Communication, Decision Making, and the Optimal Degree of Transparency of Monetary Policy Committees*

Anke Weber
International Monetary Fund

This paper develops a theoretical model of a monetary policy committee with heterogeneous members whose decisions and public communications are observed by the financial markets. It thereby provides a link between the literatures on monetary policy committees and central bank communication. The results show that transparency about the different views among committee members surrounding the economic outlook is beneficial. However, communicating the diversity of views about the monetary policy decision may not be welfare enhancing, at least in the short term. These results support previous empirical findings and have strong implications for how committees should communicate.

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1. Introduction

The conduct of monetary policy has changed markedly since the 1990s. Over the past two decades, a number of central banks have shifted responsibility for interest rate setting to a monetary policy

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committee (MPC).[1] In addition, central banks have become more independent and now pay close attention to explaining what they do and what underlies their decisions. Greater transparency and increased communication are consequences of these developments (de Haan, Eijffinger, and Rybinski 2007).[2]

This paper provides a link between the literatures on monetary policy committees and central bank communication, both of which are important elements in modern central bank design. It develops a theoretical model of a monetary policy committee whose decisions and public communications are observed by the financial markets, and thereby analyzes how committees should communicate. The model contrasts in several ways with previous work on central bank transparency and communication. First, decisions are set by a monetary policy committee with heterogeneous members rather than by a representative central banker. It is assumed that policymakers face uncertainty in assessing the state of the economy.[3] They receive different signals on the state of the economy and face uncertainty about the precision of these observations. They also have different preferences regarding the optimal level of the output gap. In addition, two sources of asymmetric information between the committee and market participants are introduced. It is assumed that market participants have imperfect information about the precision of public information on the state of the economy and about the policy preferences of committee members.

Several interesting insights are obtained. It is shown that there is a decreasing marginal benefit of increasing the committee size. It is also found that communication matters for financial markets' expectations of inflation and future short-term interest rates. Committee members should communicate their views on the state of the economy without error, as this reduces inflation and output-gap

[1] A recent survey by Pollard (2004) shows that seventy-nine out of eighty-eight central banks conduct monetary policy by committee.

[2] Eijffinger and Geraats (2006) provide an index of transparency for a set of developed countries that includes some inflation targeters (United Kingdom, Sweden, Australia, and Canada) as well as non-targeters (Japan, United States, and Switzerland). They show that between 1998 and 2002 transparency increased for virtually all of the central banks they studied.

[3] The fact that central banks do not know the current state of the economy with certainty has been stressed by Orphanides (2003) and Aoki (2006).

variability. Communication of a divergence of views by committee members regarding the monetary policy decision (as, for example, the publication of voting records) may lead to greater variability in inflation and the output gap in the short run. In the long run, welfare is enhanced, as financial markets are able to infer members' preferences from voting records once they have a better estimate of the precision of public information.

This paper contributes to the previous theoretical and empirical literature on monetary policy committees and central bank communication.[4] Blinder (2007) argues that delegating monetary policy to a committee leads to superior policy for a number of reasons, such as the ability to pool judgments of different members and the possibility of learning from other members. The finding that committees make superior decisions to individual policymakers has been confirmed by the experimental literature (Blinder and Morgan 2005; Lombardelli, Proudman, and Talbot 2005). Furthermore, the theoretical literature has concluded that a committee of limited size is optimal due to the costs of acquiring information about different members and coordination costs (Sibert 2006). This paper argues that committee members are not efficient at pooling different information sets when they do not know their precision and that this implies that there are decreasing marginal benefits of increasing the committee size.

An increasing number of papers have examined the optimal communication strategy of central banks. Some economists stress the importance of communication in providing central banks with the means to influence key asset prices in the economy (Blinder 1998; Bernanke 2004). However, others, such as Morris and Shin (2002), argue that too much communication may not be desirable. Morris and Shin (2002) develop a model in which welfare decreases when private agents rely on a sufficiently noisy public signal to coordinate their actions and thus disregard their own private information.

Ehrmann and Fratzscher (2005) investigate communication by three major central banks (the Bank of England, the Federal Reserve, and the European Central Bank) empirically and evaluate the effectiveness of central bank communication on financial

[4]Vandenbussche (2006) and Blinder (2007) provide comprehensive overviews of the literature on central bank committees whilst Blinder et al. (2008) provide a survey of the literature on central bank communication.

markets in terms of their ability to anticipate monetary policy decisions. They conclude that a higher degree of communication dispersion among committee members about monetary policy worsens the ability of financial markets to anticipate future monetary policy decisions. They also find that communication of the risks and diversity of views of the committee surrounding the economic outlook enhances the ability of the public to anticipate future monetary policy decisions, at least in the case of the Federal Reserve. Gerlach-Kristen (2004), on the other hand, investigates the voting records of committee members at the Bank of England and finds that those records can convey information about the views of individual members. Their publication may hence lead to greater policy predictability. The present paper is best seen as providing some theoretical underpinning to explain those previous empirical findings.

The remainder of this paper is structured as follows. Section 2 sets out the basic model. The solution of this model is discussed in section 3. Section 4 presents the results, and conclusions are summarized in section 5.

2. The Model

2.1 The General Setup

Inflation is determined by a New Keynesian Phillips-curve relationship:

$$\pi_t = E_t\pi_{t+1} + y_t + s_t, \tag{1}$$

where π_t denotes inflation and y_t is the output gap defined as the difference between actual and potential output, where the latter is conveniently normalized to 0. For convenience, the coefficients of the New Keynesian Phillips curve are set to 1. This does not affect the qualitative results. In addition, s_t is a persistent supply shock, which follows a simple AR(1) process:

$$s_t = \alpha s_{t-1} + v_t, \tag{2}$$

where $0 < \alpha < 1$ and v_t is i.i.d. white noise with variance σ_v^2.

Following Kozicki and Tinsley (2008), the output gap is determined by the following simple relationship:[5]

$$y_t = -R_t, \tag{3}$$

where R_t denotes the long-term real interest rate. The assumption that the output gap is decreasing in the long-term real interest rate can be justified by the fact that the interest-rate-sensitive components of aggregate demand generally depend on the yield on financial assets with longer maturity (Eijffinger, Schaling, and Tesfaselassie 2004).

To facilitate the derivation of closed-form results, we replace the n-period real interest rate in (3) with a two-period rate. The two-period real interest rate, R_t, and the current and future short-term real interest rates, $i_t - E_t\pi_{t+1}$ and $E_t i_{t+1} - E_t\pi_{t+2}$, are related by the expectations theory of the term structure:[6]

$$R_t = \frac{1}{2}(i_t - E_t\pi_{t+1}) + \frac{1}{2}(E_t i_{t+1} - E_t\pi_{t+2}). \tag{4}$$

Replacing the n-period bond rate with a two-period bond rate could be interpreted as describing a situation in which the central bank deals with the current situation given expectations about the near future (two periods ahead) while too little is known about the long run (Gosselin, Lots, and Wyplosz 2008).

The central bank controls the short-term nominal interest rate, i_t, and has exogenously given inflation and output-gap targets, π^* and y^*. It also wants to minimize deviations of inflation and the output gap from those assigned targets. The central bank can observe and respond directly to private-sector expectations, and it sets its interest rate after private expectations are set in every period. This timing implies that monetary policy is set under discretion. Since i_t affects only y_t and π_t and there are no endogenous state variables, the central bank will set interest rates to minimize the following loss function:

[5]This equation can be derived from a forward-looking IS curve of the form $y_t = E_t y_{t+1} - (i_t - E_t\pi_{t+1})$. After recursive forward substitution, the relationship can be approximated as $y_t \simeq -E_t[\frac{1}{n}\sum_{i=1}^{n} i_{t+i} - \frac{1}{n}\sum_{i=1}^{n} \pi_{t+i+1}]$, where i_t denotes the short-term nominal interest rate.

[6]Without loss of generality, the unobserved term premium is set to 0.

$$L = \frac{1}{2}[(\pi_t - \pi^*)^2 + \mu(y_t - y^*)^2], \tag{5}$$

where $0 < \mu < 1$ is the relative weight on output-gap stabilization. In order to find the optimal reaction function, (5) is minimized subject to (1), (2), (3), and (4). The central bank's reaction function can be written as

$$\begin{aligned} i_t = &\left(1 + \frac{2}{1+\mu}\right) E_t\pi_{t+1} + E_t\pi_{t+2} - E_t i_{t+1} \\ &+ \frac{2}{1+\mu}(s_t - \pi^*) - \frac{2\mu}{1+\mu}y^*. \end{aligned} \tag{6}$$

Hence, i_t is increasing in the current supply shock because it determines current inflation. Optimal policy is also inversely related to financial markets' forecast of the future short-term real rate, since the higher $E_t i_{t+1} - E_t\pi_{t+2}$, the lower the optimal short-term real interest rate can be. The higher the relative weight that the central bank gives to output-gap stabilization, μ, the smaller is the response of i_t to changes in expected inflation and the aggregate supply shock.

The two-period real rate can be expressed as

$$R_t = \frac{1}{1+\mu}(E_t\pi_{t+1} + s_t - \pi^*) - \frac{\mu}{1+\mu}y^*,$$

where equations (4) and (6) have been used. Intuitively, the two-period real interest rate is a positive function of expected inflation and the supply shock and a negative function of the inflation and output-gap targets.

The method of undetermined coefficients is used to obtain the public's rational expectation of inflation as[7]

$$E_t\pi_{t+1} = \frac{\mu}{1+\mu(1-\alpha)}\alpha s_t + \pi^* + \mu y^*. \tag{7}$$

Private-sector inflation expectations are increasing in the current supply shock and the inflation and output-gap targets of the central

[7]The solution method is outlined in the appendix.

bank. Substituting (4) and (7) into (1) and (3) yields expressions for inflation and the output gap:

$$\pi_t = \frac{\mu}{[1+\mu(1-\alpha)]} s_t + \pi^* + \mu y^* \quad \text{and} \quad y_t = -\frac{1}{[1+\mu(1-\alpha)]} s_t.$$

Hence inflation is increasing in the supply shock and the central bank's targets for inflation and the output gap. Moreover, it is a positive function of μ. Therefore, the greater the preference of the central bank for output-gap stabilization, the stronger is the response of inflation to supply shocks. If $s_t > 0$, the output gap is also a positive function of the central bank's preference for output-gap stabilization. Furthermore, it is a negative function of the supply shock.

2.2 Imperfect Information about the State of the Economy

The central bank and the public are assumed to face uncertainty about the current supply shock but to have their own best estimate of s_t. Sections 3.1 and 3.2 show how such an estimate can be derived. The central bank and the private sector know the structural equations of the economy, and the central bank continues to observe perfectly the public's inflation expectations, which are set before the central bank makes an interest rate decision. This assumption is made in order to be able to derive closed-form solutions of the model under uncertainty about the state of the economy and asymmetric information between the central bank committee and the financial markets. If policy is set under discretion, then the committee does not need to consider the effect of its short-term interest rate decision on financial markets' expectations of future inflation and interest rates, since these are already set. As Svensson and Woodford (2004) show, under asymmetric information between the central bank and the public and uncertainty about the state of the economy, certainty equivalence continues to hold under discretion; that is, the committee can continue to set interest rates as it would under certainty about the supply shock but use its best estimate of the supply shock instead. Furthermore, the signal-extraction problem of finding an optimal estimate of the supply shock can be treated separately from the optimization problem of finding an optimal response coefficient for the reaction function of the committee. This is because the best estimate of the supply shock does not depend on the current nominal interest rate, inflation, or output and thus a separation principle applies (Svensson and Woodford 2004). Furthermore, financial markets use their best estimate of the current supply shock and ignore the uncertainty surrounding this estimate when forming expectations about future inflation and interest rates.

It is assumed that in the final stage of each period t, the supply shock is realized and observed both by the central bank and the public. This assumption is made in order to simplify the analysis. Whilst it would be more reasonable to assume that a new and better estimate of the supply shock becomes available at the end of each period, this would make the signal-extraction procedure significantly more complicated.

Using (6), the short-term nominal interest rate under uncertainty is given by

$$i_t = \left(1 + \frac{2}{1+\mu}\right) E_t\pi_{t+1} + E_t\pi_{t+2} - E_t i_{t+1} + \frac{2}{1+\mu}\left(s_{t|t}^{(CB)} - \pi^*\right) - \frac{2\mu}{1+\mu} y^*, \tag{8}$$

where $s_{t|t}^{CB}$ denotes the optimal estimate of the central bank for the supply shock in period t.

Inserting the central bank's reaction function (8) into (4) and using (7), the two-period real interest rate under uncertainty can be written as

$$R_t = \frac{\mu\alpha}{(1+\mu)[1+\mu(1-\alpha)]} s_{t|t}^{(F)} + \frac{1}{1+\mu} s_{t|t}^{(CB)}, \tag{9}$$

where $s_{t|t}^{F}$ denotes the optimal estimate of the financial markets for the supply shock in period t.

Using (7) and (9), inflation and the output gap in period t will equal

$$\pi_t = \frac{\mu^2\alpha}{(1+\mu)[1+\mu(1-\alpha)]} s_{t|t}^{(F)} - \frac{1}{1+\mu} s_{t|t}^{(CB)} + \pi^* + \mu y^* + s_t \tag{10}$$

and

$$y_t = -\frac{\mu\alpha}{(1+\mu)[1+\mu(1-\alpha)]} s_{t|t}^{(F)} - \frac{1}{1+\mu} s_{t|t}^{(CB)}. \tag{11}$$

Thus, inflation continues to increase with higher central bank targets for inflation and the output gap. It is a positive function of the true supply shock and the estimated supply shock by the public. The higher the perceived supply shock by the central bank, the lower will be inflation. This is because the higher the current estimate of the supply shock by the central bank, the higher will be the short-term nominal interest rate that it sets. The output gap, on the other hand, is decreasing in both the central bank's and the public's estimates of the supply shock. This paper assumes that $\alpha > 0$ and $\mu > 0$. From equations (10) and (11) it can be seen why these assumptions are made. If $\alpha = 0$, then the private sector's estimate of the supply shock has no effect on inflation or the output gap. In this case, if the inflation and output-gap targets of the central bank are known to the public, there is no role for communication by committee members regarding their views on the innovation to the supply shock. The same is true for $\mu = 0$. In this case, there is also no effect of the output-gap target on inflation. Thus, for the results in this paper to hold, the supply shock should be persistent and the central bank should not be a strict inflation targeter. Empirical studies typically confirm that supply shocks are persistent (Ireland 2004). In addition, whether they explicitly target inflation or not, the central banks of most developed economies act as flexible inflation targeters (Cukierman 2007).

