

IMF Working Paper

Monetary Policy Committees, Learning, and Communication

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Abstract

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This paper considers optimal communication by monetary policy committees in a model of imperfect knowledge and learning. The main policy implications are that there may be costs to central bank communication if the public is perpetually learning about the committee's decision-making process and policy preferences. When committee members have heterogeneous policy preferences, welfare is greater under majority voting than under consensus decision-making. Furthermore, central bank communication under majority voting is more likely to be beneficial in this case. It is also shown that a chairman with stable policy preferences who carries significant weight in the monetary policy decision-making process is welfare enhancing.

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I. INTRODUCTION

Over the past two decades, there have been several notable developments in central banking, including a greater emphasis on central bank communication as well as the formal adoption of decision-making by monetary policy committees. These changes have spawned a new scholarly literature on central bank communication and the optimal design of monetary policy committees.¹ However, there remain important but barely touched issues including the question of how the optimal communication strategy of a central bank depends on the nature of its decision-making process and the structure of its monetary policy committee (Blinder et al, 2008).

This paper attempts to fill this gap by examining how different types of committee should optimally communicate. Blinder and Wyplosz (2004) distinguish between autocratically-collegial, genuinely-collegial, and individualistic committees. A committee in which the chairman more or less dictates the group consensus is autocratically-collegial. The chairman listens to the debate that forms part of the deliberation process and his decision may be influenced by the views of other committee members. However, he will eventually announce the group's consensus, expecting everyone else to fall in line. The Federal Reserve under Alan Greenspan was often seen as such a committee. In an individualistic committee each member expresses his or her own opinion and the group decision is made by majority voting. Blinder and Wyplosz (2004) argue that the Bank of England and the Swedish Riksbank fit this description. Finally, a committee in which decisions are made by consensus is referred to as genuinely-collegial. The chairman in such a committee gets more public attention, but is not necessarily more influential than other members. The European Central Bank is often cited as representing such a committee although the Federal Reserve under Bernanke also seems to have moved in that direction. In a survey of 94 central banks, Fry et al. (2000) find that of the 79 that make decisions by committee only 36 do so through formal voting. The other 43 reach decisions by consensus.

The present paper provides a first attempt to analyze theoretically how the optimal communication strategy of a monetary policy committee depends on its decision-making process. The model assumes that committee members have different preferences regarding the weight given to inflation stabilization that are unknown to the private sector. The public is learning about those preferences and the decision-making process of the committee in order to form an expectation of inflation. The paper thus follows a number of earlier studies in investigating central bank communication in an environment of imperfect knowledge (e.g. Dale et al, 2008 and Berardi and Duffy, 2007).

In modelling the private sector as perpetually learning, it is shown that central bank

¹For a recent survey on central bank communication and monetary policy see Blinder et al (2008). For a comprehensive survey of the literature on monetary policy committees, see Blinder (2007) and Vandenbusche (2006).

communication has a significant effect on private sector expectations. Whether or not communication is welfare enhancing depends on the decision-making strategy of the committee. If committee members have heterogeneous preferences about the weight given to inflation stabilization, it is preferable for decisions to be made by majority voting. Under majority voting, the public has to predict the preferences of the median policymaker and can ignore policymakers with variable preferences that are hard to predict. This leads to greater policy predictability, which is shown to be welfare enhancing. In addition, given a certain degree of private sector imperfect knowledge about the decision-making process of the committee, when committee members are heterogeneous, central bank communication is more likely to be welfare enhancing under majority voting than when decisions are made by consensus. However, under both majority voting and decision-making by consensus, if the public faces a significant degree of imperfect knowledge about the decision-making process of the committee, then communication by the central bank committee leads to more variability in inflation and the output gap and reduces welfare. In this case the public is unable to process and utilize the information communicated by the central bank effectively. The results of this paper show furthermore that it is welfare enhancing when a chairman with stable policy preferences carries significant weight in the policy decision-making process. The presence of such a chairman leads to greater predictability of committee preferences and thus improves the accuracy of private sector inflation expectations.

The fact that central bank communication may not always be beneficial has been well documented in the literature. In general, central bank communication enhances the effectiveness of monetary policy by disseminating news and thereby moving short-term interest rates in a desired direction or by reducing noise and thereby lowering market uncertainty (Blinder et al, 2008). Thus if communication is able to steer expectations successfully, policy decisions should become more predictable. Empirical studies show that the predictability of interest rate decisions of the major central banks has improved remarkably in recent years due to more transparency and a greater emphasis on central bank communication (Blinder et al, 2008). However, poorly designed communication can also be harmful. As shown by Morris and Shin (2002), public information might be undesirable if it crowds out private information. In their model, private agents have an incentive to match the underlying economic fundamentals about which they have both private and public information, and at the same time want to coordinate their actions with other agents. This coordination motive leads private agents to put more weight on the public signal than is justified by its precision, thereby exacerbating volatility if the public signal is sufficiently noisy.

