O}\right]$ if and only if $\left(2-(1+\lambda)\,\delta\right)(1-\lambda)\,\delta > 0$. So, indeed, the public always prefers transparency.[8]

However, central banks do not necessarily agree with the desirability of transparency. Because the regime is exogenous so that $\mathrm{E}\left[\pi^*|\mathcal{T}\right] = \mathrm{E}\left[\pi^*|\mathcal{O}\right] = \tau$, (20) and (26) imply that

$$\mathrm{E}\left[U|\pi^*,\mathcal{T}\right] > \mathrm{E}\left[U|\pi^*,\mathcal{O}\right] \Leftrightarrow \left(2-(1+\lambda)\,\delta\right)\frac{\beta b}{2\alpha} > \pi^*-\tau.$$

So, strong central banks with low inflation targets would be happy to publish their forecasts, whereas weak central banks with sufficiently high inflation targets would rather be enveloped by secrecy. This suggests that if central banks could choose the regime themselves, strong central banks would have a greater incentive to adopt openness. Endogeneity of the regime will be further explored in section 3.2.

[8] This conclusion even holds for the more general social welfare function $W_t^S = -\frac{1}{2}\alpha^S\left(\pi_t-\tau\right)^2 - \frac{1}{2}\beta^S\left(y_t-\bar{y}\right)$ and $U^S = W_1^S + \delta^S W_2^S$.

## 2.4 Conditional versus Unconditional Forecasts

So far, the analysis has focused on the publication of conditional forecasts, which are based on the assumption of constant interest rates. However, the disclosure of unconditional forecasts, which incorporate changes in the policy instrument, need not have the same effect. In fact, releasing the unconditional forecast for inflation leads to the worst possible outcome.

To understand this it is important to realize that the release of conditional central bank forecasts both reduces the uncertainty about the central bank's inflation target $\pi^*$, and gives the central bank better incentives to invest in reputation since market expectations are more sensitive to the interest rate. The publication of the unconditional inflation forecast also reduces uncertainty because it directly reveals the inflation target. But, the big difference is that the public does not need the interest rate $i_1$ to infer $\pi^*$. This means that the behavioral incentive is absent. As a result, there is no reduction in the inflation bias.

Formally, let superscript $U$ denote the disclosure of the unconditional inflation forecast. Then, (10), (3) and (4) give the unconditional central bank forecast for inflation,

$$\pi_1^U = \pi^* + \left(1 + \frac{b}{a}\delta v^U\right)\frac{\beta b}{\alpha}.$$

Since $\mathrm{E}\left[\pi^* | \pi_1^U, \Omega\right] = \pi^*$, it follows that $v^U = 0$ so that $\pi_1^U = \pi^* + \frac{\beta b}{\alpha}$.

The same outcome can be obtained when the central bank releases unconditional forecasts for both inflation and output. However, the public could also use the interest rate $i_1$ to infer $\varepsilon_1^d$ and $\varepsilon_1^s$ from the forecasts, and use this to deduce $\pi^*$ from the interest rate. In that case, the incentive effect is present and reduces the inflation bias. In principle, the public is indifferent between either method. But when there is a (tiny) cost associated with the processing of a forecast, the public simply relies on the unconditional inflation forecast and the full inflation bias arises.

So, the publication of conditional or unconditional central bank forecasts both lead to ex post political transparency as the market is able to infer $\pi^*$. But, the incentive effect that reduces the inflation bias need not be present in the case of unconditional forecasts as the public may be tempted to ignore the central bank's actions and focus on the unconditional inflation forecast.[9]

[9] Tarkka and Mayes (1999) favor the publication of unconditional forecasts. However, in their model there is no inflation bias, so the beneficial incentive effect of conditional forecasts is absent.

# 3 Extensions

In this section several extensions to the basic model are analyzed. First, the results on economic transparency are extended to include asymmetric information on the structure of the economy. Second, a simple model is considered in which the transparency regime is endogenous. Third, an alternative central bank objective function that is quadratic in both inflation and output will be examined. And fourth, several potentially important forces against transparency are discussed.

## 3.1 Model Uncertainty

In the basic model in section 2, it is assumed that there may be asymmetric information about demand and supply shocks that affect the economy, but that there is perfect information about the structure of the economy. In practice, economic transparency may also fail because the public is uncertain about the model of the economy that the central bank adopts. Such model uncertainty has two implications.

First, it complicates the interpretation of central bank forecasts. For instance, if the public does not know the value of the natural rate of output $\bar{y}$, it is unable to infer the economic shocks, $\varepsilon_t^d$ and $\varepsilon_t^s$, from the conditional forecasts of output and inflation. So, the publication of these central bank forecasts is no longer sufficient to achieve economic transparency. The central bank also needs to convey the level of the natural rate of output that is implicit in the forecasts.

But even if there is no asymmetric information about economic shocks, uncertainty about the central bank's model of the economy can have an impact. Suppose the public is not sure about the level of the long-run real interest rate $\bar{r}$. This makes the nominal interest rate a noisier signal of the central bank's inflation target. As a result, inflation expectations become less sensitive to the nominal interest rate which loosens the discipline imposed on the central bank to reduce the inflation bias.[10]

This suggests that greater economic transparency, in terms of both economic shocks and the economic model, is generally beneficial.

[10]More precisely, assume that $\bar{r} \sim N\left(\rho, \sigma_\rho^2\right)$, independently of $\pi^*$, $\varepsilon_t^s$ and $\varepsilon_t^d$. Then, for the linear objective function (2), $v^O = -\lambda \frac{a}{b}$, where the signal-to-noise ratio becomes $\lambda = \frac{b^2\sigma_\tau^2}{a^2\sigma_\rho^2+b^2\sigma_\tau^2+\sigma_d^2+\sigma_s^2}$. Greater uncertainty about the long-run real interest rate, $\sigma_\rho^2$, reduces $\lambda$ which increases inflation using (25).

## 3.2 Endogenous Regime

So far, the analysis was for an exogenous regime of transparency or opaqueness. In practice, however, the regime need not be imposed by the public but could be chosen by the central bank itself. Section 2.3 indicates that the regime preferred by the central bank depends on its inflation target $\pi^*$. In particular, strong central banks favor transparency, whereas weaker types like opaqueness. But if central banks choose their own transparency regime, the market realizes this and adjusts its beliefs accordingly, so that typically $\mathrm{E}[\pi^*|\mathcal{T}] < \mathrm{E}[\pi^*|\mathcal{O}]$. Thus, one can distinguish an additional reputation effect. The market updates its expectations about the unobservable inflation target after the central bank's choice of regime. This penalizes opaque central banks, which therefore have a greater incentive to be transparent. In fact, the negative feedback from the market in response to secrecy could induce all central banks to become transparent.