2.3 Transparency and the Monetary Policy Committee

This section introduces a model of a monetary policy committee with N members whose decisions and public communications are observed by the financial markets. Each committee member, j, receives a signal on the innovation, v_t, to the supply shock, s_t:

$$v_t^{(j)} = v_t + \varepsilon_t^{(j)}, \tag{12}$$

where $\varepsilon_t^{(j)}$ is i.i.d. with variance $\sigma^2_{\varepsilon,j}$ for $j = 1, 2, \ldots, N$. Thus $E(v_t^{(j)} - v_t)^2 = \sigma^2_{\varepsilon,j}$.

It is assumed that the error terms of those signals are uncorrelated among committee members. Furthermore, their true variance is unknown. The precision of committee member j's observation is estimated in period t by member k as $\widetilde{\sigma}^{2(k,j)}_{\varepsilon,t}$ for $j = 1, \ldots, N$ and

$k = 1, \ldots, N$. Whilst committee members may receive the same information on the state of the economy, they interpret and process this information differently, resulting in different observations on the state of the economy. Furthermore, committee members are likely to be uncertain about the correct underlying model of the economy, and this is reflected in different variances of observation errors and uncertainty about the precision of information.

In addition, committee members are modeled as having different preferences regarding the level of the output-gap target, y^*. Even though the objectives of a central bank are often assigned by law, these are usually defined in terms of a specific inflation target, whereas the objectives regarding the optimal level of the output target are less precisely defined (Cukierman 2007). Thus, it is likely that committee members have different views about the optimal level of the output-gap target, and this is confirmed by the empirical literature (Chappell, McGregor, and Vermilyea 2005). The paper assumes that these output-gap preferences are constant and denoted by $\theta^{(j)}$ for member j. This may not be the case in reality. Cukierman (2007) argues that these preferences fluctuate due to changes in the intensity of political pressures on members. However, the assumption that the output-gap target preferences are constant greatly simplifies the analysis of the paper. If they were following an autoregressive process as in Faust and Svensson (2002), this would add another signal-extraction problem to the paper. However, the basic conclusions should still hold.

There are two important information asymmetries between the monetary policy committee and financial markets. First, financial markets do not observe the signals that individual committee members receive on the innovation to the supply shock. Instead, financial markets receive public information on the state of the economy from committee members—for instance, in the form of speeches. This communication takes the following form for each committee member j:

$$x_t^{(j)} = v_t^{(j)} + \varpi_t^{(j)}, \tag{13}$$

where $\varpi_t^{(j)}$ is i.i.d. with variance $\sigma^2_{\varpi,j}$ for $j = 1, \ldots, N$. It is assumed that $E_t(\varpi_t^{(F,j)}, \varpi_t^{(F,k)}) = 0$ for $j \neq k$. Thus, each committee member, j, communicates his view on the innovation to the supply shock to the financial markets, but may do so imperfectly, which is reflected in the error term $\varpi_t^{(j)}$. When $\sigma_{\varpi,j}^2 = 0$, the signals $x_t^{(j)}$ communicate $v_t^{(j)}$ without noise and there is perfect actual transparency about committee member j's observation on the innovation to the supply shock. In reality, it will be difficult for the private sector to establish how transparent the central bank is, and it is unlikely that the private sector will know the variance of the communication error, $\sigma_{\varpi,j}^2$. Thus, the paper follows Geraats (2007) and introduces the notion of perceived transparency. Committee member j is perceived to be perfectly transparent about his signal on the innovation to the supply shock if $\widetilde{\sigma}_{\varpi,t}^{2(j)} = 0$.

Equation (13) can alternatively be written as

$$x_t^{(j)} = v_t + \varepsilon_t^{(j)} + \varpi_t^{(j)} = v_t + \zeta_t^{(j)}, \tag{14}$$

where the variance of $\zeta_t^{(j)}$ equals $Var(\zeta_t^{(j)}) = \sigma_{\varepsilon,j}^2 + \sigma_{\varpi,j}^2$ for $j = 1, 2, \ldots, N$. There is no communication about the estimated precision of signals by committee members, and financial markets are uncertain about the variance of $\varpi_t^{(j)}$. The variance of $\zeta_t^{(j)}$ is estimated by financial markets as $\widetilde{\sigma}_{\zeta,t}^{2(j)} = \widetilde{\sigma}_{\varepsilon,t}^{2(F,j)} + \widetilde{\sigma}_{\varpi,t}^{2(j)}$.

Financial markets also have imperfect knowledge about the policy preferences of committee members. As Beetsma and Jensen (1998) argue, policymakers are likely to have private information about their preferences. Financial markets have a prior on the preferred output-gap targets of policymakers.[8] Denote this prior for the preferred output-gap target of committee member j as $z^{(j)} = \theta^{(j)} + \psi^{(j)}$, where $\psi^{(j)}$ is i.i.d. with variance $\sigma_{z,j}^2$ for $j = 1, 2, \ldots, N$. The variance of this prior is estimated by the financial markets as $\widetilde{\sigma}_{z,j}^2$.

It should be noted that the paper follows the definition of Geraats (2002) and defines transparency as the absence of asymmetric information between policymakers and financial markets. The paper focuses exclusively on what Geraats (2006) refers to as the information effect of transparency—that is, the effect of giving the private sector new information to act upon. It does not investigate

[8] This prior could have been derived as a result of some previous communication by committee members about their preferences.

the indirect incentive effects of transparency, whereby the committee members would adjust their behavior according to which information is disclosed. These incentive effects are particularly relevant for the question of whether voting records should be published. There certainly is a concern that if the European Central Bank were to publish voting records, this would induce members of the Governing Council to vote for the optimal interest rate of the country they represent (Issing 1999; Gersbach and Hahn 2005). Strategic voting behavior has received considerable attention in the theoretical literature.[9] However, policymakers themselves do not believe that strategic considerations play an important role in policy meetings. For instance, Yellen (2005) claims that "in fact, I think FOMC members behave far less individualistically and strategically than assumed in some of these models."

The timing of events in any period t is as follows: First, each committee member receives a signal on the innovation to the current supply shock (denote this stage as t_{first}). Subsequently, the financial markets receive the public information $x_t^{(j)}$ and rationally form expectations of inflation and short-term nominal interest rates. The committee then meets, deliberates, votes on an interest rate by majority, and publishes its interest rate decision (t_{third}). The committee may also publish its voting records (t_{fourth}).[10] Finally, and before the beginning of period $t+1$, the supply shock, s_t, is realized and observed by both the committee and the financial markets.

3. Solving the Model

3.1 Committee Decision Making

When the committee meets and deliberates, each committee member combines his signal on the innovation to the supply shock with those

[9] An extensive overview of the game-theoretic literature that includes an analysis of strategic voting behavior of committee members and its relevance for monetary policy committees has been provided by Gerling et al. (2003).

[10] We hence assume that the publication of voting records occurs in between policy meetings. In the case of the Bank of England, for example, voting records and minutes are published at 9:30 a.m. on the Wednesday thirteen days after the monthly committee decision, so that they are available to the public before the committee next meets.

of the other members in order to form an assessment of the state of the economy in period t.[11] The optimal combination of signals for each committee member j is a linear combination of all signals with the weights determined by the precision of signals:

$$\widetilde{v}_t^{(j)} = v_t + \widetilde{\mathbf{B}}_{j,t}\left[\varepsilon_t^{(1)} \ \ \varepsilon_t^{(2)} \ \ \ldots \ \ \varepsilon_t^{(N)}\right]' \tag{15}$$

for $j = 1, 2, \ldots, N$. The weights given to the different signals, the vector $\widetilde{\mathbf{B}}_{j,t}$, is given by (44). It follows that $E_t(\widetilde{v}_t^j) = v_t$ and that $Var(\widetilde{v}_t^j) = \sigma_v^2 + \widetilde{\mathbf{B}}_{j,t}\mathbf{\Omega}\widetilde{\mathbf{B}}_{j,t}'$.

Committee members can form an optimal assessment of the innovation to the supply shock for period t using (15) and the fact that the innovation to the supply shock has zero mean. This assessment is given by[12]

$$v_{t|t}^{(j)} = \frac{\sigma_v^2}{\sigma_v^2 + \widetilde{\mathbf{B}}_{j,t}\widetilde{\mathbf{\Omega}}_{j,t}\widetilde{\mathbf{B}}_{j,t}'}\widetilde{v}_t^{(j)}, \tag{16}$$

where it is assumed that σ_v^2 is known to all committee members. An important characteristic of equation (16) is that the more precise the optimal combination of signals is perceived to be, the more weight it will be given by committee member j. In particular, the signal-extraction parameter, $\frac{\sigma_v^2}{\sigma_v^2 + \widetilde{\mathbf{B}}_{j,t}\widetilde{\mathbf{\Omega}}_{j,t}\widetilde{\mathbf{B}}_{j,t}'}$, will approach 0 as $\widetilde{\mathbf{B}}_{j,t}\widetilde{\mathbf{\Omega}}_{j,t}\widetilde{\mathbf{B}}_{j,t}' \rightarrow \infty$. If $\widetilde{\mathbf{B}}_{j,t}\widetilde{\mathbf{\Omega}}_{j,t}\widetilde{\mathbf{B}}_{j,t}' = 0$ and the optimally combined signal is perceived to be fully accurate, the signal-extraction parameter will be equal to 1.

The optimal prediction for the supply shock by member j in period t is given by

$$s_{t|t}^{(j)} = \alpha s_{t-1} + v_{t|t}^{(j)}, \tag{17}$$

where $v_{t|t}^{(j)}$ is given by (16). As long as $\widetilde{\mathbf{B}}_{j,t} \neq \widetilde{\mathbf{B}}_{k,t}$ for $j = 1, \ldots, N$, $k = 1, \ldots, N$, and $j \neq k$, it is true that $v_{t|t}^{(j)} \neq v_{t|t}^{(k)}$. Thus, there will

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[11] Signals are combined using the methods developed by Bates and Granger (1969) and Dickinson (1973) on the optimal combination of forecasts.

[12] The basic Kalman filtering formulae have been used with (15) as the observation equation. For a derivation of the Kalman filtering formulae, see, for example, Hamilton (1994).

be disagreement between committee members after the deliberation process when members vote on the interest rate. Actual voting data of MPCs (Gerlach-Kristen 2003, 2009) confirm this feature of the model.

The interest rate that will be voted for by each committee member j will equal

$$i_{t|t}^{(j)} = \left(1 + \frac{2}{1+\mu}\right) E_t\pi_{t+1} + E_t\pi_{t+2} - E_t i_{t+1} + \frac{2}{1+\mu}\left(s_{t|t}^{(j)} - \pi^*\right) - \frac{2\mu}{1+\mu}\theta^{(j)} \tag{18}$$

for $j = 1, 2, \ldots, N$.

Since monetary policy decisions are made by majority voting, the interest rate set by the committee is determined by the median voter:

$$i_{t|t}^{(c)} = median\left(i_{t|t}^{(1)}, i_{t|t}^{(2)}, \ldots, i_{t|t}^{(N)}\right). \tag{19}$$

3.2 Financial Markets

This section derives expressions for inflation and interest rate expectations of financial markets. In order to fully understand the role of the two information asymmetries in the model, in section 3.2.1 it is assumed that policy preferences of committee members are identical (and equal to y^*) and that financial markets face only uncertainty about the supply shock and the precision of public information. In section 3.2.2, uncertainty about committee members' preferences regarding the level of the output-gap target, $\theta^{(j)}$, is added.

3.2.1 Imperfect Common Knowledge about Signals and Their Precision

Financial markets solve a signal-extraction problem similar to that faced by committee members. The optimally combined public signal can be written as

$$\widetilde{v}_t^F = v_t + \widetilde{\mathbf{B}}_{F,t}\left[\zeta_t^{(1)} \;\; \zeta_t^{(2)} \;\; \ldots \;\; \zeta_t^{(N)}\right]', \tag{20}$$

where the vector $\widetilde{\mathbf{B}}_{F,t}$ is defined in equation (49). It follows that $E_t(\widetilde{v}_t^F) = v_t$ and that $Var(\widetilde{v}_t^F) = \sigma_v^2 + \widetilde{\mathbf{B}}_{F,t}\Omega_F\widetilde{\mathbf{B}}'_{F,t}$. Such a combination of the public information implies that the more accurate the public signal of a specific committee member is perceived to be by the markets, the more weight it will be given. This can provide an explanation for the finding by Ehrmann and Fratzscher (2007) that financial markets reacted significantly stronger to statements by Alan Greenspan than to statements by other FOMC members. Alan Greenspan might have been viewed by the markets as a particularly able policymaker with a precise observation on the state of the economy.[13]

Financial markets use (20) to form an optimal assessment of the innovation to the supply shock in period t:

$$v_{t|t}^{(F)} = \frac{\sigma_v^2}{\sigma_v^2 + \widetilde{\mathbf{B}}_{F,t}\widetilde{\mathbf{\Omega}}_{F,t}\widetilde{\mathbf{B}}'_{F,t}}\widetilde{v}_t^F. \tag{21}$$

The assessment of financial markets of the current supply shock equals

$$s_{t|t}^{(F)} = \alpha s_{t-1} + v_{t|t}^{(F)}. \tag{22}$$

The interest rate set by the median committee member is given by (8), where

$$s_{t|t}^{(CB)} = median\left(s_{t|t}^{(1)}, s_{t|t}^{(2)}, \ldots, s_{t|t}^{(N)}\right).$$

Inflation and the output gap are given by equations (10) and (11).

3.2.2 Imperfect Common Knowledge about Committee Members' Preferences

Financial markets continue to form an optimal estimate of the current supply shock as in section 3.2.1. However, financial markets also need to derive optimal estimates of committee members' output-gap target preferences. It will be shown how voting records provide financial markets with partial information about those preferences. It is first investigated how private-sector expectations are formed when voting records are not published.

[13] An alternative explanation for this empirical finding lies in the institutional power of the chairman.