The findings of this paper also contribute to the emerging literature on the optimal design of monetary policy committees. When committee members are heterogeneous, it is shown that it is preferable for decisions to be made by majority voting. This finding has been confirmed by the literature. Gerlach-Kristen (2006) examines whether majority voting or averaging performs better in terms of choosing the correct policy instrument under uncertainty about the state of the economy. She shows that when policymakers have different abilities and thus the quality of their estimates of the state

of the economy differs, majority voting leads to better policy decisions. Furthermore, the results of the present paper demonstrate that an influential chairman is welfare enhancing. The previous empirical and theoretical literature has often argued that the chairman of the committee can exert disproportionate influence on the committee decision (Blinder, 2004). In an empirical study on decision-making at the Federal Reserve Open Market Committee, Chappell et al (2004) estimate that the impact of the chairman on policy decisions corresponds to a voting weight of 40 to 50 percent. As Gerlach-Kristen (2008) argues, this influence may come from the chairman’s ability to influence the discussion and summarize the different views of committee members but it may also be the result of his superior monetary policy making skills or due to the institutional setup of the committee. Gerlach-Kristen (2008) simulates a simple model in which policymakers have different estimates of the optimal level of the interest rate. She finds that the influence of the chairman on the quality of policy itself is limited and that the chairman’s main impact is to help build consensus in the committee, which enhances the credibility of monetary policy. The present paper does not evaluate how an influential chairman affects the quality of the policy decision under uncertainty about the state of the economy, but how an influential chairman enhances the predictability of policy decisions and thereby welfare.

The remainder of the paper is organized as follows: Section II. outlines the general model of the economy. Section III. introduces committee decision-making. Section IV. analyses private sector expectations given different communication strategies of the committee. Section V. presents the results whilst Section VI. concludes.

II. THE MODEL

A. General Setup

Inflation is described by the expectations-augmented Phillips curve:

$$\pi_t = \pi_t^e + y_t + \eta_t \tag{1}$$

where π_t denotes inflation, π_t^e is the private sector expectation of time t inflation and y_t is the output gap defined as the difference between actual and potential output, where the latter is conveniently normalized to zero. Furthermore η_t is an i.i.d. disturbance with properties $\eta_t \sim N(0, \sigma_\eta^2)$. For analytical convenience the coefficients of the Phillips curve have been normalized to one. This does not affect any of the qualitative results.

Similarly to Walsh (2007), the transmission mechanism from the central bank’s instrument to the output gap is modelled in the simplest way possible by assuming that the central bank is able to control the output gap perfectly so that the output gap, y_t , is equal to the policy instrument, x_t .

It is assumed that the central bank minimizes a quadratic loss function of the form:

$$L = (1 - \omega)Var(y - y^*) + \omega Var(\pi - \pi^*) \quad (2)$$

where ω denotes the central bank's weight on inflation stabilization ($0 < \omega < 1$) and π^* and y^* denote the inflation and output gap targets of the central bank respectively.

The central bank minimizes this loss function with respect to x_t and subject to equation (1) taking private sector inflation expectations as given and fully observing the aggregate supply shock. Thus policy is set under discretion. It can be shown that optimal policy is set as

$$x_t = \omega (\pi^* - \pi_t^e - \eta_t) + (1 - \omega)y^*. \quad (3)$$

This yields the intuitive result that the policy instrument is increasing in the central bank's inflation and output gap targets and decreasing in private sector inflation expectations and the aggregate supply shock.

The resulting level of inflation is given as

$$\pi_t = (1 - \omega)\pi_t^e + \omega\pi^* + (1 - \omega)y^* + (1 - \omega)\eta_t. \quad (4)$$

Inflation is increasing in private sector inflation expectations, the inflation and output gap targets of the central bank and the aggregate supply shock.