To analyze the reputation effects associated with the choice of regime, consider the following simplified model. First, the inflation target $\pi^*$ is drawn from a nondegenerate normal distribution, $\pi^* \sim N(\tau, \sigma_\tau^2)$ where $\sigma_\tau^2 > 0$; the realization of $\pi^*$ is only observed by the central bank, but its distribution is common knowledge. Next, the central bank announces a regime of transparency or opaqueness. Then, the public forms its expectations $\mathrm{E}[\pi^*|\mathcal{R}]$ depending on the regime $R \in \{T, O\}$. This in turn affects the central bank's expected payoff, which equals

$$\mathrm{E}[U|\pi^*, \mathcal{R}] = A^R(\pi^* - \mathrm{E}[\pi^*|\mathcal{R}]) + B^R, \tag{27}$$

where $0 < A^T < A^O$ and $B^O \leq B^T$. When the inflation target is higher than expected, the central bank faces a more favorable trade-off between output and inflation which increases its expected payoff. In the case of opacity, the deviation between actual and expected inflation target persists longer so that the effect on the central bank's expected payoff is larger than under transparency. In addition, (27) reflects the assumption that on average, the public is not worse off under transparency ($\mathrm{E}[U|\mathcal{O}] \leq \mathrm{E}[U|\mathcal{T}]$). These properties are consistent with the expected payoffs (20) and (26) in the exogenous regime model in section 2.[11]

The central bank chooses the regime that produces the highest expected payoff subject to the equilibrium condition that the market's expectations $\mathrm{E}[\pi^*|\mathcal{R}]$ are con-

[11]It should be noted that the model in section 2 becomes nonlinear under opaqueness if not all central bank types choose the same regime. In the case of an endogenous regime, $\partial\,\mathrm{E}[\pi^*|i,\mathcal{O}]/\partial i = (1 - \upsilon(i))\frac{\mathrm{Cov}\{\pi^*, i|\mathcal{O}\}}{\mathrm{Var}[i|\mathcal{O}]}$ where $0 < \upsilon(i) < 1$ and $\upsilon'(i) > 0$, so the expected central bank payoff in (27) is consistent with a linearized version of the basic model.

sistent with the central banks' choices that follow from those expectations. When the market's beliefs off the equilibrium path are also restricted to be rational, transparency is the unique, pure-strategy perfect equilibrium.[12] The proof of this result appears in appendix A.1.

Intuitively, weak central banks with high inflation targets are inclined to select opaqueness, because it obscures their true type. But, the market realizes that opaqueness signals high inflation targets, which increases $\mathrm{E}[\pi^*|\mathcal{O}]$. This loss of reputation is costly, and fewer central banks will prefer opaqueness. As it turns out, rational market expectations in combination with a normal prior distribution of $\pi^*$ make transparency the optimal choice for every type.

This simple model suggests that if central banks choose the regime themselves, market discipline suffices to make every bank transparent. However, this prediction is at odds with the facts; not all central banks are transparent. This could be due to at least three reasons. First, the maintained assumption of rationality of market expectations, both on and off the equilibrium path, may be too strong. If the public applies Bayesian updating to form its expectations, one would expect that a given situation of secrecy unravels to the transparency equilibrium only gradually. Second, the model may be incorrect; in particular, the choice of a central bank objective function that is linear in output may be too simplistic. To investigate this possibility, a quadratic objective function is analyzed in the next section. Third, central bankers may have other motives for secrecy. Political, financial and bureaucratic incentives against openness are discussed in section 3.4.

## 3.3 Quadratic Central Bank Objective

One may wonder to what extent the benefits of economic transparency are specific to the central bank's objectives. This section analyzes the model in section 2, but for a central bank objective function that is quadratic:

$$W_t = -\frac{1}{2}\alpha\left(\pi_t - \pi^*\right)^2 - \frac{1}{2}\beta\left(y_t - \bar{y}\right)^2. \tag{28}$$

The outcomes for this specification are derived in appendix A.2. This quadratic objective function completely eliminates the reputation effect present under the linear objective (2), because there is no inflation bias. So, it is no longer the case that

[12] Without this restriction, no pure-strategy perfect equilibrium exists. Mixed equilibria, in which some central bank types randomize between transparency and opaqueness, are possible but not considered here.

transparency brings lower (first-period) inflation. In fact, with the quadratic objective, the expected value of inflation conditional on the regime is constant over time and across regimes: $\mathrm{E}[\pi_t|\mathcal{R}] = \mathrm{E}[\pi^*|\mathcal{R}]$ for $t \in \{1,2\}$ and $\mathcal{R} \in \{\mathcal{T}, \mathcal{O}\}$. And so is the conditional expected value of output.[13]

Yet, economic transparency still makes a difference and gives rise to significant benefits. The reason is that transparency induces more accurate expectations of the central bank's inflation target and that more accurate inflation expectations lead to a higher expected payoff.[14] As before, the magnitude of the effect of the interest rate $i_1$ on inflation expectations $\pi_2^e$ is smaller under opaqueness $\left(\left|v^T\right| > \left|v^O\right|\right)$, because the signal is noisier. Under transparency, the central bank's inflation target can already be perfectly inferred from its actions. But under opaqueness, the central bank has an incentive to provide a more accurate signal of its type. In its attempt to make the interest rate a better signal of its inflation target, it restrains the stabilization of economic shocks. As a result, the effect of demand shocks on output is no longer completely offset and the response of inflation to supply shocks is larger. More precisely,[15]

$$\begin{aligned} y_1^O &= \bar{y} + \mu \frac{\alpha a b}{\gamma} \left(1 - \frac{\delta \beta b^3}{\gamma} v^O\right) (\pi^* - \mathrm{E}[\pi^*|\mathcal{O}]) + (1-\mu)\,\varepsilon_1^d + \mu \frac{\alpha a}{\gamma} \varepsilon_1^s \\ \pi_1^O &= \mathrm{E}[\pi^*|\mathcal{O}] + \mu \frac{\alpha a}{\gamma} \left(1 - \frac{\delta \beta b^3}{\gamma} v^O\right) (\pi^* - \mathrm{E}[\pi^*|\mathcal{O}]) \\ &\quad + \frac{1}{b}(1-\mu)\,\varepsilon_1^d - \left(1 - \mu \frac{\alpha a}{\gamma}\right) \frac{1}{b} \varepsilon_1^s, \end{aligned}$$

where $\gamma \equiv a(\alpha + \beta b^2)$ and $\mu \equiv \gamma^2 / \left(\gamma^2 + \delta \alpha \beta b^4 \left(v^O\right)^2\right)$, so $0 < \mu < 1$. For comparison, in a static context (and under transparency), demand shocks affect neither output nor inflation, and the coefficients for the effect of supply shocks on output and inflation equal $\frac{\alpha a}{\gamma}$ and $-\left(1 - \frac{\alpha a}{\gamma}\right)\frac{1}{b}$, respectively.[16] But, in the case of opaqueness, the central bank reduces the adjustment of the interest rate to prevent distorting people's expectations. So, it lets demand shocks seep into inflation. Similarly, its interest rate response to supply shocks is smaller, which leads to a diminished effect of supply shocks on output, but a larger effect on inflation. Thus, a central bank under opaqueness no longer fully offsets demand shocks and no longer vigorously counters

[13] For the commonly used objective function $W_t = -\frac{1}{2}\alpha(\pi_t - \pi^*)^2 - \frac{1}{2}\beta(y_t - y^*)^2$, where $y^* > \bar{y}$, however, the reputation effects still apply and transparency reduces the inflation bias.