Voting Records Are Not Published. In this case financial markets receive a signal on the output-gap target of the median voter in period t once the policy decision is published. However, in the next period, $t + 1$, the assessments of the innovation to the current supply shock by committee members have changed and the median voter is likely to be a different committee member than in period t. Thus the usefulness of the policy decision for deducing preferences of committee members is limited. Financial markets realize this and use their priors on committee members' preferences. Private-sector expectations of the median member's preferences are thus given by $z^C = median(z^{(1)}, z^{(2)}, \ldots, z^{(N)})$.

Voting Records Are Published. Voting records provide financial markets with information on the preferences of committee members. Financial markets know that the interest rate voted for by committee member j in period $t - 1$ follows

$$\begin{aligned} i^{(j)}_{t-1|t-1} = &\left(1 + \frac{2}{1+\mu}\right) E_{t-1}\pi_t + E_{t-1}\pi_{t+1} - E_{t-1}i_t \\ &+ \frac{2}{1+\mu}\left(s^{(j)}_{t-1|t-1} - \pi^*\right) - \frac{2\mu}{1+\mu}\theta^{(j)}. \end{aligned} \tag{23}$$

Thus, if market agents were able to observe $s^{(j)}_{t-1|t-1}$, they would be able to perfectly infer $\theta^{(j)}$ from the individual voting records. Unless committee members communicate their optimal assessment of the economy after deliberation has taken place, financial markets observe $s^{(j)}_{t-1|t-1}$ imperfectly. The estimate by financial markets of $s^{(j)}_{t-1|t-1}$ for all $j = 1, 2, \ldots, N$ is equal to $s^{(F)}_{t-1|t-1}$. Therefore the signal financial markets receive on $\theta^{(j)}$ in period $t - 1$ is given by

$$\xi^{(j)}_{t-1} = \theta^{(j)} + \frac{1}{\mu}\left[s^{(F)}_{t-1|t-1} - s^{(j)}_{t-1|t-1}\right], \tag{24}$$

where $E_{t-1}(\xi^{(j)}_{t-1}) = \theta^{(j)}$ and $E_{t-1}(\xi^{(j)}_{t-1} - \theta^{(j)})^2 = (\frac{1}{\mu})^2(E_{t-1}(s^{(F)}_{t-1|t-1} - s^{(j)}_{t-1|t-1})^2)$. It should be noted that the true variance of $\xi^{(j)}_{t-1}$ is unknown to financial markets. This variance is a function of the precision of committee members' observations on the innovation to the supply shock and the precision of the public information.

Financial markets can update their initial prior and derive a new assessment of $\theta^{(j)}$. In period $t-1$ after voting records have been published, the best assessment of $\theta^{(j)}$ equals

$$\theta^{(F,j)}_{t-1|t-1} = \theta^{(F,j)}_{t-1|t-2} + \frac{\widetilde{Var}\big(\theta^{(F,j)}_{t-1|t-2}\big)}{\widetilde{Var}\big(\theta^{(F,j)}_{t-1|t-2}\big) + \widetilde{Var}\big(\xi^{(j)}_{t-1}\big)}\big[\xi^{(j)}_{t-1} - \theta^{(F,j)}_{t-1|t-2}\big], \tag{25}$$

where the weights are written in perceived terms because the true variances are unknown to financial markets. Equation (25) shows that the best assessment of $\theta^{(j)}$ in period $t-1$, $\theta^{(F,j)}_{t-1|t-1}$, is a linear combination of the previous best assessment, $\theta^{(F,j)}_{t-1|t-2}$, and the signal on preferences contained in voting records, $\xi^{(j)}_{t-1}$. The more precise the signal on committee member j's preference, $\xi^{(j)}_{t-1}$, is perceived to be, the more weight it will be given in the signal-extraction procedure. If this signal is perceived to be perfectly accurate, $\widetilde{Var}(\xi^{(j)}_{t-1}) = 0$, then from (25) the best assessment of $\theta^{(j)}$ will equal $\xi^{(j)}_{t-1}$. If, on the other hand, $\widetilde{Var}(\xi^{(j)}_{t-1}) \rightarrow \infty$, then $\theta^{(F,j)}_{t-1|t-1} \rightarrow \theta^{(F,j)}_{t-1|t-2}$ and thus the weight given to the signal on preferences contained in voting records will turn to 0.

The best assessment of the median member's output-gap target in period t before voting records in that period are published is given by

$$z^C_{t|t} = median\big(\theta^{(F,1)}_{t-1|t-1}, \theta^{(F,2)}_{t-1|t-1}, \ldots, \theta^{(F,N)}_{t-1|t-1}\big). \tag{26}$$

It is assumed that the public ignores the uncertainty surrounding its estimates of the supply shock and the preference of the median policymaker and instead uses its own best estimates to form expectations of inflation and short-term nominal interest rates. In order to be able to obtain a closed-form expression for inflation expectations, the public is modeled as making the implicit assumption that the median voter also has the median output-gap target preference. This clearly need not be the case, since committee members' interest rate recommendations are determined both by their best assessment of the supply shock and their output-gap target preference.

Using (7), (22), and (26), we can derive private-sector expectations of inflation in period $t+1$ as

$$E_t\pi_{t+1} = \frac{\mu\alpha}{1+\mu(1-\alpha)} s_{t|t}^{(F)} + \pi^* + \mu z_{t|t}^C. \tag{27}$$

The public's expectation of the future short-term nominal interest rate can be written as

$$E_t i_{t+1} = \frac{2\alpha + \mu(1+\alpha)\alpha^2}{(1+\alpha)[1+\mu(1-\alpha)]} s_{t|t}^{(F)} + \pi^* + \mu z_{t|t}^C. \tag{28}$$

Therefore, the two-period real interest rate is given by

$$R_t = \frac{1}{2}\left(i_{t|t}^{(c)} - E_t\pi_{t+1}\right) + \frac{1}{2}(E_t i_{t+1} - E_t\pi_{t+2}), \tag{29}$$

where $i_{t|t}^{(c)}$ is given by (19). Substituting for R_t and $E_t\pi_{t+1}$ in (1) and (3) then yields inflation and the output gap under the publication of voting records. It is straightforward to derive inflation and the output gap when voting records are not published, the only difference being the financial markets' estimate of the median member's output-gap target.

4. Results

Sections 4.1 and 4.2 solve a version of the model with a single central banker under both perfect and imperfect knowledge of the central bank's output-gap target. Section 4.3 then turns to the committee case and investigates welfare when there is only uncertainty about the state of the economy and the precision of public information. Section 4.4 introduces imperfect information about preferences of committee members, and the desirability of publishing voting records is analyzed when committee members meet repeatedly over time.

The parameters and variances are set as follows: $\alpha = 0.8$, $\mu = 0.5$, and $\sigma_v^2 = 1$ and $\sigma_{z,j}^2 = 1$ for all $j = 1, 2, \ldots, N$. In addition, π^* and y^* are set to 2. For all simulations, the true variances, $\sigma_{\varepsilon,j}^2$ and $\sigma_{\varpi,j}^2$, and perceived variances, $\widetilde{\sigma}_{\varepsilon,t}^{2(k,j)}$ and $\widetilde{\sigma}_{\varpi,t}^{2(j)}$, are randomly drawn for each committee member $j = 1, \ldots, N$. The perceived and true variances are drawn as follows for each committee member: $\sigma^2 = (u^{(j)})^2$, where $u^{(j)} \sim N(0, \sqrt{\frac{1}{2}})$ and σ^2 can stand for the true variances, $\sigma^2_{\varepsilon,j}$ and $\sigma^2_{\varpi,j}$, or the perceived variances, $\widetilde{\sigma}^{2(k,j)}_{\varepsilon,t}$ and $\widetilde{\sigma}^{2(j)}_{\varpi,t}$. This implies that σ^2 is basically drawn from a χ^2_1 distribution, which has a variance of 1.[14] The covariance matrices—$\mathbf{\Omega}$, $\mathbf{\Omega}_F$, $\widetilde{\mathbf{\Omega}}_{j,t}$, and $\widetilde{\mathbf{\Omega}}_{F,t}$—are then computed. Given these covariance matrices, it is possible to draw random shocks with the covariance properties of the system being modeled. In all simulations, those random shocks are generated using 10,000 draws.

The baseline parameters are chosen so that the perceived and true variances on the signals received on the innovation to the supply shock are drawn from a distribution with a variance of 1. Given that the variance of the innovation to the supply shock, σ^2_v, is also set to 1, this seems a sensible baseline parameter specification. Section 4.5 considers the effects of changing the variance of $u^{(j)}$.

4.1 A Single Central Banker: Perfect Common Knowledge of Policy Preferences

It follows directly from (12) and section 3.1 that the best estimate of the innovation to the supply shock by the central banker is given by

$$v^{(CB)}_{t|t} = \frac{\sigma^2_v}{\sigma^2_v + \widetilde{\sigma}^{2(CB)}_{\varepsilon,t}} v^{(CB)}_t = \widetilde{\tau}_{CB} v^{(CB)}_t. \tag{30}$$

Similarly for financial markets, it can be deduced from (14) and section 3.2 that

$$v^{(F)}_{t|t} = \frac{\sigma^2_v}{\sigma^2_v + \widetilde{\sigma}^{2(F,CB)}_{\varepsilon,t} + \widetilde{\sigma}^{2(CB)}_{\varpi,t}} x^{(CB)}_t = \widetilde{\tau}_F x^{(CB)}_t. \tag{31}$$

In what follows, the optimal weights that should be given to the observation on the innovation to the supply shock by the central

[14] It is possible to convert $u^{(j)} \sim N(0, \sigma^2_u)$ into a standard normal random variable, $Z \sim N(0,1)$, where $Z = \frac{u^{(j)}}{\sigma^2_u}$. If a standard normal random variable is squared, it follows a χ^2_1 distribution with variance 2. Thus, in order to find the variance of $(u^{(j)})^2$, the variance of Z^2 needs to be multiplied by $(\sigma^2_u)^2$.

bank and the public information are defined as $\tau_{CB} = \frac{\sigma_v^2}{\sigma_v^2+\sigma_{\varepsilon,CB}^2}$ and $\tau_F = \frac{\sigma_v^2}{\sigma_v^2+\sigma_{\varepsilon,CB}^2+\sigma_{\varpi,CB}^2}$, respectively. These are the weights that would be given to the signal by the central bank and the public information if their precision were perfectly known. Furthermore, let $A_1 = \frac{\mu^2\alpha}{(1+\mu)[1+\mu(1-\alpha)]}$ and $A_2 = \frac{1}{1+\mu}$.

Using equations (10) and (11) as well as (12), (14), (17), and (22), the following expressions for inflation and the output gap are obtained:

$$\pi_t = (A_1 - A_2 + 1)\alpha s_{t-1} + [A_1\widetilde{\tau}_F - A_2\widetilde{\tau}_{CB} + 1]v_t + [A_1\widetilde{\tau}_F - A_2\widetilde{\tau}_{CB}]\varepsilon_t^{(CB)} + A_1\widetilde{\tau}_F\varpi_t^{(CB)} + \pi^* + \mu y^* \quad (32)$$

and

$$y_t = -\left(\frac{1}{\mu}A_1 + A_2\right)\alpha s_{t-1} - \left(\frac{1}{\mu}A_1\widetilde{\tau}_F + A_2\widetilde{\tau}_{CB}\right)\left(v_t + \varepsilon_t^{(CB)}\right) - \widetilde{\tau}_F\frac{1}{\mu}A_1\varpi_t^{(CB)}. \quad (33)$$

In the appendix it is shown the expected loss can be written as

$$E(L) = \frac{1}{2}\sigma_v^2\begin{bmatrix}\left(A_1^2\left(1+\frac{1}{\mu}\right) + 2A_1 - A_2 + 1\right)\frac{\alpha^2}{1-\alpha^2} \\ +(A_1\widetilde{\tau}_F)^2\left[1+\frac{1}{\mu}\right]\left[\frac{1}{\tau_F}\right] + A_2\widetilde{\tau}_{CB}^2\left[\frac{1}{\tau_{CB}}\right] \\ +2A_1\widetilde{\tau}_F - 2A_2\widetilde{\tau}_{CB} + 1\end{bmatrix}. \quad (34)$$

It is possible to evaluate how the overall loss depends on τ_{CB} and $\widetilde{\tau}_{CB}$ as well as τ_F and $\widetilde{\tau}_F$. It is straightforward to deduce that $\frac{\partial E(L)}{\partial \tau_{CB}} < 0$. Thus it is optimal for $\tau_{CB} = 1$. This is intuitive, as in this case the true variance of the signal received by the central bank is 0. Furthermore,

$$\frac{\partial E(L)}{\partial \widetilde{\tau}_{CB}} = 2A_2\left(\frac{\widetilde{\tau}_{CB}}{\tau_{CB}} - 1\right).$$

The sign of this derivative is ambiguous. As long as $\widetilde{\tau}_{CB} \leq \tau_{CB}$, the loss will be a decreasing function of $\widetilde{\tau}_{CB}$. Thus if the central bank receives a signal on the innovation that is fully accurate, $\tau_{CB} = 1$, it should understand that this is the case and use this signal as an estimate of the innovation to the supply shock.

It can easily be derived that $\frac{\partial E(L)}{\partial \tau_F} < 0$. The derivative of the loss with respect to $\widetilde{\tau}_F$ equals

$$\frac{\partial E(L)}{\partial \widetilde{\tau}_F} = 2A_1 \left(1 + A_1 \frac{\widetilde{\tau}_F}{\tau_F}\left(1 + \frac{1}{\mu}\right)\right) > 0.$$

Thus it is optimal for the central bank to provide perfect transparency, $\sigma^2_{\varpi,CB} = 0$, with regard to its information on the supply shock and therefore maximize τ_F, which is decreasing in $\sigma^2_{\varpi,CB}$. However, since the expected loss is increasing in $\widetilde{\tau}_F$, perceived transparency should be minimal in order to maximize $\widetilde{\sigma}^{2(CB)}_{\varpi,t}$ and thus minimize $\widetilde{\tau}_F$. These results are summarized in the following proposition.

PROPOSITION 1. *When the committee consists of a single central banker and there is perfect common knowledge of central bank output-gap preferences,*

(i) it is optimal for the central banker to be perfectly transparent about its observation on the innovation to the supply shock, and

(ii) transparency about the innovation to the supply shock as perceived by the financial markets should be minimal.