Taking expectations of equation (4) gives the private sector's expected inflation rate:

$$\pi_t^e = \pi^* + \frac{(1 - \omega)}{\omega}y^* \quad (5)$$

where it is assumed that the private sector does not observe the supply shock when it forms an expectation of inflation. This yields the intuitive result that the private sector's expectation of inflation is increasing in both the inflation and output gap targets and decreasing in the preference for inflation stabilization by the central bank if $y^* > 0$. Substituting equation (5) into equations (3) and (4), yields the equilibrium output gap and inflation rate in this economy. The output gap is given by

$$y_t = -\omega\eta_t \quad (6)$$

and inflation can be denoted as

$$\pi_t = \pi^* + \frac{(1 - \omega)}{\omega}y^* + (1 - \omega)\eta_t. \quad (7)$$

Thus under rational expectations of the public, the output gap is solely determined by the aggregate supply shock and the preference for inflation stabilization of the central bank. Inflation on the other hand is a positive function of both the inflation and output gap targets of the central bank as well as the aggregate supply shock. Furthermore, inflation is decreasing in the central bank's preference for inflation versus output gap stabilization if $y^* > 0$.

B. Uncertainty About The Central Bank's Preferences

Following Demertzis and Hughes Hallett (2007), uncertainty about the central bank's inflation stabilization preference is introduced to illustrate that welfare is decreasing in the variance of the public's estimate of ω . The public's best estimate of the central banks' preference for inflation stabilization is assumed to be on average correct and is given by $\hat{\omega} = \omega + \lambda$, where λ is i.i.d. with variance σ_λ^2 . Thus the expectation of inflation of the private sector becomes

$$\pi_t^e = \pi^* + \frac{(1 - \hat{\omega})}{\hat{\omega}} y^*. \quad (8)$$

The private sector inflation expectation is still a positive function of the inflation and output gap targets of the central bank, which continue to be perfectly known. However, it is now a negative function of the public's best estimate of the central bank's inflation stabilization preference. Substituting equation (8) into equations (3) and (4), yields the resulting output gap and inflation rate. The output gap can be written as

$$y_t = \frac{(\hat{\omega} - \omega)}{\hat{\omega}} y^* - \omega \eta_t \quad (9)$$

whilst inflation is given by

$$\pi_t = \pi^* + \frac{(1 - \omega)}{\hat{\omega}} y^* + (1 - \omega) \eta_t. \quad (10)$$

Thus inflation and the output gap are a function of both the true preference for inflation stabilization by the central bank and the public's best estimate of this preference. It is straightforward to show that expected inflation and the expected output gap are equal to inflation and the output gap under certainty about the inflation stabilization preference of the central bank, namely equations (6) and (7). The variance

of the output gap can be linearly approximated by a Taylor series expansion²:

$$\text{Var}(y_t) \approx \frac{\sigma_\lambda^2}{\omega^2}(y^*)^2 + \omega^2\sigma_\eta^2.$$

It can easily be verified that this variability is minimized for $\sigma_\lambda^2 = 0$. The variance of inflation can also be approximated by a Taylor series expansion:

$$\text{Var}(\pi_t) \approx (1 - \omega)^2 \frac{\sigma_\lambda^2}{\omega^4}(y^*)^2 + (1 - \omega)^2\sigma_\eta^2.$$

The variability of inflation is increasing in the variance of the private sector's estimate of the central bank's inflation stabilization preference, σ_λ^2 . Hence, the variance of inflation is minimized for $\sigma_\lambda^2 = 0$. This result is confirmed by Beetsma and Jensen (2003) who show that preference uncertainty increases the variability of inflation and output and thus is not desirable.

Therefore, welfare in this setup is enhanced, when the inflation stabilization preference of the central bank is known. In this case, output gap variability is reduced to $\text{Var}(y_t) = \omega^2\sigma_\eta^2$ and inflation variability to $(1 - \omega)^2\sigma_\eta^2$. When $\sigma_\lambda^2 = 0$, there is no asymmetric information between the central bank and the public about ω and there is perfect transparency about the central bank's preferences. This is an important result as in the subsequent analysis, the paper assesses how different communication practices and institutional setups of the central bank committee influence the predictability of preferences of the monetary policy committee.

III. MONETARY POLICY COMMITTEE DECISION-MAKING

A. The Preferences Of Committee Members

It is assumed that the committee consists of N members, in addition to the chairman. For simplicity, the only source of heterogeneity between committee members are different preferences about the weight that should be given to inflation and output gap stabilization. Blinder (2007) argues that policymakers are very likely to have different preferences in that some (the "hawks") may be far more concerned with inflation while others (the "doves") put more weight on output. Hence committee member j 's loss function can be written as

$$L_{jt} = (1 - \omega_{jt})\text{Var}(y_t - y^*) + \omega_{jt}\text{Var}(\pi_t - \pi^*). \quad (11)$$

²This uses the result that the linear approximation via a Taylor series expansion gives the approximate variance for $1/X$ where X denotes a random variable as: $\text{Var}\left(\frac{1}{X}\right) \approx \frac{1}{[E(X)]^4}\text{Var}(X)$.