[14] For the latter, see (31) in appendix A.2.

[15] These equations correspond to (41) and (42), and are derived in appendix A.2.

[16] This follows from (29) and (30), and for the case of transparency (36) and (37).

supply shocks, even when it perfectly anticipates those shocks. Instead, it engages in interest rate 'smoothing'. For a given inflation target $\pi^*$, the variability of the interest rate is smaller under opaqueness: $\mathrm{Var}\left[i_1^O|\pi^*\right] < \mathrm{Var}\left[i_1^T|\pi^*\right]$. But under transparency, central banks need not worry about the repercussions their stabilization efforts have on inflation expectations, because they know that people are able to interpret their actions correctly. Thus, transparency has the advantage that it gives central banks greater flexibility to respond to economic shocks.

Given the benefits of transparency, in terms of less uncertainty about the inflation target and less volatility due to economic disturbances, it is not surprising that the public prefers transparency when the regime is exogenous and the public shares the central bank's objective function. However, central banks need not agree with the public when the regime is endogenous. The reason is that the central bank's expected payoff is concave in $\pi^*$ and reaches a maximum at $\pi^* = \mathrm{E}[\pi^*|\mathcal{R}]$, where $\mathcal{R} \in \{\mathcal{T}, \mathcal{O}\}$.[17] For a given level of expectations, $\mathrm{E}[\pi^*|\mathcal{T}] = \mathrm{E}[\pi^*|\mathcal{O}]$, the expected payoff under opaqueness is strictly lower than under transparency, because opaqueness leads to greater uncertainty about the inflation target $\pi^*$. But, when $\mathrm{E}[\pi^*|\mathcal{O}]$ and $\mathrm{E}[\pi^*|\mathcal{T}]$ are sufficiently different, central banks that are close enough to the inflation target expected under opaqueness, $\mathrm{E}[\pi^*|\mathcal{O}]$, prefer to deviate from transparency. If the beliefs off the equilibrium path are not restricted, transparency may survive as a perfect equilibrium when the expected payoff is quadratic. But, when rationality is imposed on those beliefs, perfect (pure strategy) equilibria exist that feature a range of central bank types that adopt opaqueness.[18]

Regarding the publication of conditional versus unconditional central bank forecasts, both result in ex post political transparency. So, the reduction in uncertainty is the same in both cases. But, in contrast to the objective that is linear in output, the economic outcome is identical whether conditional or unconditional forecasts are disclosed.[19] The reason is that the additional incentive effect is immaterial because the socially optimal level of inflation is already obtained in either case.[20]

[17] See (38) and (43).

[18] See appendix A.2 for further details.

[19] To see this, observe that merely using the unconditional forecasts leads to $v^U = 0$ and $u^U = \pi^*$, and substitute this into (32) to get the same outcome as with the publication of conditional forecasts, (36) and (37).

[20] However, when $W_t = -\frac{1}{2}\alpha\left(\pi_t - \pi^*\right)^2 - \frac{1}{2}\beta\left(y_t - y^*\right)^2$ and $y^* > \bar{y}$, the incentive effect becomes relevant again; the publication of unconditional forecasts can be detrimental because the public is able to use the unconditional forecasts for inflation and output to infer the inflation target $\pi^*$ without relying on the interest rate.

Last but not least, since the central bank's payoff is maximized at $\pi^* = \mathrm{E}[\pi^*|\mathcal{R}]$, it is incentive-compatible for the central bank to reveal its internal forecasts truthfully so that the public can correctly infer its inflation target. As a result, credibility of the central bank's forecasts is simply not an issue with the quadratic objective function (28).

### 3.4 Arguments for Obfuscation

There may be other motives for opacity. They could be political, financial or bureaucratic. First, transparency also means greater accountability. If a central bank lacks political independence, transparency could make it more prone to political pressures. So, a central bank with insufficient independence may decide to envelop itself in secrecy to protect itself from political influence. The same could hold for central banks that lack a clear political mandate, like for instance the Federal Reserve.

Second, transparency gives central banks greater flexibility to offset economic shocks, but it also leads to larger fluctuations in the interest rate. If the financial sector is structurally weak, a large change in the interest rate could trigger a crisis. So, in the presence of a weak financial sector, transparency should be applied with caution.

Finally, like any bureaucracy, central banks may have an incentive to hide mistakes or embarrassing forecasts, or to cherish the information rents that secrecy brings, like extensive media attention (see Stiglitz 1999). Suppose that central bank officials therefore attach a cost $C$ to transparency so that the central bank's payoff equals $U_{CB}^T = U^T - C$ under transparency and $U_{CB}^O = U^O$ under opaqueness. This is a straightforward extension of the model. For $C$ sufficiently large, transparency is no longer the perfect equilibrium for the linear specification in (27) and opaqueness will become more likely for the quadratic case. Clearly, such private incentives make central banks more reluctant to adopt greater openness. Unfortunately, this imposes a big cost on society.

## 4 Discussion

The analysis in this paper relies on two important presumptions. There is asymmetric information between the central bank and the public about the central bank's preferences and the economic information available to the central bank. In addition, the public's inflation expectations are affected by the interest rate set by the central bank. Both presumptions are now substantiated.

First, the presence of asymmetric information about the central bank's objectives may seem questionable since many central banks have adopted explicit inflation targets. However, such targets are often formulated as ranges. Moreover, they need not be perfectly credible. Bernanke, Laubach, Mishkin and Posen (1999) provide empirical support for this. They show that the adoption of an explicit inflation target affects inflation expectations only gradually. In fact, there is always likely to be some uncertainty about the central bank's preferences because they cannot be directly observed and may change over time. Since a slight ex ante uncertainty about the inflation target ($\sigma_\tau^2 > 0$) already suffices, this assumption does not seem contentious.[21]

Furthermore, it is assumed that there is asymmetric information about the economic situation. In practice, central banks do not seem to have an information advantage on economic data, since data is generally released to the public as soon as it becomes available. In addition, many central banks publish their economic models. Nevertheless, central banks may have a significant advantage in the interpretation of economic information. They typically have a large staff devoted to the explanation and prediction of the economy, which exceeds the resources available to agents in the private sector. Thus, central banks are likely to have different (and often better) economic forecasts than the market. Romer and Romer (1996) provide evidence of such asymmetric information. They show that Federal Reserve forecasts of inflation are superior to those of commercial forecasters, even at a short horizon of one or two quarters ahead. This suggests that central banks may indeed have private information about economic disturbances. Although the model assumes that the central bank has superior information, the result on interest rate smoothing in section 3.3 only requires an information asymmetry, and the conclusions of the basic model in section 2 already hold when the private sector is merely unsure of the central bank's forecasts of economic shocks.

The second presumption is that the inflation expectations of the market are influenced by the central bank's actions. Figure 2 shows the association between the central bank's base rate and market expectations of inflation in the United Kingdom. The latter reflect average expected inflation rates over a five, ten and twenty year

[21] The assumption of a normal distribution for $\pi^*$ implies infinite support ($\pi^* \in \mathbb{R}$). This may seem unrealistic, but it provides a good approximation when there are no (perfectly credible) ex ante boundaries on the inflation target.