These results correspond to the results by Geraats (2007), who in contrast to this paper uses a model with no long-term interest rate and no uncertainty about the supply shock by the central bank. As Geraats (2007) explains, the intuition for this result is as follows: Actual transparency about the innovation to the supply shock reduces the noise of the public information on the supply shock and thus makes inflation expectations more stable, thereby reducing the variability in the output gap and inflation. Lower perceived transparency, on the other hand, reduces the response of private-sector expectations to the supply shock (as the less precise the signal is perceived to be, the less weight it will be given). This will lead to a smaller variability in inflation, and thus the central bank needs to adjust the short-term nominal interest rate by less to offset this increased variability in inflation, thereby muting the variability of the output gap.

4.2 A Single Central Banker: Asymmetric Information about Policy Preferences

The best estimates of the innovation to the supply shock by the central bank and the financial markets continue to be given by (30) and (31), respectively. However, in contrast to section 4.1, financial markets now need to derive an optimal estimate of the level of the output-gap target of the central bank, $\theta^{(CB)}$, in order to form expectations of inflation and nominal short-term interest rates.

Using equation (25), and assuming that voting records are published for the first time in period $t-1$, financial markets form the following estimate of the output-gap target for period t given their prior $z^{(CB)}$:

$$\theta_{t|t-1}^{(F,CB)} = (1-\widetilde{\tau}_{\xi})z^{(CB)} + \widetilde{\tau}_{\xi}\xi_{t-1}^{(CB)},$$

where $\widetilde{\tau}_{\xi} = \frac{\widetilde{\sigma}_z^2}{\widetilde{\sigma}_z^2 + \widetilde{Var}(\xi_{t-1}^{(CB)})}$. Thus, the more accurate the information on the central bank's policy preference contained in voting records is perceived to be, the more weight it will be given by the financial markets. When the perceived variance of the signal on the central bank's output-gap target contained in voting records is 0, $\widetilde{Var}(\xi_{t-1}^{(CB)}) = 0$, then $\widetilde{\tau}_{\xi} = 1$, so that the estimate of the output-gap target in period $t-1$ will be equal to the signal contained in voting records in that period. If, on the other hand, $\widetilde{Var}(\xi_{t-1}^{(CB)}) \rightarrow \infty$, then $\widetilde{\tau}_{\xi} \rightarrow 0$, so that the weight given to the prior, $z^{(CB)}$, will turn to 1.

Using equations (17), (22), and (24), and taking into account that there is only a single central banker, the variance of the signal on policy preferences, $\xi_{t-1}^{(CB)}$, can be written as follows:

$$Var\left(\xi_{t-1}^{(CB)}\right) = \left(\frac{1}{\mu}\right)^2 \left[E_{t-1}\left(v_{t-1|t-1}^{(F)} - v_{t-1|t-1}^{(CB)}\right)\right]^2.$$

Using equations (30) and (31), this expression can be simplified to

$$Var\left(\xi_{t-1}^{(CB)}\right) = \left(\frac{1}{\mu}\right)^2 \sigma_v^2 \left[\frac{\widetilde{\tau}_F^2}{\tau_F} + \frac{\widetilde{\tau}_{CB}}{\tau_{CB}}[\widetilde{\tau}_{CB} - 2\widetilde{\tau}_F]\right],$$

where the fact that $Var(\varepsilon_t^{(CB)}) = \frac{1-\tau_{CB}}{\tau_{CB}}\sigma_v^2$ and $Var(\varpi_t^{(CB)}) = (\frac{1}{\tau_F} - \frac{1}{\tau_{CB}})\sigma_v^2$ was used. Intuitively, when $\widetilde{\tau}_F = \widetilde{\tau}_{CB}$ and $\tau_F = \tau_{CB}$, the variance of the signal on policy preferences, $Var(\xi_{t-1}^{(CB)})$, is equal to 0. In this case, it follows from the definitions of τ_F and τ_{CB} in section 4.1 that $\sigma^2_{\varpi,CB} = 0$ and that the central bank communicates its signal on the innovation to the supply shock without any noise. In addition, since $\widetilde{\tau}_F = \widetilde{\tau}_{CB}$, the central bank and the private sector attach the same weight to their observations on the innovation to the supply shock. Thus, the information on preferences contained in voting records is perfectly accurate in this case.

Given the estimate of the output-gap target, $\theta_{t|t-1}^{(F,CB)}$, and the resulting private-sector expectations, inflation and the output gap can be derived using equations (1), (3), (18), (27), (28), and (29). Simplifying the resulting expression and substituting using the definitions of section 4.1, inflation can be written as follows:

$$\begin{aligned}\pi_t = {} & (A_1 - A_2 + 1)\alpha s_{t-1} + [A_1\widetilde{\tau}_F - A_2\widetilde{\tau}_{CB} + 1]v_t \\ & + [A_1\widetilde{\tau}_F - A_2\widetilde{\tau}_{CB}]\varepsilon_t^{(CB)} + A_1\widetilde{\tau}_F\varpi_t^{(CB)} + \pi^* + \mu A_2\theta^{(CB)} \\ & + A_2\mu^2\theta_{t|t-1}^{(F,CB)}. \qquad (35)\end{aligned}$$

Similarly, the output gap will be given by

$$\begin{aligned}y_t = {} & -\left(\frac{1}{\mu}A_1 + A_2\right)\alpha s_{t-1} - \left(\frac{1}{\mu}A_1\widetilde{\tau}_F + A_2\widetilde{\tau}_{CB}\right)\left(v_t + \varepsilon_t^{(CB)}\right) \\ & - \widetilde{\tau}_F\frac{1}{\mu}A_1\varpi_t^{(CB)} - \mu A_2\left[\theta_{t|t-1}^{(F,CB)} - \theta^{(CB)}\right]. \qquad (36)\end{aligned}$$

As shown in the appendix, the expected loss function can now be written as

$$\begin{aligned}E(L_{asym}) = {} & E(L) + \frac{1}{2}\sigma_v^2\frac{\mu}{1+\mu}\left[\widetilde{\tau}_\xi^2\left(\frac{\widetilde{\tau}_F^2}{\tau_F} + \frac{\widetilde{\tau}_{CB}}{\tau_{CB}}[\widetilde{\tau}_{CB} - 2\widetilde{\tau}_F]\right)\right. \\ & \left. + \widetilde{\tau}_\xi(\widetilde{\tau}_F - \widetilde{\tau}_{CB})\frac{\mu\alpha^2}{1+\mu(1-\alpha)}\right] + \frac{\mu^3}{1+\mu}(1-\widetilde{\tau}_\xi)^2\sigma_z^2.\end{aligned}$$

This is clearly decreasing in τ_F, making actual transparency again optimal. Intuitively, if the central bank communicates its observation on the innovation to the supply shock without error, then this improves the estimate of the supply shock of financial markets, making voting records a less noisy signal on the central bank's desired level of the output-gap target. Because the sign of $\frac{\partial Var(\xi_{t-1}^{(CB)})}{\partial \widetilde{\tau}_F}$ will depend on the sizes of $\widetilde{\tau}_F$, $\widetilde{\tau}_{CB}$, τ_F, and τ_{CB}, how welfare depends on $\widetilde{\tau}_F$ is ambiguous.

When the vote is not communicated to financial markets, financial markets will use their prior on the output-gap target of the central bank and thus $\widetilde{\tau}_\xi = 0$. The expected loss will then equal

$$E(L_{asym/nc}) = E(L) + \frac{\mu^3}{1+\mu}\sigma_z^2.$$

When voting records are not published, the findings of section 4.1 apply, and thus the expected loss is decreasing in τ_F and increasing in $\widetilde{\tau}_F$. Therefore, the central bank should be transparent about the supply shock and minimize $\sigma^2_{\varpi,CB}$. However, since the expected loss is increasing in $\widetilde{\tau}_F$, perceived transparency should be minimal.

It is straightforward to deduce that if $\widetilde{\tau}_F = \widetilde{\tau}_{CB}$ and $\tau_F = \tau_{CB}$, the expected loss when voting records are published becomes

$$E(L_{asym,\widetilde{\tau}_F=\widetilde{\tau}_{CB},\tau_F=\tau_{CB}}) = E(L) + \frac{\mu^3}{1+\mu}(1-\widetilde{\tau}_\xi)^2\sigma_z^2.$$

In this special case, publishing the vote is always preferable as long as $\sigma_z^2 > 0$. If $\sigma_z^2 = 0$, then the variance of the prior on preferences is 0, and thus the expected loss when voting records are published will be identical to the expected loss when they are not published.

From the above analysis it follows that as long as the difference between the perceived variance of the innovation to the supply shock of the central bank and the financial markets is sufficiently small and the central bank is transparent about its view on the innovation to the supply shock, publishing voting records will lead to a smaller expected loss compared with the case when voting records are not published.

The following proposition summarizes these findings.

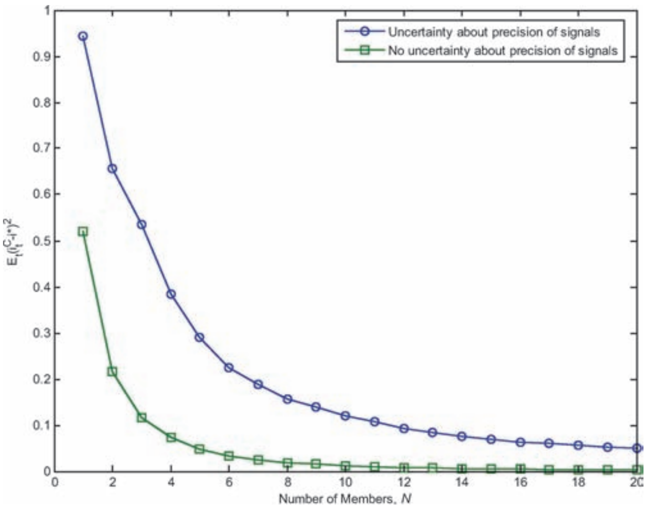
PROPOSITION 2. *When the committee consists of a single central banker and there is imperfect common knowledge of the central banker's preferred level of the output gap,* $\theta^{(CB)}$*,*

(i) it is optimal for the central banker to be perfectly transparent about its observation on the innovation to the supply shock;
(ii) if voting records are not published, transparency about the innovation to the supply shock as perceived by the financial markets should be minimal; and
(iii) publishing voting records will always be beneficial if the central bank is perfectly transparent and the central bank and the financial markets share the same perceived variance of the signal on the innovation to the supply shock.

4.3 The Committee Case: Perfect Common Knowledge of Policy Preferences

An interesting aspect of committee decision making is to analyze how the committee size influences welfare. One issue that can be evaluated is the average difference between the interest rate set by a committee of size N under uncertainty about the state of the economy and the interest rate set by the committee if the supply shock were perfectly known. This is depicted in figure 1 for $u^{(j)} \sim N(0, \sqrt{\frac{1}{2}})$. Figure 1 assumes that there is no communication by the committee with the financial markets, so that financial market expectations are independent of the committee size. The figure shows that a larger committee sets interest rates under uncertainty closer to the level that would be set if the supply shock were perfectly known. However, when there is imperfect knowledge about the true variances of observations, then a committee of size N will set an interest rate further away from the optimal interest rate than a committee that is not facing such imperfect knowledge. This is because when committee members are uncertain about the precision of members' observations on the innovation to the supply shock, they are not efficient at pooling those different information sets, resulting in a welfare loss compared with the case when the underlying variances of signals are known. In this case the policy error is not converging toward 0. Figure 1 also shows that the marginal benefit of having a larger committee is decreasing with the number of

Figure 1. Policy Errors under Different Committee Sizes



Notes: This figure depicts policy errors for different committee sizes, under both uncertainty and perfect knowledge of the precision of signals. Perceived and true variances are randomly drawn for $\sigma^2 = (u^{(j)})^2$, where $u^{(j)} \sim N(0, \sqrt{\frac{1}{2}})$. $E_t(i_t^C - i^*)^2$ denotes the average squared deviation of the interest rate set by the committee under uncertainty about the supply shock from the interest rate set if there was no such uncertainty.

members. Given that coordination costs are likely to be increasing with committee size (Sibert 2006), this may provide a partial explanation for the empirical fact that the size of committees is limited (Ehrhart, Lehment, and Vasquez-Paz 2007; Berger and Nitsch 2008; Berger, Nitsch, and Lybeck 2008). Whilst real-world MPCs vary greatly in size—ranging from three members at the Swiss National Bank to twenty-one at the European Central Bank—Berger, Nitsch, and Lybeck (2008) show that the median size is around seven to nine members.

It is possible to derive a general expression for the expected loss in the committee case. The optimal estimates of the innovation to the supply shock of committee members and financial markets are given by (16) and (21). Thus $\widetilde{\tau}_{CB}$ and $\widetilde{\tau}_F$ can be written as

$$\widetilde{\tau}_{CB} = \frac{\sigma_v^2}{\sigma_v^2 + \widetilde{\mathbf{B}}_{CB,t}\widetilde{\mathbf{\Omega}}_{CB}\widetilde{\mathbf{B}}'_{CB,t}} \text{ and } \widetilde{\tau}_F = \frac{\sigma_v^2}{\sigma_v^2 + \widetilde{\mathbf{B}}_{F,t}\widetilde{\mathbf{\Omega}}_{F,t}\widetilde{\mathbf{B}}'_{F,t}},$$

where $\widetilde{\tau}_{CB}$ denotes the weight given to the optimally combined observations by the median member and $\widetilde{\tau}_{CB}$ and $\widetilde{\tau}_F$ are the signal-extraction parameters in equations (16) and (21). The more accurate the optimally combined signal, $\widetilde{v}_t^{(CB)}$, is perceived to be by the median member, and thus the smaller is $\widetilde{\mathbf{B}}_{CB,t}\widetilde{\mathbf{\Omega}}_{CB}\widetilde{\mathbf{B}}'_{CB,t}$, the larger will be $\widetilde{\tau}_{CB}$. The same is true for the signal-extraction parameter of the financial markets, $\widetilde{\tau}_F$. In addition, define

$$\tau_{CB} = \frac{\sigma_v^2}{\sigma_v^2 + \widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}\widetilde{\mathbf{B}}'_{CB,t}} \text{ and } \tau_F = \frac{\sigma_v^2}{\sigma_v^2 + \widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t}}.$$

The parameters τ_{CB} and τ_F are similar to the signal-extraction parameters of equations (16) and (21). However, their size will depend on the true underlying variance of the combined signals on the innovation to the supply shock, $\widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}\widetilde{\mathbf{B}}'_{CB,t}$ and $\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t}$, rather than the perceived variances. Therefore, τ_{CB} will be decreasing in $\widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}\widetilde{\mathbf{B}}'_{CB,t}$. If $\widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}\widetilde{\mathbf{B}}'_{CB,t} = 0$, then $\tau_{CB} = 1$. If $\widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}\widetilde{\mathbf{B}}'_{CB,t} \rightarrow \infty$, $\tau_{CB} \rightarrow 0$. The same applies to τ_F, which is decreasing in $\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t}$.