Committee member j 's preference for inflation stabilization is given by

$$\omega_{jt} = \omega + \nu_{jt}. \quad (12)$$

It is assumed that ν_{jt} follows an autoregressive process of order 1. Thus

$$\nu_{jt} = \rho_j \nu_{jt-1} + \varepsilon_{jt} \quad (13)$$

where $\varepsilon_{jt} \sim N(0, \sigma_{\varepsilon,j}^2)$ and $0 < \rho_j < 1$ for $j = 1, \dots, N + 1$. For each committee member j , ε_{jt} is uncorrelated with the aggregate supply shock, η_t . Furthermore, the innovations to ν_{jt} are assumed to be uncorrelated across members. Thus, the mean preference is identical among policymakers and given by ω . However the variance of preferences differs among committee members. For committee member j this variance is given by $Var(\omega_{jt}) = \frac{\sigma_{\varepsilon,j}^2}{1-\rho_j^2}$. Whilst preferences are not constant over time there exists some inertia in committee members' preferences. The assumption about inertia in members' preferences is similar to that made by Faust and Svensson (2002), who assume that the output target of the central bank follows an $AR(1)$ process. It can be justified by arguing that it is unlikely for members' preferences to change completely every period and that even if a member is replaced, it is likely that his successor has similar preferences if he is appointed by the same government. As Cukierman (2007) argues, it is also very unlikely that the inflation and output gap stabilization preference of committee members will stay constant over time. This paper abstracts from uncertainty about the state of the economy to simplify the mathematical analysis whereas in reality policymakers very likely to only imperfectly observe the current output gap and inflation rate. In this case they will be unwilling to make a long-term commitment to a weight attached to a highly unreliable measure.

B. Timing

The timing in any period t is as follows: First, policy preferences of committee members are realized. Each committee member observes his own preference but preferences are unknown to the public. Second, the committee may or may not communicate with the public in the form of speeches. These speeches imperfectly reveal committee members' preferences for that particular period. The private sector then forms an expectation of the aggregated weight given to inflation stabilization by the central bank and thus an expectation of inflation. Subsequently, the aggregate supply shock is realized and observed by both the public and the central bank. Having observed both the aggregate supply shock and private sector expectations, the central bank sets the policy instrument. How this instrument is set will depend on the decision-making procedure of the committee. Finally, the minutes and voting records of the policy meeting are published and these perfectly convey the preference of each

committee member in period t^3 .

C. The Policy Decision

The determination of policy will depend on the decision-making process of the committee. If the committee decides by consensus, the policy rate is assumed to be a function of the average of desired instrument rates. If the committee is individualistic and votes by majority, the policy rate is a function of the median of the desired instrument rates by committee members. In addition, the chairman may have added influence. In what follows, decision-making by consensus will first be evaluated. The section will then turn to the case of an individualistic committee. In both cases, the chairman may have added influence.

C.1 Decision-making by consensus

Using equation (3) and given different preferences of policymakers regarding the weight given to inflation stabilization, the desired policy instrument of each committee member is given by

$$x_{j,t} = \omega_{j,t}(\pi^* - \pi_t^e - \eta_t) + (1 - \omega_{j,t})y^*. \quad (14)$$

Thus the desired policy instrument of member j will be a function of his or her preferences for the weight given to inflation stabilization. It is assumed that the policy instrument if decisions are made by consensus is a function of the mean of the different desired policy instruments:

$$x_t^C = c_1 \text{Mean}[x_{1,t}, x_{2,t}, \dots, x_{N,t}, x_{CH,t}] + c_2(x_{CH,t}) + \chi_t \quad (15)$$

where χ_t has zero mean and variance, $\sigma_{\chi,t}^2$. The separate term added for the chairman reflects the fact that he may have added influence ($c_2 > 0$). The paper models committee decision-making following the econometric models of Chappell et al (2004). If decision-making follows a consensual pattern, one would expect that the adopted policy directive broadly reflects the views of all committee members. Thus, the committee decision is assumed to be a function of the mean of members' preferences. This of course oversimplifies complexity. In reality, for instance in the case of the European Central Bank, where decisions are made by consensus, no outside observer