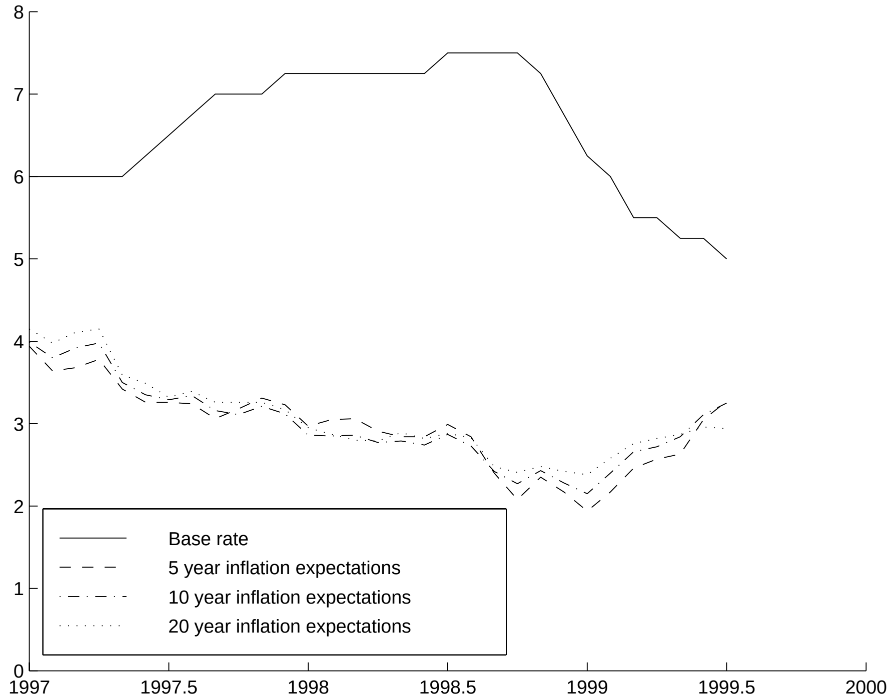


Figure 2: Market expectations of inflation and the base rate in the United Kingdom.

horizon, derived from prices of nominal and indexed government bonds (gilts).[22] The figure displays a striking, negative relationship. This is confirmed by more formal econometric analysis. Regressing market inflation expectations over a ten year horizon (INFL_EXP) on a constant, the base rate (BASE_RATE) and one period lagged inflation expectations gives

$$INFL\_EXP_t = \underset{(0.303)}{1.092} - \underset{(0.0349)}{0.105}\ BASE\_RATE_t + \underset{(0.0511)}{0.858}\ INFL\_EXP_{t-1}$$

using monthly data from 1997:1 to 1999:7, where $\bar{R}^2 = 0.915$, $s.e.e. = 0.146$ and standard errors are in parentheses.[23] The base rate has a negative effect on inflation expectations that is statistically significant (with a p-value of 0.006). Similar results

[22] The base rate used is the repo rate on the first day of the month. The inflation expectations are equal to the zero coupon inflation curves at the specified horizons, using monthly averages. The data are from the Bank of England, *Statistical Abstract*, tables 20.1 and 20.5, respectively.

[23] The lagged dependent variable is included to take care of autocorrelation. Regarding diagnostic tests, Durbin's $h = -0.158$ [0.875], and the LM test statistic for heteroskedasticity equals 1.245 [0.265], with $p$-values in brackets.

are obtained for the five and twenty year horizons, or using a measure of the real base rate. A regression of changes in inflation expectations on three-month changes in the base rate also tends to give a significant negative coefficient. These results suggest that the base rate has a negative effect on market expectations of inflation, consistent with the updating of inflation expectations in the model.[24]

Hence, the two presumptions underlying the model seem plausible.

# 5 Concluding Remarks

This paper has analyzed the effect of transparency in monetary policy, in particular the publication of central bank forecasts. It focuses on 'economic transparency', which gives the public access to all economic information, like data, models and forecasts, pertinent to the central bank's decisions. The paper identifies several benefits of such transparency. It enhances the central bank's ability to build reputation and reduces the inflation bias. In addition, it gives the central bank greater flexibility to respond to shocks in the economy. These advantages of economic transparency can be achieved through the publication of the conditional central bank forecasts of both inflation and output. Furthermore, it is shown that when the transparency regime is exogenous, society always prefers transparency. But, when the central bank is allowed to choose the regime, transparency need not be the outcome.

This paper has a clear message: Transparency helps to build reputation. Thus, it provides a rationale for the adoption of greater openness by central banks with histories of relatively high inflation, like the Bank of England, the Sveriges Riksbank and the Reserve Bank of New Zealand. In addition, transparency is likely to have significant benefits for a young central bank, like the ECB.

The ECB may be reluctant to disclose its internal forecasts because they are based on euro area models and statistics which have properties that are not yet completely understood. However, this only increases the importance of the publication of forecasts, because the market will face the same or even greater uncertainties, making the interpretation of the ECB's actions more difficult. Thus, it will be much harder for the ECB to establish the reputation of a strong central bank if it does not release

[24] For the U.S., Romer and Romer (1996) show that commercial inflation forecasts respond *positively* to changes in the Federal Funds rate, contradicting the negative effect predicted by the present model. However, a variation of the model with a different timing structure is able to generate results consistent with their findings (and the puzzling behavior of the U.S. term structure in response to monetary policy). This is addressed in a paper in progress.

its forecasts.

Another counter argument could be that the ECB should be judged on its inflation performance, not its forecasts. However, it will take several years before the ECB has established a track record. Meanwhile, the market will try to find out the ECB's commitment to low inflation by looking at its actions, changes in the interest rate. The release of conditional forecasts allows the market to interpret this signal of the ECB's intentions more accurately.

So, the ECB has a lot to gain from economic transparency. Of course, economic transparency would also benefit central banks that already have a well-established reputation, like the Federal Reserve. It allows the public to infer the central bank's intentions more accurately from its actions, which contributes to greater stability in financial markets. This in turn, gives the central bank more freedom to respond to economic disturbances, providing greater stability in the economy.

Furthermore, the publication of conditional forecasts provides an excellent way to improve accountability. A central bank can use it to explain the public why adjustments in interest rates are needed. After all, if monetary policy is very effective, inflation will remain subdued and the public may accuse the central bank of unnecessarily depressing output when it raises the interest rate. However, the conditional forecasts help to motivate the central bank's actions; they tell the public what would happen if the central bank didn't act.

Finally, it should be mentioned that many central banks have not adopted transparency, despite all the benefits. But with the recent trend towards independent central banks with a clear political mandate for price stability, it would not be surprising if more central banks become convinced of the advantages of economic transparency.

# A Appendix

This appendix contains the derivation of the results discussed in section 3.