The expected loss under the committee case is derived in the appendix, and it is shown that the expression is equivalent to the expected loss in the single central banker case, given by equation (34). The only difference is that $\widetilde{\tau}_{CB}$ is a function of all the perceived weights given to committee members by the median given to committee members by the median policymaker. Similarly, $\widetilde{\tau}_F$ will be a function of the perceived weights given by the public to the communication of each member. Thus, the loss is decreasing in τ_F and τ_{CB} and increasing in $\widetilde{\tau}_F$. Furthermore, if $\tau_{CB} \geq \widetilde{\tau}_{CB}$, the expected loss will be a decreasing function of $\widetilde{\tau}_{CB}$. Therefore, all committee members should be actually transparent and communicate their signals on the innovation to the supply shock without error (thereby minimizing $\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t}$ and maximizing τ_F) but perceived transparency should be minimized.[15] These theoretical findings are summarized in the following proposition.

PROPOSITION 3. *When the output-gap targets of committee members are identical and known to the public but there exists uncertainty about the precision of committee members' signals and communication,*

(i) actual transparency about committee members' observations on the innovation to the supply shock leads to lower variability in both inflation and the output gap and thus greater welfare, and
(ii) transparency as perceived by the financial markets should be minimal.

The intuition for these results is as follows. When committee members are perfectly transparent about their observations on the innovation to the supply shock, this reduces the noise in the public information on the supply shock. It can be easily inferred from equation (21) that the variance of the public's estimate of the innovation to the supply shock is a positive function of the variance of the combined public signals, i.e., $\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t}$. The variance of this optimally combined signal is given by (47). This is minimized when $\sigma^2_{\varpi,j} = 0$ for $j = 1, 2, \ldots, N$. When the noise in the public information on the supply shock is smaller, this makes inflation expectations more stable, thereby reducing the variability of inflation and the output gap. Lower perceived transparency, on the other hand, reduces the response of the private-sector expectations to the innovation to the supply shock. This again directly follows from equation (21). The larger is $\widetilde{\sigma}^{2(j)}_{\varpi,t}$, the smaller is $\widetilde{\tau}_F$, which is the weight given to $\widetilde{v}^F_t$ in (21). This will lead to a smaller variability in inflation, and thus the committee needs to adjust the short-term nominal interest rate by less, also muting the variability of the output gap.

In order to evaluate how the expected loss depends on the committee size, it needs to be investigated how $\tau_F, \tau_{CB}, \widetilde{\tau}_F$, and $\widetilde{\tau}_{CB}$ vary

[15] The fact that $\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t}$ is minimized for $\sigma^2_{\varpi,j} = 0$ where $j = 1, 2, \ldots, N$ directly follows from (47). Similarly, from expression (48) it can be deduced that $\widetilde{\mathbf{B}}_{F,t}\widetilde{\mathbf{\Omega}}_{F,t}\widetilde{\mathbf{B}}'_{F,t}$ is increasing in $\widetilde{\sigma}^{2(j)}_{\varpi,t}$.

with committee size. It is straightforward to deduce from expressions (46) and (48) that as $N \to \infty, \widetilde{\mathbf{B}}_{CB,t}\widetilde{\mathbf{\Omega}}_{CB,t}\widetilde{\mathbf{B}}'_{CB,t} \to 0$ and $\widetilde{\mathbf{B}}_{F,t}\widetilde{\mathbf{\Omega}}_{F,t}\widetilde{\mathbf{B}}'_{F,t} \to 0$. Thus, it follows from the discussion above that $\widetilde{\tau}_F$ and $\widetilde{\tau}_{CB}$ are increasing in N. How the true variances of the combined information, (45) and (47), vary with committee size is less obvious. Therefore, it is not clear whether τ_F and τ_{CB} are increasing or decreasing with committee size. However, when simulating τ_F and τ_{CB} under different committee sizes for $u^{(j)} \sim N(0, \sqrt{\frac{1}{2}})$, it is found that they are increasing with committee size. This is shown in figure 2. Thus, it follows that as N increases, $\widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}\widetilde{\mathbf{B}}'_{CB,t}$ and $\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t}$ decrease. In order to provide some intuition for this numerical finding, it is interesting to evaluate the expression for the true underlying variance of the combined signals, (45), when $N = 1$ and $N = 2$. It is straightforward to deduce that the true underlying variance is greater when $N = 1$ than when $N = 2$, if

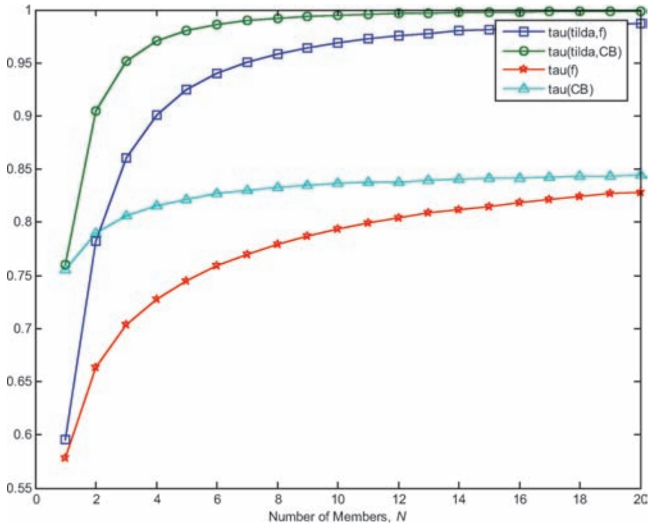
$$\frac{1}{\left(\widetilde{\sigma}^{2(j,2)}_{\varepsilon,t}\right)}\left(\sigma^2_{\varepsilon,1} - \sigma^2_{\varepsilon,2}\right) + 2\frac{\sigma^2_{\varepsilon,1}}{\widetilde{\sigma}^{2(j,1)}_{\varepsilon,t}} > 0.$$

This inequality will generally hold unless $\sigma^2_{\varepsilon,2}$ exceeds $\sigma^2_{\varepsilon,1}$ significantly. Figure 2 also shows that $\widetilde{\tau}_F$ and $\widetilde{\tau}_{CB}$ exceed τ_F and τ_{CB}. This is because as N increases, the perceived variances of the combined signals, (46) and (48), decrease more rapidly than the true variances, (45) and (47).

It is now possible to evaluate numerically how welfare varies with committee size. The model is simulated assuming that $u^{(j)} \sim N(0, \sqrt{\frac{1}{2}})$. As figure 3 shows, as N increases, the expected loss decreases but there is a decreasing marginal benefit of adding further committee members. Given that there are costs associated with larger committees, such as coordination costs, this supports the conclusion of the previous literature that a committee of limited size is optimal.

The intuition for these results is as follows: As N increases, both $\widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}\widetilde{\mathbf{B}}'_{CB,t}$ and $\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t}$ decrease whilst τ_{CB} and τ_F increase. This reduces the variability of inflation and the output gap and thus increases welfare. However, $\widetilde{\mathbf{B}}_{F,t}\widetilde{\mathbf{\Omega}}_{F,t}\widetilde{\mathbf{B}}'_{F,t}$ also decreases. Thus, $\widetilde{\tau}_F$ increases, which reduces welfare. The numerical results show that the first effect dominates. Therefore, at least for the

Figure 2. Signal-Extraction Parameters



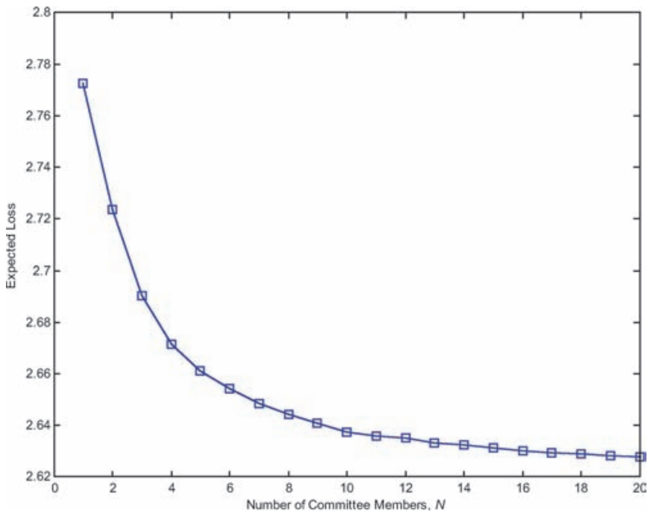
Notes: The figure depicts the weights given to the combined signals by committee members and financial markets for $u^{(j)} \sim N(0, \sqrt{\frac{1}{2}})$. It should be noted that tau(tilda,f) denotes $\widetilde{\tau}_F$ in the text. Similarly, tau(tilda,CB) $= \widetilde{\tau}_{CB}$, tau(f) $= \tau_F$, and tau(CB) $= \tau_{CB}$.

parameter configuration considered here, when N increases, the benefit of reducing the noise in both the median member's and the public's assessment of the innovation to the supply shock outweighs the costs of increasing the response of the private-sector expectations to the innovation to the supply shock.

4.4 The Committee Case: Asymmetric Information about Policy Preferences

This section investigates how the expected loss varies over time for a given committee size, if committee members not only face uncertainty about the supply shock but also have different preferences regarding the desired level of the output gap. Financial markets have imperfect information about both the state of the economy and the policy preferences of committee members. It is assumed furthermore that committee members are appointed in the same period and meet repeatedly over time.

Figure 3. Welfare under Different Committee Sizes



Notes: This figure depicts welfare under different committee sizes when output-gap targets by committee members are identical and there is no uncertainty about them and for $u^{(j)} \sim N(0, \sqrt{\frac{1}{2}})$.

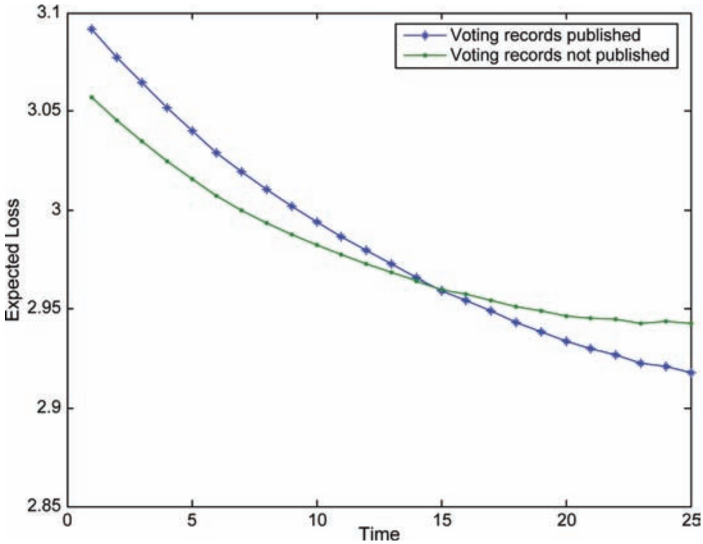
After the committee has met, the true supply shock in that period is revealed to all committee members. It is hence possible for each member to observe $v_t^{(j)} - v_t$, and this difference can be used to update the previous estimate of the variance of that committee member's observation. As shown in the appendix, estimates of the variance of observations converge over time as the asymmetry in assessing precision matrices disappears. Similarly, financial markets observe $x_t^{(j)} - v_t$ after the policy decision has been made in period t. This means that they can calculate their estimate of $\widetilde{\sigma}_{\zeta,t}^{2(j)}$ using (50). Over time, the initial prior will be given less and less weight and hence the estimated variance of financial markets, $\widetilde{\sigma}_{\zeta,t}^{2(j)}$, will converge to the true variance, $\sigma_{\zeta,j}^2$.

Given these results on the convergence of perceived and actual variances over time, it is possible to evaluate under which circumstances it is beneficial to publish voting records. In the simple version with just one central banker, it was shown that if the optimal and perceived weights given to the information on the supply shocks are identical between the central bank and the financial markets, then publishing voting records will be beneficial. In this case, the signal on the preference of the central bank regarding the level of the output-gap target is perfectly accurate. Thus as long as the difference between the optimal and perceived weights is not too significant, publishing voting records is welfare enhancing.

Whether or not this result holds in the committee case has to be numerically evaluated. In the committee case, when $N > 1$, it is no longer possible to find closed-form solutions for the expected loss when there is imperfect information regarding the output-gap targets of committee members. However, we can simulate the model for N members and evaluate how the expected loss varies over time, comparing the case when voting records are published with the case when they are not. As is illustrated in figure 4 for $u^{(j)} \sim N(0, \sqrt{\frac{1}{2}})$ and $N = 9$, the expected loss is generally decreasing over time as policymakers and financial markets learn the optimal weights, which they should use in the signal-extraction process. Initially, welfare is greater when voting records are not published. This changes over time, when the publication of voting records eventually becomes beneficial.

The intuition for these results is as follows: It can be seen from equation (25) that for each committee member j, the weight given to the noisy signal of j's output-gap target preference in period t depends on the perceived precision of the information on θ^j contained in the voting records in period $t-1$, i.e., $\widetilde{Var}(\xi^{(j)}_{t-1})$. This is a function of the perceived expected squared deviation of the best assessment of the supply shock of financial markets from the best assessment of committee member j, i.e., $\widetilde{E}_{t-1}(s^{(F)}_{t-1|t-1} - s^{(j)}_{t-1|t-1})^2$. Because of the uncertainty about the true variances of the public information, initially there may be too much or too little weight given to the information contained in voting records, relative to what is optimal. However, over time the true variances of the public information, $\sigma^2_{\zeta,j}$, will be learned by the financial markets. Thus, the weight given to the information on j's output-gap target contained in voting records will become more accurate. In addition, voting records become a less noisy signal on the true preferences of committee members as the estimates of the supply shock by the financial markets and committee members are converging to each other. Thus, whilst there may be losses in welfare in the short term

Figure 4. Welfare under Different Communication Strategies of the Committee



Notes: Time denotes the number of meetings of a committee in which all members are appointed at the same time. The model is simulated for a committee with $N = 9$ members and $u^{(j)} \sim N(0, \sqrt{\frac{1}{2}})$.

when voting records are published, eventually, publishing voting records becomes beneficial.