³In the case of an individualistic approach to decision-making, the committee makes decisions by majority voting and thus voting records reflect committee members' preferences. Under a consensus based approach to decision-making, it is assumed that this information is conveyed through policy minutes. In order for these minutes to convey the preferences of each policymaker, these minutes have to be attributed. This is rare in practice (Geraats, 2009). But there are examples, such as the Swedish Riksbank, which has recently introduced attributed minutes.

really knows the precise meaning of 'consensus'. Thus, our simple model is at best an approximation of the very complex process of decision-making by committee. The reason that monetary policy is specified as some function of the mean of preferences and not as just the mean is the belief that there will always be some other factors influencing the committee decision during the meeting and the deliberation process, which are part of the error term and difficult to formalize.

The paper also abstracts from strategic voting. It is also assumed that the chairman does not vote so as always to be on the 'winning side' but that minutes and voting records reveal his preferences. The paper furthermore ignores the effects that transparency about policy deliberations could have on the behavior of committee members. Incentive effects, whereby committee members adjust their behavior according to which information is disclosed, may also play an important role for the question of the desirability of publishing voting records and minutes. Whilst there is a growing game-theoretic literature on strategic behavior in committees⁴, policymakers themselves do not believe that such 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'.

It is straightforward to rewrite equation (15) as

$$\begin{aligned} x_t^C &= (\pi^* - \pi_t^e - \eta_t) [c_1 \text{Mean}[\omega_{1,t}, \omega_{2,t}, \dots, \omega_{N,t}, \omega_{CH,t}] + c_2(\omega_{CH,t})] \\ &\quad + y^* [c_1 (1 - \text{Mean}[\omega_{1,t}, \omega_{2,t}, \dots, \omega_{N,t}, \omega_{CH,t}]) + c_2(1 - \omega_{CH,t})] + \chi_t. \end{aligned} \quad (16)$$

Thus the desired policy instrument by the committee is a function of the mean of the different weights given to inflation stabilization by committee members. If the restriction that $c_1 + c_2 = 1$ is imposed, the aggregated committee preference can be defined as follows

$$\omega_t^C = c_1 \text{Mean}(\omega_{1,t}, \omega_{2,t}, \dots, \omega_{N,t}, \omega_{CH,t}) + c_2(\omega_{CH,t}) + \kappa_t. \quad (17)$$

The error term κ_t is assumed to be i.i.d with zero mean and variance σ_κ^2 .⁵ The domain of its normal distribution is truncated to the interval $[a, -a]$, where a is such that $0 < \omega_t^C < 1$.⁶ Thus it is assumed that the central bank committee is not a strict

⁴An extensive overview of this literature and its relevance for monetary policy committees has been provided by Gerling et al (2003).

⁵In order for 17 to be derived exactly from 15, $\chi_t = \kappa_t(\pi^* - \pi_t - \eta_t - y^*)$ and thus its variance is not independent of time.

⁶In simulations, any observations of the aggregated committee preference that do not lie between 0 and 1 are discarded. Values of κ_t are randomly drawn until the desired number of aggregated committee

inflation targeter. This seems a reasonable assumption in practice, because the central banks of most developed economies act as flexible inflation targeters whether they explicitly target inflation or not (Cukierman, 2007). This aggregated preference can alternatively be written as

$$\omega_t^C = \omega + c_1 \text{Mean}(\nu_{1,t}, \nu_{2,t}, \dots, \nu_{N,t}, \nu_{CH,t}) + c_2(\nu_{CH,t}) + \kappa_t \quad (18)$$

and thus $\omega_t^C = \omega + e_t^C$, where e_t^C is a composite error term with zero mean and variance $\sigma_{e_C}^2$. The expectation of the aggregated preference will thus be equal to the mean preference of committee members, ω . The desired instrument set by the committee is given by

$$x_t^C = \omega_t^C(\pi^* - \pi_t^e - \eta_t) + (1 - \omega_t^C)y^*. \quad (19)$$

The policy instrument set by the committee is thus a function of the aggregated preference of the committee for the weight given to inflation stabilization as well as the inflation and output gap targets, the expected inflation by the public and the aggregate supply shock. Given this instrument set by the committee, inflation equals

$$\pi_t = \pi_t^e + x_t^C + \eta_t \quad (20)$$

Therefore, inflation depends on the private sector inflation expectation, the instrument set by the committee and the aggregate supply shock.