## A.1 Perfect Equilibrium for Endogenous Regime

This section proves that transparency is the unique, pure-strategy perfect equilibrium in the simplified model of section 3.2, when the market's beliefs off the equilibrium path are restricted to be rational. First, it is shown that opaqueness cannot be an equilibrium because central banks with low inflation targets prefer to deviate. Second, it is shown that there is no equilibrium in which some central banks decide to adopt transparency and some opaqueness. Finally, it is shown that transparency is indeed an equilibrium.

Suppose that opaqueness is a perfect equilibrium, so $\mathrm{E}[\pi^*|\mathcal{O}] = \tau$. Consider now whether it is optimal for some central banks to deviate and adopt transparency. Using (27), central banks would prefer to deviate if and only if

$$\pi^* < \frac{1}{A^O - A^T}\left(A^O\tau - A^T\,\mathrm{E}[\pi^*|\mathcal{T}] + B^T - B^O\right)$$

The central bank that would be indifferent, whose threshold inflation target is denoted by $\tilde{\tau}$, satisfies the previous equation with equality. Rational expectations imply that $\mathrm{E}[\pi^*|\mathcal{T}] = \mathrm{E}[\pi^*|\pi^* < \tilde{\tau}]$. Let $\phi(.)$ denote the probability density function of the standard normal distribution and $\Phi(.)$ the corresponding cumulative density function. Then[25]

$$\frac{\tilde{\tau} - \tau}{\sigma_\tau} = \frac{A^T}{A^O - A^T}\frac{\phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)}{\Phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)} + \frac{B^T - B^O}{A^O - A^T}\frac{1}{\sigma_\tau}$$

Since the right-hand side is decreasing in $(\tilde{\tau} - \tau)/\sigma_\tau$, there exists a threshold $\tilde{\tau}$ so that opaqueness cannot be a perfect equilibrium.

Suppose that there is a threshold equilibrium such that a central bank with inflation target $\tilde{\tau}$ is indifferent between transparency and opaqueness, i.e. $\mathrm{E}[U|\tilde{\tau}, \mathcal{T}] = \mathrm{E}[U|\tilde{\tau}, \mathcal{O}]$. Since $\mathrm{E}[U|\pi^*, \mathcal{T}]$ and $\mathrm{E}[U|\pi^*, \mathcal{O}]$ are increasing in $\pi^*$ with slopes $A^T$ and $A^O$, respectively, where $A^O > A^T$, it follows that for $\pi^* < \tilde{\tau}$ ($\pi^* > \tilde{\tau}$) the central bank prefers a regime of transparency (opaqueness). Rational expectations imply that $\mathrm{E}[\pi^*|\mathcal{T}] = \mathrm{E}[\pi^*|\pi^* < \tilde{\tau}]$ and $\mathrm{E}[\pi^*|\mathcal{O}] = \mathrm{E}[\pi^*|\pi^* > \tilde{\tau}]$.[26] Using (27) one can

[25]Recall that $\pi^* \sim N(\tau, \sigma_\tau^2)$, so that $\mathrm{E}[\pi^*|\pi^* < \tilde{\tau}] = \tau - \sigma_\tau\phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)/\Phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)$.

[26]Note that $\mathrm{E}[\pi^*|\pi^* > \tilde{\tau}] = \tau + \sigma_\tau\phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)/\left[1 - \Phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)\right]$.

show that the threshold $\tilde{\tau}$ (if any) satisfies

$$\frac{\tilde{\tau}-\tau}{\sigma_\tau}=\frac{A^O}{A^O-A^T}\frac{\phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)}{1-\Phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)}+\frac{A^T}{A^O-A^T}\frac{\phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)}{\Phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)}+\frac{B^T-B^O}{A^O-A^T}\frac{1}{\sigma_\tau}$$

Note that the right-hand side is strictly positive. In addition, $\phi/\Phi$ and $\phi/\left(1-\Phi\right)$ are both convex in $\tilde{z}\equiv\left(\tilde{\tau}-\tau\right)/\sigma_\tau$,[27] so that the right-hand side is convex as well. Furthermore, the sum of the first two terms on the right-hand side has an asymptote of $-\frac{A^T}{A^O-A^T}\tilde{z}$ as $\tilde{z}\to-\infty$ and $\frac{A^O}{A^O-A^T}\tilde{z}$ as $\tilde{z}\to\infty$. Hence, the right-hand side is strictly greater than $\tilde{z}$ for any $\tilde{z}$. This means that no threshold equilibrium exists.

Finally, suppose that transparency is a perfect equilibrium, so $\mathrm{E}\left[\pi^*|\mathcal{T}\right]=\tau$. Consider now whether it is optimal for some central banks to deviate and adopt opaqueness. Using (27), central banks would prefer to deviate if and only if

$$\pi^*>\frac{1}{A^O-A^T}\left(A^O\,\mathrm{E}\left[\pi^*|\mathcal{O}\right]-A^T\tau+B^T-B^O\right)$$

The central bank that would be indifferent, whose inflation target is denoted by $\tilde{\tau}$, satisfies the previous equation with equality. Rational expectations imply that $\mathrm{E}\left[\pi^*|\mathcal{O}\right]=\mathrm{E}\left[\pi^*|\pi^*>\tilde{\tau}\right]$. Hence,

$$\frac{\tilde{\tau}-\tau}{\sigma_\tau}=\frac{A^O}{A^O-A^T}\frac{\phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)}{1-\Phi\left(\frac{\tilde{\tau}-\tau}{\sigma_\tau}\right)}+\frac{B^T-B^O}{A^O-A^T}\frac{1}{\sigma_\tau}$$

Note that the right-hand side is strictly positive. Furthermore, the right-hand side is increasing and convex in $\tilde{z}\equiv\left(\tilde{\tau}-\tau\right)/\sigma_\tau$, with a horizontal asymptote of 0 as $\tilde{z}\to-\infty$ and an asymptote of $\frac{A^O}{A^O-A^T}\tilde{z}$ as $\tilde{z}\to\infty$. Hence, this equation has no solution for $\tilde{z}$, which means that there exists no threshold $\tilde{\tau}$ such that deviation from transparency is preferred. Therefore, transparency is the unique, pure-strategy perfect equilibrium.[28]

[27] For a proof, see Sampford (1953) who shows that $f\left(z\right)=\frac{\phi(z)}{1-\Phi(z)}$ is convex, which implies that $f\left(-z\right)=\frac{\phi(z)}{\Phi(z)}$ is also convex.

[28] Without the restriction that beliefs off the equilibrium path (i.e. $\mathrm{E}\left[\pi^*|\mathcal{O}\right]$) are rational, transparency would not be a perfect equilibrium because there would always exist types with sufficiently large $\pi^*$ that prefer to deviate. This is a consequence of the unbounded support of the distribution of $\pi^*$.