From equation (25) it can be deduced that the variance of the updated estimates of policymakers' preferences, $Var(\theta^{(F,j)}_{t-1|t-1})$, is a function of $Var(\xi^{(F,j}_{t-1})$. This in turn is a function of $E_t[(v^{F}_{t-1|t-1} - v^{(j)}_{t-1|t-1})]^2$ and hence the actual communication error of the committee. Using equations (15), (16), (20), and (21), it is straightforward to show that $E_t[(v^{(F)}_{t-1|t-1} - v^{(j)}_{t-1|t-1})]^2 = \widetilde{B}_{F,t}\Omega_F\widetilde{B}'_{F,t} + \widetilde{B}_{j,t}\Omega\widetilde{B}'_{j,t} - 2\widetilde{B}_{F,t}\Omega\widetilde{B}'_{j,t}$. From (47), it can be seen that $\widetilde{B}_{F,t}\Omega_F\widetilde{B}'_{F,t}$ is minimized when $\sigma^2_{\omega,j} = 0$ for $j = 1, 2, \ldots, N$. Therefore, the more transparent the committee is about the signals it receives on the innovation to the supply shock (i.e., the smaller $\sigma^2_{\varpi,j}$), the smaller will be the possible short-term loss of publishing voting records.

Thus, when there are two sources of information asymmetry between the committee and financial markets, it is still optimal for committee members to be actually transparent about the state of the economy. Even if there is full transparency about the economic outlook, depending on the differences between perceived and actual variances, there may be a short-term welfare loss from publishing voting records resulting from the uncertainty about the precision of public information. Morris and Shin's (2002) finding that financial markets may overreact to the public information (here the information contained in voting records) hence may hold in the short run.

Ehrmann and Fratzscher (2005) analyze the communication strategies pursued by the Bank of England, the European Central Bank, and the Federal Reserve between January 1999 and May 2004 and show that the predictability of policy decisions decreases when the committee communicates its diverging views about policy decisions. Our theoretical model provides an explanation for this result in the short term.

Empirical findings by Geraats (2009) using a sample of ninety-eight central banks show that in 2006 only ten of those central banks published their voting records, whereas fifty-six published numerical economic forecasts. In addition, only five central banks released individual voting records. The other five only published non-attributed voting patterns. This paper provides a partial explanation of this finding because it shows that transparency about the state of the economy is always beneficial, whereas there may be short-term losses from the publication of voting records.

It should be noted that these results are based on the simulation of a committee in which committee members that are appointed in the same period do not change over time. In practice, committee members are not appointed at the same time and their terms are staggered. This means that the overall uncertainty about policymakers' observation errors should be roughly constant over time. This procedure might be able to ensure that the uncertainty about the precision of the public information is never large enough to make the publication of voting records undesirable and could be beneficial in this respect.[16]

[16] On the other hand, short staggered terms, in which membership changes quite frequently, could ensure that uncertainty remains sufficiently high to make the publication of voting records detrimental.

Table 1. Sensitivity Analysis of Figure 1

N	Unknown Signal Precision $E_t(i_t^C - i^*)^2$		Known Signal Precision $E_t(i_t^C - i^*)^2$	
	$u^{(j)} \sim N(0, 0.25)$	$u^{(j)} \sim N(0, 1)$	$u^{(j)} \sim N(0, 0.25)$	$u^{(j)} \sim N(0, 1)$
1	0.4494	1.2358	0.2842	0.6075
2	0.2596	0.8944	0.0965	0.2882
3	0.2136	0.7733	0.0455	0.1571
4	0.1517	0.5256	0.0260	0.0953
5	0.1134	0.4101	0.0167	0.0608
6	0.0849	0.3150	0.0119	0.0439
7	0.0693	0.2589	0.0088	0.0329
8	0.0596	0.2166	0.0067	0.0252
9	0.0499	0.1899	0.0053	0.0207
10	0.0424	0.1649	0.0043	0.0169
11	0.0379	0.1500	0.0037	0.0145
12	0.0338	0.1299	0.0031	0.0122
13	0.0307	0.1175	0.0027	0.0107
14	0.0275	0.1074	0.0023	0.0091
15	0.0253	0.0992	0.0020	0.0078

Notes: This table depicts policy errors for different committee sizes. $E_t(i_t^C - i^*)^2$ denotes the average squared deviation of the interest rate set by the committee under uncertainty about the supply shock from the interest rate set if there was no such uncertainty.

4.5 Sensitivity Analysis

The model considered in this paper is highly stylized and, as such, the numerical results are likely to depend on its precise parameter specification. This section evaluates the sensitivity of the numerical results in sections 4.3 and 4.4 to the distribution of $u^{(j)}$. Two alternative specifications are considered—$u^{(j)} \sim N(0, 1)$ and $u^{(j)} \sim N(0, 0.25)$—compared with the benchmark case of $u^{(j)} \sim N(0, \sqrt{\frac{1}{2}})$. When $u^{(j)} \sim N(0, 1)$, the variance of the χ_1^2 distribution from which σ^2 is drawn is 2. When $u^{(j)} \sim N(0, 0.25)$, this variance will equal 0.125.

Tables 1 and 2 show that the qualitative results are broadly similar to those discussed in section 4.3 when $u^{(j)} \sim N(0, 1)$ and $u^{(j)} \sim N(0, 0.25)$. However, it is interesting to note that when $u^{(j)} \sim N(0, 0.25)$, the expected loss is generally smaller for different

Table 2. Sensitivity Analysis of Figures 2 and 3

Signal-Extraction Parameters and Expected Loss, Perfect Common Knowledge of y*						
	$u^{(j)} \sim N(0,1)$			$u^{(j)} \sim N(0,0.25)$		
N	τ_F	τ_{CB}	EL	τ_F	τ_{CB}	EL
1	0.4614	0.6533	3.0163	0.7720	0.8450	2.6053
2	0.5204	0.6899	3.0030	0.7827	0.8715	2.5830
3	0.5604	0.7063	2.9932	0.8131	0.8812	2.5698
4	0.5874	0.7164	2.9821	0.8306	0.8873	2.5591
5	0.6103	0.7244	2.9741	0.8433	0.8914	2.5525
6	0.6269	0.7301	2.9704	0.8531	0.8940	2.5498
7	0.6393	0.7355	2.9685	0.8611	0.8962	2.5471
8	0.6516	0.7396	2.9648	0.8668	0.8971	2.5457
9	0.6629	0.7436	2.9628	0.8719	0.8984	2.5440
10	0.6698	0.7446	2.9607	0.8762	0.8999	2.5435
11	0.6773	0.7467	2.9595	0.8793	0.9009	2.5427
12	0.6841	0.7481	2.9590	0.8825	0.9012	2.5421
13	0.6902	0.7490	2.9584	0.8851	0.9018	2.5412
14	0.6965	0.7496	2.9578	0.8874	0.9027	2.5410
15	0.7018	0.7508	2.9575	0.8894	0.9031	2.5401

Notes: This table depicts the signal-extraction parameters attached to the combined signals by committee members and financial markets and the expected loss (EL) under different committee sizes when the output-gap targets of committee members are identical and known to the markets.

committee sizes than in the baseline simulation shown in figure 3. On the other hand, when $u^{(j)} \sim N(0,1)$, the expected loss is generally greater than in the benchmark case. This is because the larger the variance of $u^{(j)}$, the more different are the perceived and actual variances on average. This decreases welfare, as committee members are less efficient at pooling the different information sets and financial markets are less able to attach a correct weight to the public information.

The sensitivity of the results in section 4.4 to different parameter specifications is also evaluated. In addition to the two alternative specifications considered above, $u^{(j)} \sim N(0, 0.5)$ is also considered. In this case, $(u^{(j)})^2$ will be drawn from a χ^2_1 distribution

Table 3. Sensitivity Analysis of Figure 4

Expected Loss, Imperfect Common Knowledge of $\theta^{(j)}$							
	$u^{(j)} \sim N(0, 0.25)$		$u^{(j)} \sim N(0, 0.5)$			$u^{(j)} \sim N(0, 1)$	
Time	**VR**	**NR**	**VR**	**NR**	**Time**	**VR**	**NR**
1	2.4671	2.5548	2.7035	2.6835	1	4.2670	3.4198
2	2.3639	2.4745	2.6884	2.6690	3	3.9072	3.2562
3	2.2842	2.4181	2.6699	2.6533	5	3.6061	3.1143
4	2.2102	2.3650	2.6516	2.6381	7	3.3764	2.0050
5	2.1533	2.3260	2.6323	2.6233	9	3.2053	2.9263
6	2.1112	2.2954	2.6137	2.6098	11	3.0810	2.8726
7	2.0818	2.2718	2.5964	2.5981	13	2.9960	2.8363
8	2.0626	2.2507	2.5816	2.5887	15	2.9314	2.8059
9	2.0482	2.2347	2.5695	2.5814	17	2.8676	2.7735
10	2.0393	2.2228	2.5535	2.5758	19	2.8035	2.7436
11	2.0391	2.2143	2.5486	2.5715	21	2.7517	2.7377
12	2.0388	2.2095	2.5450	2.5678	23	2.7130	2.7316
13	2.0387	2.2093	2.5421	2.5643	25	2.6928	2.7217
14	2.0484	2.2091	2.5395	2.5608	27	2.6674	2.7173
15	2.0383	2.2089	2.5322	2.5571	29	2.6466	2.7116

Notes: This table shows the expected loss when voting records are published (VR) and when they are not published (NR) over time. Time denotes the number of meetings of a committee in which all members are appointed at the same time. The model is simulated for a committee with $N = 9$ members.

with variance 0.5. The qualitative results of section 4.4 are sensitive to the distribution of $u^{(j)}$ and thus it is interesting to evaluate a larger number of parameter specifications and to analyze for which specifications the results hold. Table 3 shows the expected loss over time for $N = 9$. The simulation results in table 3 for $u^{(j)} \sim N(0, 1)$ and $u^{(j)} \sim N(0, 0.5)$ confirm the results of section 4.4 shown in figure 4. For these parameter specifications, initially the publication of voting records is not beneficial. It can be seen that the publication of voting records is detrimental for a longer period of time than in the benchmark case when $u^{(j)} \sim N(0, 1)$. This is intuitive, as the differences between perceived and actual variances will be larger in this case. When $u^{(j)} \sim N(0, 0.5)$, the period of time during which the publication of voting records is detrimental is shorter than in the benchmark case since the initial difference between perceived and actual variance is smaller than in the baseline simulations. However, if the initial difference between perceived and actual variances is sufficiently small, then the publication of voting records is always welfare improving, as the results for $u^{(j)} \sim N(0, 0.25)$ show. Therefore, whether or not there is a short-term loss from publishing voting records is not independent of the parameters used in the simulation. The publication of voting records will only be detrimental in the short run if the initial difference between perceived and actual variances is sufficiently large.

5. Conclusion

Recently, there has been a growing number of theoretical and empirical papers investigating the optimal degree of transparency and communication of central banks. This paper addresses these questions within a model of a monetary policy committee with heterogeneous members whose communications and public decisions are observed by the financial markets.

The results show that it is optimal for the committee to be transparent about information regarding the current state of the economy. However, perceived transparency should be minimal. Moreover, there may be losses from publishing voting records and thereby revealing possible disagreement within the committee regarding the policy decision. This is because financial markets might overreact to the information contained in voting records, depending on their ability to estimate the true precision of the information on preferences contained in voting records. Financial markets can learn about the precision of the public information, which will make voting records less noisy and financial markets become better at attaching the correct weight to this information. Thus, in the long run, the publication of voting records is always beneficial. If committee members' terms are staggered, this might ensure that uncertainty is never large enough to make the publication of voting records undesirable, and such an institutional setup could prove useful in this respect.

There are also implications for the optimal design of monetary policy committees. It is found that a committee of limited size is optimal since there are decreasing marginal benefits of adding additional members and coordination costs are likely to increase as the committee size gets larger. Furthermore, uncertainty about the precision of members' observations on the economy is welfare reducing. Such uncertainty should be kept at a minimum, and therefore it would be detrimental to replace all members at the same time. Staggering might again be beneficial.

Some useful directions for further research should be noted. Whilst the paper builds a model of individualistic decision making, in practice, monetary policy committees around the world use different decision-making strategies. Decisions could be made by consensus or by a committee with a chairman that dominates the proceedings. It would be interesting to make the model more applicable to such different decision-making processes and to investigate how the optimal communication strategy of a central bank depends on the decision-making procedure of its monetary policy committee.