C.2 Individualistic decision-making

If decisions are made by majority voting, the aggregated preference for the policy instrument will be given as a function of the median of the different desired policy instruments:

$$x_t^M = m_1 \text{Median}[x_{1,t}, x_{2,t}, \dots, x_{N,t}, x_{CH,t}] + m_2(x_{CH,t}) + \varsigma_t \quad (21)$$

where ς_t has zero mean and variance $\sigma_{\varsigma,t}^2$.

As in the consensus case, this is equivalent to expressing the committee preference for the policy instrument as

$$x_t^M = \omega_t^M(\pi^* - \pi_t^e - \eta_t) + (1 - \omega_t^M)y^* \quad (22)$$

The aggregated preference for the weight given to inflation stabilization, ω_t^M , is now

 preferences that lie in this range are obtained.

given by

$$\omega_t^M = \omega + m_1 \text{Median}(\nu_{1,t}, \nu_{2,t}, \dots, \nu_{N,t}, \nu_{CH,t}) + m_2(\nu_{CH,t}) + v_t. \quad (23)$$

where again the restriction was imposed that $m_1 + m_2 = 1$. The error term v_t is assumed to be i.i.d with zero mean and constant variance, σ_v^2 . Again, the domain of its normal distribution is truncated to the interval $[b, -b]$, where b is such that $0 < \omega_t^M < 1$. Thus $\omega_t^M = \omega + e_t^M$, where e_t^M is a composite error term with zero mean and variance σ_{eM}^2 .

Inflation under individualistic decision-making equals

$$\pi_t = \pi_t^e + x_t^M + \eta_t. \quad (24)$$

IV. THE PRIVATE SECTOR

The public is aware of the general form of the reaction function of each committee member and also knows whether the committee sets the policy instrument by consensus or majority rule. However, private agents do not know the preferences of committee members regarding the weight given to inflation stabilization and only know the average preference of each member, that is ω . The private sector furthermore does not know the parameters in equations (17) and (23). The public hence has to estimate the parameters just like an econometrician would do. This is the adaptive learning approach to expectations in macroeconomics. As Evans and Honkapohja (2001) point out this viewpoint introduces a specific form of 'bounded rationality'. Economic agents have limited common knowledge since they estimate their own perceived laws of motion by making forecasts of the economy using their own estimates of parameters (Evans and Honkapohja, 2008). This paper follows a number of earlier studies (Orphanides and Williams (2005), Dale et al (2008)) in modelling learning as perpetual and assumes that agents estimate model parameters by constant gain least squares (CGLS). Let y_t denote the dependent variable at time t , whereas \mathbf{x}_t denotes a $k \times 1$ vector of independent variables including a constant and \mathbf{c}_t denotes a $k \times 1$ coefficient vector. Then \mathbf{c}_t can be updated recursively over time using the following formulae:

$$\mathbf{c}_t = \mathbf{c}_{t-1} + \gamma \mathbf{R}_t^{-1} \mathbf{x}_t (y_t - \mathbf{x}_t' \mathbf{c}_{t-1}) \quad (25)$$

and

$$\mathbf{R}_t = \mathbf{R}_{t-1} + \gamma (\mathbf{x}_t \mathbf{x}_t' - \mathbf{R}_{t-1}) \quad (26)$$

where \mathbf{R}_t denotes the moment matrix for \mathbf{x}_t and $0 < \gamma < 1$.

Constant gain learning implies that more recent observations are given a higher

weight⁷. A natural way to motivate this is to assume that agents are concerned about the possibility of structural change (Evans and Honkapohja, 2008). Empirical studies for the US and Europe show that constant gain least squares learning provides an accurate description of forecaster behavior (Branch and Evans, 2006, Pfajfar and Santoro, 2006, Weber, 2010). Evans and Honkapohja (2001) show that constant gain least squares learning differs in small but persistent ways from full rationality and that there is generally no convergence to a rational expectations equilibrium.

In what follows, private sector learning will be evaluated for different communication strategies of the committee. Section A. analyses what happens when the committee is completely opaque. Section B. investigates the formation of private sector inflation expectations when only voting records and minutes of policy meetings are published. Finally, Section C. will consider the case in which committee members also communicate with the private sector through speeches before committee meetings.