## A.2 Quadratic Objective Function

This section derives the results for the quadratic central bank objective function (28). In period two, the central bank maximizes $W_2$ with respect to $i_2$ subject to (4) and (3), and given $\pi_2^e$, $\varepsilon_2^d$ and $\varepsilon_2^s$. The first order condition implies

$$i_2 = \frac{b\alpha + a\left(\alpha + \beta b^2\right)}{a\left(\alpha + \beta b^2\right)}\pi_2^e - \frac{\alpha b}{a\left(\alpha + \beta b^2\right)}\pi^* + \bar{r} + \frac{1}{a}\varepsilon_2^d - \frac{\alpha}{a\left(\alpha + \beta b^2\right)}\varepsilon_2^s.$$

Using (3) and (4) this yields

$$y_2 = \bar{y} - \frac{b\alpha}{\alpha + \beta b^2}\left(\pi_2^e - \pi^*\right) + \frac{\alpha}{\alpha + \beta b^2}\varepsilon_2^s \quad (29)$$

$$\pi_2 = \pi_2^e + \frac{\alpha}{\alpha + \beta b^2}\left(\pi^* - \pi_2^e\right) - \frac{\beta b}{\alpha + \beta b^2}\varepsilon_2^s. \quad (30)$$

Substituting (29) and (30) into (28) and taking expectations gives

$$\mathrm{E}\left[W_2 | \pi_2^e, \Omega\right] = -\frac{1}{2}\frac{\alpha\beta}{\alpha + \beta b^2}\left(b^2\left(\pi_2^e - \pi^*\right)^2 + \sigma_s^2\right) \quad (31)$$

So, expected wealth in period two is maximized when the market perfectly anticipates the central banks type: $\pi_2^e = \pi^*$. Thus, it is in the central bank's interest to reveal its type through its actions.

In the first period, the central bank maximizes the expected value of $U$ with respect to $i_1$ subject to (4) and (3), given $\pi_1^e$, $\varepsilon_1^d$ and $\varepsilon_1^s$, and assuming (9). The first order condition implies

$$\begin{aligned} i_1 = {} & \frac{\gamma^2}{\gamma^2 + \delta\alpha\beta b^4 v^2}\bar{r} + \frac{\gamma^2 + b\alpha\gamma}{\gamma^2 + \delta\alpha\beta b^4 v^2}\pi_1^e - \frac{b\alpha\gamma - \delta\alpha\beta b^4 v}{\gamma^2 + \delta\alpha\beta b^4 v^2}\pi^* \\ & - \frac{\delta\alpha\beta b^4 v}{\gamma^2 + \delta\alpha\beta b^4 v^2}u + \frac{\frac{1}{a}\gamma^2}{\gamma^2 + \delta\alpha\beta b^4 v^2}\varepsilon_1^d - \frac{\alpha\gamma}{\gamma^2 + \delta\alpha\beta b^4 v^2}\varepsilon_1^s, \end{aligned} \quad (32)$$

where $\gamma \equiv a\left(\alpha + \beta b^2\right)$.

Under either regime of transparency or opaqueness, rational expectations and (7) give, after rearranging, $\left(\pi_2^e\right)^R = \mathrm{E}\left[\pi^* | i_1, \mathcal{R}_1\right]$. Using the fact that $i_1$ in (32) is normally distributed,

$$\left(\pi_2^e\right)^R = \mathrm{E}\left[\pi^* | \mathcal{R}_1\right] + \frac{\mathrm{Cov}\left\{\pi^*, i_1 | \mathcal{R}_1\right\}}{\mathrm{Var}\left[i_1 | \mathcal{R}_1\right]}\left(i_1^T - \mathrm{E}\left[i_1 | \mathcal{R}_1\right]\right). \quad (33)$$

Under transparency, $\varepsilon_1^d$ and $\varepsilon_1^s$ are observed so that the market can infer $\pi^*$ from $i_1$. Hence, (30) implies

$$\left(\pi_2^e\right)^T = \pi^*. \quad (34)$$

Using (32) and matching coefficients between (33) and (9) yields after rearranging

$$\begin{aligned} v^T &= -\frac{\gamma}{\alpha b} \\ u^T &= \frac{\gamma}{\alpha b}\bar{r} + \frac{\gamma+\alpha b}{\alpha b}\left(\pi_1^e\right)^T + \frac{\alpha+\beta b^2}{\alpha}\frac{1}{b}\varepsilon_1^d - \frac{1}{b}\varepsilon_1^s. \end{aligned}$$

Substituting this into (32), using (3) and (4), and imposing rational expectations produces

$$i_1^T = \bar{r} + \mathrm{E}\left[\pi^*|\mathcal{T}\right] - \frac{\alpha}{\alpha+\beta b^2}\frac{b}{a}\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{T}\right]\right) - \frac{\alpha}{\alpha+\beta b^2}\frac{1}{a}\varepsilon_1^s + \frac{1}{a}\varepsilon_1^d \tag{35}$$

$$y_1^T = \bar{y} + \frac{\alpha}{\alpha+\beta b^2} b\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{T}\right]\right) + \frac{\alpha}{\alpha+\beta b^2}\varepsilon_1^s \tag{36}$$

$$\pi_1^T = \mathrm{E}\left[\pi^*|\mathcal{T}\right] + \frac{\alpha}{\alpha+\beta b^2}\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{T}\right]\right) - \frac{\beta b^2}{\alpha+\beta b^2}\frac{1}{b}\varepsilon_1^s \tag{37}$$

Substituting (34) into (31), and using (36) and (37) gives the expected payoff for the central bank

$$\mathrm{E}\left[U|\pi^*,\mathcal{T}\right] = -\frac{1}{2}\frac{\alpha\beta b^2}{\alpha+\beta b^2}\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{T}\right]\right)^2 - \frac{1}{2}\frac{\alpha\beta}{\alpha+\beta b^2}\left(1+\delta\right)\sigma_s^2. \tag{38}$$

In the case of opaqueness, using (32) and matching coefficients between (33) and (9) gives after rearranging

$$-\delta\alpha^2\beta b^5\gamma\sigma_\tau^2\left(v^O\right)^2 + \gamma^2\left(\alpha b^2\left(\alpha-\delta\beta b^2\right)\sigma_\tau^2 + \frac{\gamma^2}{a^2}\sigma_d^2 + \alpha^2\sigma_s^2\right)v^O + \alpha b\gamma^3\sigma_\tau^2 = 0.$$

This equation has two roots, $v_1^O > 0$ and $v_2^O < 0$. However, the positive root $v_1^O$ can be excluded based on an argument by McCallum (1983).[29] The remaining negative root can be written as

$$\begin{aligned} v^O = \; & \frac{\gamma}{2\delta\alpha^2\beta a^2 b^5\sigma_\tau^2}\left\{\alpha^2a^2b^2\sigma_\tau^2 - \delta\alpha\beta a^2b^4\sigma_\tau^2 + \gamma^2\sigma_d^2 + \alpha^2a^2\sigma_s^2\right. \\ & \left. - \sqrt{\left(\alpha^2a^2b^2\sigma_\tau^2 + \delta\alpha\beta a^2b^4\sigma_\tau^2 + \gamma^2\sigma_d^2 + \alpha^2a^2\sigma_s^2\right)^2 - 4\delta\alpha\beta a^2b^4\left(\gamma^2\sigma_d^2 + \alpha^2a^2\sigma_s^2\right)\sigma_\tau^2}\right\} \end{aligned}$$

Clearly, $v^O > -\gamma/\alpha b$. Hence, $\left|v^O\right| < \left|v^T\right|$; the magnitude of the effect of the interest rate on inflation expectations is smaller under opaqueness because it is a noisier signal of the inflation target. Note that $\lim_{\sigma_d^2,\sigma_s^2\to 0} v^O = -\frac{\gamma}{\alpha b} = v^T$. In the absence of uncertainty about the shocks, the effect of interest rates on inflation expectations is the same for opaqueness and transparency.[30]

[29] To be precise, $v_1^O$ is not valid for all admissible parameter values, because $\lim_{\sigma_d^2,\sigma_s^2\to 0} v_1^O \neq v^T$.