Appendix

Finding a Solution for Private-Sector Expectations under Certainty

To find a rational-expectations equilibrium, the technique of undetermined coefficients is employed, where the bubble-free solution is obtained through a minimal-state-variable procedure as outlined by McCallum (1983). The best guess is that the nominal interest rate will be of the form

$$i_t = a_0 s_t + a_1 \pi^* + a_2 y^*. \tag{37}$$

Taking expectations and shifting the time index one period ahead gives

$$E_t i_{t+1} = a_0 \alpha s_t + a_1 \pi^* + a_2 y^*. \tag{38}$$

Using (1) together with (3) and (4) yields the following expression for inflation:

$$\pi_t = E_t \pi_{t+1} - \frac{1}{2}[i_t - E_t \pi_{t+1} + E_t i_{t+1} - E_t \pi_{t+2}] + s_t. \tag{39}$$

It is apparent that π_t will be of the form

$$\pi_t = b_0 s_t + b_1 \pi^* + b_2 y^*. \tag{40}$$

Thus

$$E_t \pi_{t+1} = b_0 \alpha s_t + b_1 \pi^* + b_2 y^* \tag{41}$$

and

$$E_t \pi_{t+2} = b_0 \alpha^2 s_t + b_1 \pi^* + b_2 y^*. \tag{42}$$

Substituting (37), (38), (41), and (42) into (39) and comparing the resulting expression with (40) yields the following:

$$b_0 = \frac{2 - a_0(1+\alpha)}{2 - \alpha(3+\alpha)}, b_1 = a_1 \text{ and } b_2 = a_2.$$

The above solution can be substituted into (40) to obtain an expression for inflation as a function of the coefficients a_i. Similarly, expressions for $E_t \pi_{t+1}$ and $E_t \pi_{t+2}$ in terms of a_i can be obtained. Together with (37) and (38), an expression for the output gap as a function of a_i can be found. To deduce the coefficients a_i, the optimality condition is used, substituting for y_t and π_t to determine the values for a_i such that (6) is satisfied. After some algebra, it is found that

$$a_0 = \frac{2 + \mu(1+\alpha)\alpha}{(1+\alpha)[1 + \mu(1-\alpha)]}, a_1 = 1, \text{ and } a_2 = \mu. \text{ Thus}$$
$$b_0 = \frac{\mu}{[1 + \mu(1-\alpha)]}.$$

The Signal-Extraction Problem of Committee Members

The optimally combined signal is a linear combination of all observations for committee member j:

$$\widetilde{v}_t^{(j)} = b_{j1} v_t^{(1)} + b_{j,2} v_t^{(2)} + b_{j,3} v_t^{(3)} + \ldots + b_{j,N} v_t^{(N)},$$

where the weights must add up to 1. Let $\widetilde{\mathbf{B}}_{j,t} = \begin{bmatrix} b_{j1} & b_{j2} & \ldots & b_{jN} \end{bmatrix}$; then the true variance of $\widetilde{v}_t^{(j)}$ is

$$E_t\left(\widetilde{v}_t^{(j)} - v_t\right)^2 = E\left(\left(\widetilde{\mathbf{B}}_{j,t}\left[\varepsilon_t^{(1)}\ \ \varepsilon_t^{(2)}\ \ \ldots\ \ \varepsilon_t^{(N)}\right]'\right)\right.$$
$$\left.\times\left(\widetilde{\mathbf{B}}_{j,t}\left[\varepsilon_t^{(1)}\ \ \varepsilon_t^{(2)}\ \ \ldots\ \ \varepsilon_t^{(N)}\right]'\right)'\right)$$
$$= \widetilde{\mathbf{B}}_{j,t}\mathbf{\Omega}\widetilde{\mathbf{B}}'_{j,t}, \tag{43}$$

where $\mathbf{\Omega}$ is an $N \times N$ diagonal covariance matrix where the diagonal elements are given by the true variances of members' signals.

Since the true variance is unknown, committee member j needs to use the matrix of perceived variances, $\widetilde{\mathbf{\Omega}}_{j,t}$. This is an $N \times N$ diagonal matrix where the diagonal elements are given by member j's estimated variances for members 1 to N. In order to optimally combine signals, members minimize $\widetilde{\mathbf{B}}_{j,t}\widetilde{\mathbf{\Omega}}_{j,t}\widetilde{\mathbf{B}}'_{j,t}$ subject to the constraint that $\mathbf{i}\mathbf{B}'_j = 1$, where $\mathbf{i} = \underset{1xN}{[1\ \ 1\ \ \ldots\ \ 1]}$. The Lagrangian of this problem can be written as

$$L = \widetilde{\mathbf{B}}_{j,t}\widetilde{\mathbf{\Omega}}_{j,t}\widetilde{\mathbf{B}}'_{j,t} - \lambda[\mathbf{i}\mathbf{B}'_j - 1].$$

Two first-order conditions are obtained:

$$2\widetilde{\mathbf{B}}_{j,t}\widetilde{\mathbf{\Omega}}_{j,t} - \lambda\mathbf{i} = 0 \text{ and } \left[\mathbf{i}\mathbf{B}'_j - 1\right] = 0.$$

These can be solved to obtain that

$$\widetilde{\mathbf{B}}_{j,t} = \frac{\mathbf{i}\widetilde{\mathbf{\Omega}}_{j,t}^{-1}}{\mathbf{i}\widetilde{\mathbf{\Omega}}_{j,t}^{-1}\mathbf{i}'}. \tag{44}$$

The true underlying variance of the combined signals equals

$$\widetilde{\mathbf{B}}_{j,t}\mathbf{\Omega}\widetilde{\mathbf{B}}'_{j,t} = \frac{\mathbf{i}\widetilde{\mathbf{\Omega}}_{j,t}^{-1}}{\mathbf{i}\widetilde{\mathbf{\Omega}}_{j,t}^{-1}\mathbf{i}'}\mathbf{\Omega}\left[\frac{\mathbf{i}\widetilde{\mathbf{\Omega}}_{j,t}^{-1}}{\mathbf{i}\widetilde{\mathbf{\Omega}}_{j,t}^{-1}\mathbf{i}'}\right]'$$
$$= \frac{\frac{1}{\left(\widetilde{\sigma}_{\varepsilon,t}^{2(j,1)}\right)^2}\sigma_{\varepsilon,1}^2 + \frac{1}{\left(\widetilde{\sigma}_{\varepsilon,t}^{2(j,2)}\right)^2}\sigma_{\varepsilon,2}^2 + \cdots + \frac{1}{\left(\widetilde{\sigma}_{\varepsilon,t}^{2(j,N)}\right)^2}\sigma_{\varepsilon,N}^2}{\left(\frac{1}{\widetilde{\sigma}_{\varepsilon,t}^{2(j,1)}} + \frac{1}{\widetilde{\sigma}_{\varepsilon,t}^{2(j,2)}} + \cdots + \frac{1}{\widetilde{\sigma}_{\varepsilon,t}^{2(j,N)}}\right)^2}. \tag{45}$$

The perceived variance of the combined signal is equal to

$$\widetilde{\mathbf{B}}_{j,t}\widetilde{\mathbf{\Omega}}_{j,t}\widetilde{\mathbf{B}}'_{j,t} = \frac{1}{\frac{1}{\widetilde{\sigma}^{2(j,1)}_{\varepsilon,t}} + \frac{1}{\widetilde{\sigma}^{2(j,2)}_{\varepsilon,t}} + \cdots + \frac{1}{\widetilde{\sigma}^{2(j,N)}_{\varepsilon,t}}}. \tag{46}$$

The Signal-Extraction Problem of Financial Markets

The solution is identical to section 5. The true variance of the combined public signal equals

$$\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t} = \frac{\frac{1}{\left(\widetilde{\sigma}^{2(1)}_{\zeta,t}\right)^2}\sigma^2_{\zeta,1} + \frac{1}{\left(\widetilde{\sigma}^{2(2)}_{\zeta,t}\right)^2}\sigma^2_{\zeta,2} + \cdots + \frac{1}{\left(\widetilde{\sigma}^{2(N)}_{\zeta,t}\right)^2}\sigma^2_{\zeta,N}}{\left(\frac{1}{\widetilde{\sigma}^{2(1)}_{\zeta,t}} + \frac{1}{\widetilde{\sigma}^{2(2)}_{\zeta,t}} + \cdots + \frac{1}{\widetilde{\sigma}^{2(N)}_{\zeta,t}}\right)^2}, \tag{47}$$

where $\widetilde{\sigma}^{2(j)}_{\zeta,t} = \widetilde{\sigma}^{2(F,j)}_{\varepsilon,t} + \widetilde{\sigma}^{2(j)}_{\varpi,t}$ and $\sigma^2_{\zeta,j} = \sigma^2_{\varepsilon,j} + \sigma^2_{\varpi,j}$, and the perceived variance of the combined public signal is equal to

$$\widetilde{\mathbf{B}}_{F,t}\widetilde{\mathbf{\Omega}}_{F,t}\widetilde{\mathbf{B}}'_{F,t} = \frac{1}{\frac{1}{\widetilde{\sigma}^{2(1)}_{\zeta,t}} + \frac{1}{\widetilde{\sigma}^{2(2)}_{\zeta,t}} + \cdots + \frac{1}{\widetilde{\sigma}^{2(N)}_{\zeta,t}}}, \tag{48}$$

where

$$\widetilde{\mathbf{B}}_{F,t} = \frac{\mathbf{i}\widetilde{\mathbf{\Omega}}_F^{-1}}{\mathbf{i}\widetilde{\mathbf{\Omega}}_F^{-1}\mathbf{i}'}. \tag{49}$$

The Expected Loss in Section 4.1

Given the expressions for inflation and the output gap—i.e., (32) and (33)—inflation and output-gap variability can be written as

$$Var(\pi_t) = \sigma^2_v \left[\begin{array}{l} \frac{((A_1 - A_2 + 1)\alpha)^2}{1-\alpha^2} + [A_1\widetilde{\tau}_F - A_2\widetilde{\tau}_{CB} + 1]^2 \\ \quad + [A_1\widetilde{\tau}_F - A_2\widetilde{\tau}_{CB}]^2 \frac{1-\tau_{CB}}{\tau_{CB}} + (A_1\widetilde{\tau}_F)^2\left(\frac{1}{\tau_F} - \frac{1}{\tau_{CB}}\right) \end{array} \right]$$

and

$$Var(y_t) = \sigma_v^2 \left[\frac{\left(\left(\frac{1}{\mu}A_1 + A_2\right)\alpha\right)^2}{1-\alpha^2} + \left(\frac{1}{\mu}A_1\widetilde{\tau}_F + A_2\widetilde{\tau}_{CB}\right)^2 \frac{1}{\tau_{CB}} \right.$$

$$\left. + \left(\frac{A_1}{\mu}\widetilde{\tau}_F\right)^2 \left(\frac{1}{\tau_F} - \frac{1}{\tau_{CB}}\right) \right],$$

where the fact that $Var(s_t) = \frac{1}{1-\alpha^2}\sigma_v^2$, $Var(\varepsilon_t^{(CB)}) = \frac{1-\tau_{CB}}{\tau_{CB}}\sigma_v^2$, and $Var(\varpi_t^{(CB)}) = (\frac{1}{\tau_F} - \frac{1}{\tau_{CB}})\sigma_v^2$ was used. It can easily be seen that the variability of both inflation and the output gap are decreasing in τ_F. Using the loss function, (5), together with the expressions for inflation and output-gap variability yields the following expression for the expected loss:

$$E(L) = \frac{1}{2}\sigma_v^2 \left[\begin{array}{l} \left(A_1^2\left(1+\frac{1}{\mu}\right) + 2A_1 - A_2 + 1\right)\frac{\alpha^2}{1-\alpha^2} \\ \quad + (A_1\widetilde{\tau}_F)^2\left[1+\frac{1}{\mu}\right]\left[\frac{1}{\tau_F}\right] \\ \quad + A_2\widetilde{\tau}_{CB}^2\left[\frac{1}{\tau_{CB}}\right] + 2A_1\widetilde{\tau}_F - 2A_2\widetilde{\tau}_{CB} + 1 \end{array} \right].$$

The Expected Loss in Section 4.2

Inflation and the output gap are given by equations (35) and (36). These expressions are similar to the ones in section 4.1, with the exception that the public's estimate of the output-gap target now enters the above equations. But $\theta_{t|t-1}^{(F,CB)}$ is a function of the difference between $s_{t-1|t-1}^{(F)}$ and $s_{t-1|t-1}^{(CB)}$. This difference can be written as $(s_{t-1|t-1}^{(F)} - s_{t-1|t-1}^{(CB)}) = (\widetilde{\tau}_F - \widetilde{\tau}_{CB})v_{t-1} + (\widetilde{\tau}_F - \widetilde{\tau}_{CB})\varepsilon_{t-1}^{(CB)} + \widetilde{\tau}_F\varpi_t^{(CB)}$. Thus $\theta_{t|t-1}^{(F,CB)}$ will be correlated with s_{t-1}. The variance of $\theta_{t|t-1}^{(F,CB)}$ equals

$$Var\left(\theta_{t|t-1}^{(F,CB)}\right) = \widetilde{\tau}_\xi^2 \frac{1}{\mu^2}\sigma_v^2 \left(\frac{\widetilde{\tau}_F^2}{\tau_F} + \frac{\widetilde{\tau}_{CB}}{\tau_{CB}}[\widetilde{\tau}_{CB} - 2\widetilde{\tau}_F]\right) + (1-\widetilde{\tau}_\xi)^2\sigma_z^2.$$

The variance of the output gap and inflation can thus be written as

$$
\begin{aligned}
&Var_{asym}(\pi_t)\\
&= \left[Var(\pi_t) + \sigma_v^2 \left[\begin{array}{l} A_2^2 \widetilde{\tau}_\xi^2 \mu^2 \left(\frac{\widetilde{\tau}_F^2}{\tau_F} + \frac{\widetilde{\tau}_{CB}}{\tau_{CB}} [\widetilde{\tau}_{CB} - 2\widetilde{\tau}_F] \right) \\ \quad + A_2 \mu \widetilde{\tau}_\xi (\widetilde{\tau}_F - \widetilde{\tau}_{CB})(A_1 - A_2 + 1)\alpha \\ \quad + A_2^2 \mu^4 (1 - \widetilde{\tau}_\xi)^2 \sigma_z^2 \end{array} \right] \right]\\
&Var_{asym}(y_t)\\
&= \left[Var(y_t) + \sigma_v^2 \left[\begin{array}{l} A_2^2 \widetilde{\tau}_\xi^2 \left(\frac{\widetilde{\tau}_F^2}{\tau_F} + \frac{\widetilde{\tau}_{CB}}{\tau_{CB}} [\widetilde{\tau}_{CB} - 2\widetilde{\tau}_F] \right) \\ \quad + A_2 \widetilde{\tau}_\xi (\widetilde{\tau}_F - \widetilde{\tau}_{CB}) \left(\frac{1}{\mu} A_1 + A_2 \right) \alpha \\ \quad + \mu^2 A_2^2 (1 - \widetilde{\tau}_\xi)^2 \sigma_z^2 \end{array} \right] \right].
\end{aligned}
$$

Using these expressions together with (5) yields the expected loss:

$$
E(L_{asym}) = \left[E(L) + \tfrac{1}{2} \sigma_v^2 \tfrac{\mu}{1+\mu} \left[\begin{array}{l} \widetilde{\tau}_\xi^2 \left(\frac{\widetilde{\tau}_F^2}{\tau_F} + \frac{\widetilde{\tau}_{CB}}{\tau_{CB}} [\widetilde{\tau}_{CB} - 2\widetilde{\tau}_F] \right) \\ \quad + \widetilde{\tau}_\xi (\widetilde{\tau}_F - \widetilde{\tau}_{CB}) \frac{\mu \alpha^2}{1+\mu(1-\alpha)} \\ \quad + \frac{\mu^3}{1+\mu} (1 - \widetilde{\tau}_\xi)^2 \sigma_z^2 \end{array} \right] \right].
$$