A. Complete Opacity By Committee Members

If only the interest rate decision of the committee is published, the private sector uses the mean preference of committee members, ω , as a best estimate of committee members' preferences. Alternatively the past policy decision of the committee could be used as the best prediction of future instrument rates. However, if there is not much inertia in committee members' preferences and the variances of the shocks to the preference aggregations, $Var(\kappa_t)$ and $Var(v_t)$, are sufficiently large, this leads to less predictability of the aggregated committee preference compared to using the mean preference, ω . This can easily be illustrated for the case when $N = 1$. Using equations (12), (13) and (18), it can be shown that when decisions are made by consensus:

$$E_t(\omega_t^C - \omega)^2 = \frac{\sigma_{\varepsilon,1}^2}{1 - \rho_1^2} + Var(\kappa_t)$$

whereas

$$E_t(\omega_t^C - \omega_{t-1}^C)^2 = 2 \left(\frac{\sigma_{\varepsilon,1}^2}{1 - \rho_1^2} (1 - \rho_1) + Var(\kappa_t) \right).$$

It is straightforward to show that $E_t(\omega_t^C - \omega_{t-1}^C)^2$ exceeds $E_t(\omega_t^C - \omega)^2$ if

$$\frac{\sigma_{\varepsilon,1}^2}{1 - \rho_1^2} (1 - 2\rho_1) + Var(\kappa_t) > 0.$$

⁷If the constant gain is denoted by γ , then this gain implies that economic agents use $(1/\gamma)/f$ years of data, where f denotes the data frequency: $f = 1$ for yearly and $f = 4$ for quarterly data for example.

The above inequality will hold as long as ρ_1 is not large and $Var(\kappa_t)$ is of sufficient magnitude. The same can be shown for individualistic decision-making when $N = 1$ ⁸.

When the private sector uses the mean preference, ω , as the best estimate for the aggregated committee preference, it forms the following inflation expectation for period t :

$$\pi_t^e = \pi^* + \frac{1 - \omega}{\omega} y^*. \quad (27)$$

Substituting the private sector's expectation into equations (19) and (22), gives the resulting output gap under both a consensus based and individualistic approach to decision-making:

$$y_t = y^* \frac{(\omega - \omega_t^k)}{\omega} - \omega_t^k \eta_t \quad (28)$$

where $k = C, M$. This takes into account the different decision-making procedures of the committee, namely a consensus based approach where $k = C$ and an individualistic approach to decision-making where $k = M$.

Similarly substituting equations (27) and (28) into equations (20) and (24) yields the resulting inflation rate under both a consensus based and individualistic approach to decision-making:

$$\pi_t = \pi^* + \frac{1 - \omega_t^k}{\omega} y^* + (1 - \omega_t^k) \eta_t \quad (29)$$

where $k = C, M$.

The variance of output can be linearly approximated via a Taylor series expansion as $Var(y_t) \approx \frac{(y^*)^2}{\omega^2} E_t (\omega - \omega_t^k)^2 + \omega^2 \sigma_\eta^2$ under both a consensus based and individualistic approach to decision-making.⁹ Furthermore, it can be shown that $Var(\pi_t) \approx \frac{(y^*)^2}{\omega^2} E_t (\omega - \omega_t^k)^2 + \sigma_\eta^2 (1 - \omega)^2$. To minimize those variances, it is optimal for ω equal ω_t^k .

B. Voting Records And Policy Minutes Published

If voting records and minutes of the committee meeting are published in period $t - 1$, the private sector can infer the preferences of each committee member for that period.

⁸When decisions are made by a consensus approach, it is straightforward to find more general expressions for $E_t(\omega_t^C - \omega_{t-1}^C)^2$ and $E_t(\omega_t^C - \omega)^2$ for $N > 1$ and $c_1 = 1$. It can be shown that the former exceeds the latter as long as $\frac{1}{N^2} \left[\frac{\sigma_{\varepsilon,1}^2}{1-\rho_1^2} (1 - 2\rho_1) + \frac{\sigma_{\varepsilon,2}^2}{1-\rho_2^2} (1 - 2\rho_2) + \dots + \frac{\sigma_{\varepsilon,N}^2}{1-\rho_N^2} (1 - 2\rho_N) \right] + Var(\kappa_t) > 0$.

⁹Where a linear approximation via a Taylor series expansion was used that gives the approximate of two independent random variables X and Y as: $Var(XY) = [E(Y)]^2 Var(X) + [E(X)]^2 Var(Y)$.

The public's forecast of committee member j 's preferences for period t will be

$$\omega_{j,t,t-1} = \omega + \rho_j \nu_{j,t-1} \quad (30)$$

for $j = 1, 2, \dots, N + 1$. The $N + 1$ th member denotes the public's prediction of the chairman's preference.