[30] If in addition $\mathrm{E}\left[\varepsilon_1^d|\mathcal{O}_1\right] = \varepsilon_1^d$ and $\mathrm{E}\left[\varepsilon_1^s|\mathcal{O}_1\right] = \varepsilon_1^s$, $u^O$ reduces to $u^T$ and the outcomes under opaqueness and transparency are identical.

In addition, matching coefficients gives

$$u^O = \mathrm{E}\left[\pi^*|\mathcal{O}\right] + \frac{\alpha b v^O}{\gamma}\left(\mathrm{E}\left[\pi^*|\mathcal{O}\right] - (\pi_1^e)^O\right) - v^O\left(\bar{r} + (\pi_1^e)^O\right).$$

Using (32), (33) yields

$$\begin{aligned}(\pi_2^e)^O &= \mathrm{E}\left[\pi^*|\mathcal{O}\right] - \frac{\alpha\gamma b v^O - \delta\alpha\beta b^4 \left(v^O\right)^2}{\gamma^2 + \delta\alpha\beta b^4 \left(v^O\right)^2}\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{O}\right]\right) \\ &\quad + \frac{\frac{1}{a}\gamma^2 v^O}{\gamma^2 + \delta\alpha\beta b^4 \left(v^O\right)^2}\varepsilon_1^d - \frac{\alpha\gamma v^O}{\gamma^2 + \delta\alpha\beta b^4 \left(v^O\right)^2}\varepsilon_1^s.\end{aligned} \tag{39}$$

Substituting $u^O$ into (32), using (3) and (4), and imposing rational expectations produces

$$i_1^O = \bar{r} + \mathrm{E}\left[\pi^*|\mathcal{O}\right] - \mu\frac{\alpha b}{\gamma}\left(1 - \frac{\delta\beta b^3}{\gamma}v^O\right)\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{O}\right]\right) + \frac{\mu}{a}\varepsilon_1^d - \frac{\alpha\mu}{\gamma}\varepsilon_1^s \tag{40}$$

$$y_1^O = \bar{y} + \mu\frac{\alpha a b}{\gamma}\left(1 - \frac{\delta\beta b^3}{\gamma}v^O\right)\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{O}\right]\right) + (1-\mu)\,\varepsilon_1^d + \frac{\alpha a}{\gamma}\mu\varepsilon_1^s \tag{41}$$

$$\begin{aligned}\pi_1^O &= \mathrm{E}\left[\pi^*|\mathcal{O}\right] + \mu\left(1 - \frac{\delta\beta b^3}{\gamma}v^O\right)\frac{\alpha a}{\gamma}\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{O}\right]\right) \\ &\quad + \frac{1}{b}(1-\mu)\,\varepsilon_1^d - \left(1 - \mu\frac{\alpha a}{\gamma}\right)\frac{1}{b}\varepsilon_1^s,\end{aligned} \tag{42}$$

where $\mu \equiv \frac{\gamma^2}{\gamma^2 + \delta\alpha\beta b^4 (v^O)^2}$ $(0 < \mu < 1)$. Notice that the responsiveness of the interest rate to demand and supply shocks is smaller under opaqueness. As a consequence, demand shocks are no longer completely offset and affect output, and thereby inflation. In addition, the magnitude of the effect of supply shocks on the level of inflation has increased from $\left(1 - \frac{\alpha a}{\gamma}\right)\frac{1}{b}$ under transparency to $\left(1 - \mu\frac{\alpha a}{\gamma}\right)\frac{1}{b}$ under opaqueness, and the effect on output has decreased from $\frac{\alpha a}{\gamma}$ under transparency to $\frac{\alpha a}{\gamma}\mu$ under opaqueness.

Substituting (39) into (31), and using (41) and (42) gives after some rearranging the expected payoff for the central bank

$$\begin{aligned}\mathrm{E}\left[U|\pi^*, \mathcal{O}\right] &= -\frac{1}{2}\left(1 + \delta\left(1 + \frac{\alpha b}{\gamma}v^O\right)^2\mu\right)\frac{\alpha a\beta b^2}{\gamma}\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{O}\right]\right)^2 \\ &\quad - \frac{1}{2}\frac{\gamma}{ab^2}(1-\mu)\,\sigma_d^2 - \frac{1}{2}\frac{\alpha a\beta}{\gamma}\left(1 + \left(1 + \frac{\alpha^2 b^2 \left(v^O\right)^2}{\gamma^2}\mu\right)\delta\right)\sigma_s^2\end{aligned} \tag{43}$$

Comparing (38) and (43), the expected payoff for a central bank with inflation target $\pi^*$ in regime $R \in \{T, O\}$ equals

$$\mathrm{E}\left[U|\pi^*, \mathcal{R}\right] = A_1^R\left(\pi^* - \mathrm{E}\left[\pi^*|\mathcal{R}\right]\right)^2 + A_2^R\sigma_d^2 + A_3^R\sigma_s^2$$

where $\mathcal{R} \in \{\mathcal{T}, \mathcal{O}\}$,

$$\begin{aligned} A_1^T &= -\frac{1}{2}\frac{\alpha a \beta b^2}{\gamma} \\ A_2^T &= 0 \\ A_3^T &= -\frac{1}{2}\frac{\alpha a \beta}{\gamma}(1+\delta) \end{aligned}$$

and[31]

$$\begin{aligned} A_1^O &= -\frac{1}{2}\left(1+\delta\left(1+\frac{\alpha b}{\gamma}v^O\right)^2\mu\right)\frac{\alpha a \beta b^2}{\gamma} \\ A_2^O &= -\frac{1}{2}\frac{\gamma}{ab^2}(1-\mu) \\ A_3^O &= -\frac{1}{2}\frac{\alpha a \beta}{\gamma}\left(1+\left(1+\frac{\alpha^2 b^2 \left(v^O\right)^2}{\gamma^2}\mu\right)\delta\right). \end{aligned}$$

Observe that $0 > A_1^T > A_1^O$ because $v^O > -\gamma/\alpha b$, and that $0 = A_2^T > A_2^O$ and $0 > A_3^T > A_3^O$ because $0 < \mu < 1$. The expected payoff for the public equals

$$\mathrm{E}[U|\mathcal{R}] = A_1^R \operatorname{Var}[\pi^*|\mathcal{R}] + A_2^R \sigma_d^2 + A_3^R \sigma_s^2.$$

So, if the regime is exogenous and randomly assigned so that $\operatorname{Var}[\pi^*|\mathcal{T}] = \operatorname{Var}[\pi^*|\mathcal{O}]$, transparency is preferred: $\mathrm{E}[U|\mathcal{O}] < \mathrm{E}[U|\mathcal{T}]$.