The Expected Loss in Section 4.3

With identical output-gap targets and no uncertainty by the public about them, inflation and the output gap continue to be given by (10) and (11). Inserting (16), (17), (21), and (22) into these expressions and simplifying yields

$$
\begin{aligned}
\pi_t = {} & (A_1 - A_2 + 1)\alpha s_{t-1} + [A_1 \widetilde{\tau}_F - A_2 \widetilde{\tau}_{CB} + 1] v_t \\
& + A_1 \widetilde{\tau}_F \widetilde{\mathbf{B}}_{F,t} \left[\zeta_t^{(1)} \ \ \zeta_t^{(2)} \ \ \cdots \ \ \zeta_t^{(j)} \right]' \\
& - A_2 \widetilde{\tau}_{CB} \widetilde{\mathbf{B}}_{CB,t} \left[\varepsilon_t^{(1)} \ \ \varepsilon_t^{(2)} \ \ \cdots \ \ \varepsilon_t^{(N)} \right]' + \pi^* + \mu y^*.
\end{aligned}
$$

Similarly for the output gap,

$$
\begin{aligned}
y_t = {} & - \left(\frac{1}{\mu} A_1 + A_2 \right) \alpha s_{t-1} - \left[\frac{1}{\mu} A_1 \widetilde{\tau}_F + A_2 \widetilde{\tau}_{CB} \right] v_t \\
& - \frac{1}{\mu} A_1 \widetilde{\tau}_F \widetilde{\mathbf{B}}_{F,t} \left[\zeta_t^{(1)} \ \ \zeta_t^{(2)} \ \ \cdots \ \ \zeta_t^{(j)} \right]' \\
& - A_2 \widetilde{\tau}_{CB} \widetilde{\mathbf{B}}_{CB,t} \left[\varepsilon_t^{(1)} \ \ \varepsilon_t^{(2)} \ \ \cdots \ \ \varepsilon_t^{(N)} \right]',
\end{aligned}
$$

where $\widetilde{\tau}_{CB}$ and $\widetilde{\mathbf{B}}_{CB,t}$ correspond to the median policymaker. Thus,

$$Var(\pi_t) = \begin{bmatrix} \sigma_v^2 \left(\frac{((A_1 - A_2 + 1)\alpha)^2}{1-\alpha^2} + [A_1\widetilde{\tau}_F - A_2\widetilde{\tau}_{CB} + 1]^2 \right) \\ + (A_1\widetilde{\tau}_F)^2 \widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t} + (A_2\widetilde{\tau}_{CB})^2\widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}_{CB}\widetilde{\mathbf{B}}'_{CB,t} \\ - 2A_1\widetilde{\tau}_F A_2\widetilde{\tau}_{CB}\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{CB,t} \end{bmatrix}$$

and

$$Var(y_t) = \begin{bmatrix} \sigma_v^2 \left(\frac{((\frac{1}{\mu}A_1 + A_2)\alpha)^2}{1-\alpha^2} + \left[\frac{1}{\mu}A_1\widetilde{\tau}_F + A_2\widetilde{\tau}_{CB}\right]^2 \right) \\ + \frac{1}{\mu^2}(A_1\widetilde{\tau}_F)^2 \widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t} + (A_2\widetilde{\tau}_{CB})^2\widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}_{CB}\widetilde{\mathbf{B}}'_{CB,t} \\ - 2\frac{1}{\mu}A_1\widetilde{\tau}_F A_2\widetilde{\tau}_{CB}\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{CB,t} \end{bmatrix}.$$

The expected loss equals

$$E(L) = \frac{1}{2}\sigma_v^2 \begin{bmatrix} \left(A_1^2\left(1 + \frac{1}{\mu}\right) + 2A_1 - A_2 + 1\right)\frac{\alpha^2}{1-\alpha^2} \\ + [A_1\widetilde{\tau}_F - A_2\widetilde{\tau}_{CB} + 1]^2 + \mu\left[\frac{1}{\mu}A_1\widetilde{\tau}_F + A_2\widetilde{\tau}_{CB}\right]^2 \\ + \frac{1+\mu}{\mu}(A_1\widetilde{\tau}_F)^2\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t} + (1+\mu)\widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}_{CB}\widetilde{\mathbf{B}}'_{CB,t} \end{bmatrix}.$$

If $\tau_{CB} = \frac{\sigma_v^2}{\sigma_v^2 + \widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}\widetilde{\mathbf{B}}'_{CB,t}}$ and $\tau_F = \frac{\sigma_v^2}{\sigma_v^2 + \widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t}}$, it can easily be seen that the above is equivalent to (34) since $\widetilde{\mathbf{B}}_{F,t}\mathbf{\Omega}_F\widetilde{\mathbf{B}}'_{F,t} = \frac{1-\tau_F}{\tau_F}$ and $\widetilde{\mathbf{B}}_{CB,t}\mathbf{\Omega}_{CB}\widetilde{\mathbf{B}}'_{CB,t} = \frac{1-\tau_{CB}}{\tau_{CB}}$.

Learning about the Precision of Signals

Committee members are assumed to recursively update their estimates of the precision of signals on the supply shock. Thus, committee member j forms the following estimate about the precision of member k's signal in period t:

$$\widetilde{\sigma}_{t,\varepsilon}^{2(j,k)} = \frac{t-1}{t}\widetilde{\sigma}_{t-1,\varepsilon}^{2(j,k)} + \frac{1}{t-1}\left(v_{t-1}^{(k)} - v_{t-1}\right)^2$$

for $j = 1, 2, \ldots, N$ and $k = 1, 2, \ldots, N$. If committee members initially have different priors, then k's evaluation will not equal j's evaluation of the variance of k's signal in period t unless $t = \infty$.

This intuitive result can be shown mathematically. When the committee meets for the first time at $t = 1$, members j and k have different priors on k's variance of the signal; i.e., $\widetilde{\sigma}^{2(j,k)}_{1,\varepsilon} \neq \widetilde{\sigma}^{2(k,k)}_{1,\varepsilon}$. When the true supply shock becomes known, member j can update his prior of k's variance:

$$\widetilde{\sigma}^{2(j,k)}_{2,\varepsilon} = \frac{1}{2}\widetilde{\sigma}^{2(j,k)}_{1,\varepsilon} + \left(v^{(k)}_1 - v_1\right)^2.$$

Hence for period t,

$$\widetilde{\sigma}^{2(j,k)}_{t,\varepsilon} = \frac{1}{t}\widetilde{\sigma}^{2(j,k)}_{1,\varepsilon} + \sum_{l=0}^{t-1}\left[\frac{t-l}{t}\frac{1}{t-l-1}\right]\left(v^{(k)}_{t-l-1} - v_{t-l-1}\right)^2,$$

where we repeatedly substituted for $\widetilde{\sigma}^{2(j,k)}_{t-1,\varepsilon}$. The first term, $\frac{1}{t}\widetilde{\sigma}^{2(j,k)}_{1,v}$, converges to 0 as $t \to \infty$. Hence, estimates of committee members converge over time as the different initial priors are given less weight. For financial markets, the estimate of the precision of the public information received from member j equals

$$\widetilde{\sigma}^{2(j)}_{\zeta,t} = \frac{t-1}{t}\widetilde{\sigma}^{2(j)}_{\zeta,t-1} + \frac{1}{t-1}\left(x^{(j)}_{t-1} - v_{t-1}\right)^2. \tag{50}$$

If committee members are actually transparent about their information on the innovation to the supply shock, $x^{(j)}_{t-1} = v^{(j)}_{t-1}$, estimates of the variance of public information converge to their true values as $t \to \infty$.

References

Aoki, K. 2006. “Optimal Commitment Policy under Noisy Information.” *Journal of Economic Dynamics & Control* 30 (1): 81–109.

Bates, J. M., and C. W. J. Granger. 1969. “The Combination of Forecasts.” *Operations Research Quarterly* 20 (4): 451–68.

Beetsma, R. M. W. J., and H. Jensen. 1998. “Inflation Targets and Contracts with Uncertain Central Banker Preferences.” *Journal of Money, Credit, and Banking* 30 (3): 384–403.

Berger, H., and V. Nitsch. 2008. “Too Many Cooks? Committees in Monetary Policy.” Working Paper No. 08-195, KOF Swiss Economic Institute, ETH Zurich.

Berger, H., V. Nitsch, and T. Lybek. 2008. "Central Bank Boards around the World: Why Does Membership Size Differ?" *European Journal of Political Economy* 24 (4): 817–32.

Bernanke, B. 2004. "Fedspeak." Remarks at the Meetings of the American Economic Association, San Diego, California, January 3.

Blinder, A. S. 1998. *Central Banking in Theory and Practice*. Cambridge, MA: MIT Press.

———. 2007. "Monetary Policy by Committee: Why and How?" *European Journal of Political Economy* 23 (1): 106–23.

Blinder, A. S., M. Ehrmann, M. Fratzscher, J. de Haan, and D. J. Jansen. 2008. "Central Bank Communication and Monetary Policy: A Survey of Theory and Evidence." *Journal of Economic Literature* 46 (4): 946–73.

Blinder, A. S., and J. Morgan. 2005. "Are Two Heads Better Than One? Monetary Policy by Committee." *Journal of Money, Credit, and Banking* 37 (5): 789–812.

Chappell, H. W. Jr., R. R. McGregor, and T. A. Vermilyea. 2005. *Committee Decisions on Monetary Policy*. Cambridge, MA: MIT Press.

Cukierman, A. 2007. "The Limits of Transparency." CEPR Discussion Paper No. 6475.

Dickinson, J. P. 1973. "Some Statistical Results in the Combination of Forecasts." *Operational Research Quarterly* 24 (2): 253–60.

Ehrhart, S., H. Lehment, and J. L. Vasquez-Paz. 2007. "Monetary Policy Committee Size and Inflation Volatility." Kiel Working Paper No. 1377.

Ehrmann, M., and M. Fratzscher. 2005. "How Should Central Banks Communicate?" ECB Working Paper No. 557.

———. 2007. "Communication by Central Bank Committee Members: Different Strategies, Same Effectiveness?" *Journal of Money, Credit, and Banking* 39 (2–3): 509–41.

Eijffinger, S. C. W., and P. M. Geraats. 2006. "How Transparent Are Central Banks?" *European Journal of Political Economy* 22 (1): 1–21.

Eijffinger, S. C. W., E. Schaling, and M. F. Tesfaselassie. 2004. "Heterogenous Information about the Term Structure of Interest Rates, Least-Squares Learning, and Optimal Interest Rate Rules." CEPR Discussion Paper No. 4279.

Faust, J., and L. E. O. Svensson. 2002. "The Equilibrium Degree of Transparency and Control in Monetary Policy." *Journal of Money, Credit, and Banking* 34 (2): 520–39.

Geraats, P. M. 2002. "Central Bank Transparency." *Economic Journal* 112 (483): 532–65.

———. 2006. "Transparency of Monetary Policy: Theory and Practice." *CESifo Economic Studies* 52 (1): 111–52.

———. 2007. "The Mystique of Central Bank Speak." *International Journal of Central Banking* 3 (1): 37–80.

———. 2009. "Trends in Monetary Policy Transparency." CESifo Working Paper No. 2584.

Gerlach-Kristen, P. 2003. "Insiders versus Outsiders at the Bank of England." *Central Banking* XIV (1): 96–102.

———. 2004. "Is the MPC's Voting Record Informative about Future UK Monetary Policy?" *Scandinavian Journal of Economics* 106 (2): 299–313.

———. 2009. "Outsiders at the Bank of England's MPC." *Journal of Money, Credit, and Banking* 41 (6): 1099–1115.

Gerling, K., H. P. Grüner, A. Kiel, and E. Schulte. 2003. "Information Acquisition and Decision Making in Committees: A Survey." ECB Working Paper No. 256.

Gersbach, H., and V. Hahn. 2005. "Voting Transparency in a Monetary Union." CEPR Discussion Paper No. 5155.

Gosselin, P., A. Lots, and C. Wyplosz. 2008. "The Expected Interest Rate Path: Alignment of Expectations vs. Creative Opacity." *International Journal of Central Banking* 4 (3): 145–85.

de Haan, J., S. C. W. Eijffinger, and K. Rybinski. 2007. "Central Bank Transparency and Central Bank Communication: Editorial Introduction." *European Journal of Political Economy* 23 (1): 1–8.

Hamilton, J. D. 1994. *Time Series Analysis.* Princeton, NJ: Princeton University Press.

Ireland, P. N. 2004. "Technology Shocks in the New Keynesian Model." *Review of Economics and Statistics* 86 (4): 923–36.

Issing, O. 1999. "The Eurosystem: Transparent and Accountable or 'Willem in Euroland'." CEPR Policy Paper No. 2.

Kozicki, S., and P. A. Tinsley. 2008. "Term Structure Transmission of Monetary Policy." *North American Journal of Economics and Finance* 19 (1): 71–92.

Lombardelli, C., J. Proudman, and J. Talbot. 2005. "Committees versus Individuals: An Experimental Analysis of Monetary Policy Decision-Making." *International Journal of Central Banking* 1 (1): 181–205.

McCallum, B. T. 1983. "On Non-Uniqueness in Rational Expectations Models: An Attempt at Perspective." *Journal of Monetary Economics* 11 (2): 139–68.

Morris, S., and H. S. Shin. 2002. "Social Value of Public Information." *American Economic Review* 92 (5): 1521–34.

Orphanides, A. 2003. "Monetary Policy Evaluation with Noisy Information." *Journal of Monetary Economics* 50 (3): 605–31.

Pollard, P. 2004. "Monetary Policy-Making around the World." PowerPoint Presentation, Federal Reserve Bank of St. Louis.

Sibert, A. 2006. "Central Banking by Committee." CEPR Discussion Paper No. 5626.

Svensson, L. E. O., and M. Woodford. 2004. "Indicator Variables for Optimal Policy under Asymmetric Information." *Journal of Economic Dynamics & Control* 28 (4): 661–90.

Vandenbussche, J. 2006. "Elements of Optimal Monetary Committee Design." IMF Working Paper No. 06/277.

Yellen, J. L. 2005. "Policymaking in the FOMC: Transparency and Continuity." Federal Reserve Bank of San Francisco Economic Letter No. 2005-22.