When the regime is endogenous, the expected payoff to the central bank can be written as[32]

$$\mathrm{E}[U|\pi^*, \mathcal{R}] = A^R (\pi^* - \mathrm{E}[\pi^*|\mathcal{R}])^2 + B^R$$

where $A^O < A^T < 0$ and $B^O < B^T$. This is a parabola in $\pi^*$ with a maximum of $B^R$ at $\pi^* = \mathrm{E}[\pi^*|\mathcal{R}]$. Observe that for $\mathrm{E}[\pi^*|\mathcal{T}] = \mathrm{E}[\pi^*|\mathcal{O}]$, every central bank prefers transparency. But when $\mathrm{E}[\pi^*|\mathcal{O}]$ is sufficiently different from $\mathrm{E}[\pi^*|\mathcal{T}]$, a range of inflation targets around $\mathrm{E}[\pi^*|\mathcal{O}]$ exists where central banks are better off with opaqueness.

To find a perfect equilibrium, suppose there are thresholds $\underline{\tau}$ and $\bar{\tau}$ $(\underline{\tau} < \bar{\tau})$ such that central banks at $\underline{\tau}$ and $\bar{\tau}$ are indifferent between transparency and opaqueness: $\mathrm{E}[U|\underline{\tau}, \mathcal{T}] = \mathrm{E}[U|\underline{\tau}, \mathcal{O}]$ and $\mathrm{E}[U|\bar{\tau}, \mathcal{T}] = \mathrm{E}[U|\bar{\tau}, \mathcal{O}]$. This implies that central banks

[31] Note that substituting $v^T$ for $v^O$ in $A_1^O$ gives $A_1^T$. This does not hold for $A_2^O$ and $A_3^O$, however, because those are affected by an additional difference; $\mathrm{E}\left[\varepsilon_1^d|\mathcal{T}_1\right] = \varepsilon_1^d$ and $\mathrm{E}[\varepsilon_1^s|\mathcal{T}_1] = \varepsilon_1^s$, whereas $\mathrm{E}\left[\varepsilon_1^d|\mathcal{O}_1\right] = 0$ and $\mathrm{E}[\varepsilon_1^s|\mathcal{O}_1] = 0$.

[32] The same caveat applies as in footnote 11.

with $\pi^* < \underline{\tau}$ and $\bar{\tau} < \pi^*$ prefer transparency and those with $\underline{\tau} < \pi^* < \bar{\tau}$ prefer opaqueness. Hence, using the fact that $\pi^* \sim N(\tau, \sigma_\tau^2)$,

$$\begin{aligned} \mathrm{E}[\pi^*|\mathcal{T}] &= \mathrm{E}[\pi^*|\pi^* < \underline{\tau}, \bar{\tau} < \pi^*] = \tau + \sigma_\tau \frac{\phi\left(\frac{\bar{\tau}-\tau}{\sigma_\tau}\right) - \phi\left(\frac{\underline{\tau}-\tau}{\sigma_\tau}\right)}{1 - \Phi\left(\frac{\bar{\tau}-\tau}{\sigma_\tau}\right) + \Phi\left(\frac{\underline{\tau}-\tau}{\sigma_\tau}\right)} \\ \mathrm{E}[\pi^*|\mathcal{O}] &= \mathrm{E}[\pi^*|\underline{\tau} < \pi^* < \bar{\tau}] = \tau - \sigma_\tau \frac{\phi\left(\frac{\bar{\tau}-\tau}{\sigma_\tau}\right) - \phi\left(\frac{\underline{\tau}-\tau}{\sigma_\tau}\right)}{\Phi\left(\frac{\bar{\tau}-\tau}{\sigma_\tau}\right) - \Phi\left(\frac{\underline{\tau}-\tau}{\sigma_\tau}\right)} \end{aligned}$$

Substituting and rearranging, the threshold $\underline{\tau}$ solves

$$\begin{aligned} A^T\left(\underline{\tau} - \mathrm{E}[\pi^*|\mathcal{T}]\right)^2 + B^T &= A^O\left(\underline{\tau} - \mathrm{E}[\pi^*|\mathcal{O}]\right)^2 + B^O \\ \sigma_\tau^2 A^T\left(\underline{z} - \frac{\phi(\bar{z}) - \phi(\underline{z})}{1 - \Phi(\bar{z}) + \Phi(\underline{z})}\right)^2 + B^T &= \sigma_\tau^2 A^O\left(\underline{z} + \frac{\phi(\bar{z}) - \phi(\underline{z})}{\Phi(\bar{z}) - \Phi(\underline{z})}\right)^2 + B^O \end{aligned}$$

where $\underline{z} \equiv (\underline{\tau} - \tau)/\sigma_\tau$ and $\bar{z} \equiv (\bar{\tau} - \tau)/\sigma_\tau$. The corresponding condition for the threshold $\bar{\tau}$ is

$$\sigma_\tau^2 A^T\left(\bar{z} - \frac{\phi(\bar{z}) - \phi(\underline{z})}{1 - \Phi(\bar{z}) + \Phi(\underline{z})}\right)^2 + B^T = \sigma_\tau^2 A^O\left(\bar{z} + \frac{\phi(\bar{z}) - \phi(\underline{z})}{\Phi(\bar{z}) - \Phi(\underline{z})}\right)^2 + B^O$$

Thus, finding a perfect equilibrium with thresholds $\underline{\tau}$ and $\bar{\tau}$ (if any) amounts to finding two solutions for $z$, $z_1$ and $z_2$ ($z_1 > z_2$), to the equation

$$\sigma_\tau^2 A^T\left(z - \frac{\phi(\bar{z}) - \phi(\underline{z})}{1 - \Phi(\bar{z}) + \Phi(\underline{z})}\right)^2 + B^T = \sigma_\tau^2 A^O\left(z + \frac{\phi(\bar{z}) - \phi(\underline{z})}{\Phi(\bar{z}) - \Phi(\underline{z})}\right)^2 + B^O \quad (44)$$

subject to the condition that $z_1 = \bar{z}$ and $z_2 = \underline{z}$. Denote this threshold equilibrium by $\{\underline{z}, \bar{z}\}$.

Note that if a threshold equilibrium$\{\underline{z}, \bar{z}\}$ exists, then $\{-\bar{z}, -\underline{z}\}$ is also an equilibrium. So, (pure strategy) threshold equilibria always come in symmetric pairs. This is not surprising given the symmetry of the problem when the objective function is quadratic in output. In addition, it is easy to see that $\{-z, z\}$ cannot be an equilibrium. Suppose it is, then $\sigma_\tau^2\left(A^T - A^O\right)z^2 = -\left(B^T - B^O\right) < 0$, which leads to a contradiction.

Pairs of threshold equilibria can be computed numerically using (44). This tends to give a unique pair of threshold equilibria. However, when the difference between $B^T$ and $B^O$ becomes very large, the magnitude of $\underline{z}$ and $\bar{z}$ gives rise to numerical problems with the evaluation of the densities and no equilibrium values can be computed.

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