The public's prediction for the committee's aggregated weight given to inflation stabilization in period t when decisions are made by consensus, will be as follows:

$$\omega_{tt-1}^{P,C} = \widehat{c}_{1,t-1} \text{Mean} [\omega_{1,t,t-1}, \omega_{2,t,t-1}, \dots, \omega_{N,t,t-1}, \omega_{CH,t,t-1}] + \widehat{c}_{2,t-1} (\omega_{CH,t,t-1}) \quad (31)$$

where $\widehat{c}_{1,t-1}$ and $\widehat{c}_{2,t-1}$ are the estimates by the public of the coefficients in equation (17). This can be rewritten as

$$\omega_{tt-1}^{P,C} = \omega + \widehat{c}_{1,t-1} \text{Mean} [\rho_1 \nu_{1,t-1}, \rho_2 \nu_{2,t-1}, \dots, \rho_N \nu_{N,t-1}, \rho_{CH} \nu_{CH,t-1}] + \widehat{c}_{2,t-1} (\rho_{CH} \nu_{CH,t-1}). \quad (32)$$

Thus the public's estimate of the aggregated weight given to inflation stabilization is equal to $\omega_{tt-1}^{P,C} = \omega + e_t^{P,C}$ where $e_t^{P,C}$ has zero mean and the variance is given by $\sigma_{e_t^{P,C}}^2$. This can alternatively be written as $\omega_{tt-1}^{P,C} = \omega_t^C + e_t^{P,C} - e_t^C$. It should be noted that given the assumptions on preferences, $e_t^{P,C}$ and e_t^C are uncorrelated.

The private sector estimates $\widehat{c}_{1,t-1}$ and $\widehat{c}_{2,t-1}$ in period t using the true preferences of committee members up to period $t - 1$ as the independent variables and the aggregated committee preference up to period $t - 1$ as the dependent variable. The aggregated committee preference in period $t - 1$ is learnt by the private sector once the committee decision and the true supply shock in period $t - 1$ become known at the end of the period. Using equations (25) and (26) when committee decisions are made by consensus, the updating process for these coefficient estimates is as follows

$$\widehat{\mathbf{c}}_{t-1} = \widehat{\mathbf{c}}_{t-2} + \gamma \mathbf{R}_{C,t-1}^{-1} \mathbf{X}_{C,t-1} (\omega_{t-1}^C - \mathbf{X}'_{C,t-1} \widehat{\mathbf{c}}_{t-2}) \quad (33)$$

where $\widehat{\mathbf{c}}_t = (\widehat{c}_{1,t}, \widehat{c}_{2,t})'$ and the variables $\mathbf{X}_{C,t-1}$ are given by

$$\mathbf{X}_{C,t-1} = (\text{Mean} [\omega_{1,t-1}, \omega_{2,t-1}, \dots, \omega_{N,t-1}, \omega_{CH,t-1}], \omega_{CH,t-1})' \quad (34)$$

whilst $\mathbf{R}_{C,t-1}$ evolves according to the following recursive equation:

$$\mathbf{R}_{C,t-1} = \mathbf{R}_{C,t-2} + \gamma (\mathbf{X}_{C,t-1} \mathbf{X}'_{C,t-1} - \mathbf{R}_{C,t-2}). \quad (35)$$

Thus the larger the difference between the best prediction for the aggregated committee preference formed for $t - 1$ and the actual aggregated preference by the committee, the more will the previous coefficient estimates be revised by the public.

When decisions are made by majority voting, the best estimate of the public for the

weight given to inflation stabilization by the committee will be given by

$$\omega_{tit-1}^{P,M} = \omega + \widehat{m}_{1,t-1} \text{Median} [\rho_1 \nu_{1,t-1}, \rho_2 \nu_{2,t-1}, \dots, \rho_N \nu_{N,t-1}, \rho_{CH} \nu_{CH,t-1}] + \widehat{m}_{2,t-1} (\rho_{CH} \nu_{CH,t-1}). \quad (36)$$

Therefore the public's estimate of the aggregated weight given to inflation stabilization under an individualistic approach to decision-making is equal to $\omega_{tit-1}^{P,M} = \omega + e_t^{P,M}$, where $e_t^{P,M}$ has zero mean and the variance is given by $\sigma_{e_{P,M}}^2$. This estimate can alternatively be expressed as $\omega_{tit-1}^{P,M} = \omega^M + e_t^{P,M} - e_t^M$. Furthermore $E_t \left(e_t^{P,M} e_t^M \right) = 0$.

When decisions are made by majority, the estimates of the coefficients in equation (23) can similarly to above be written as

$$\widehat{\mathbf{m}}_{t-1} = \widehat{\mathbf{m}}_{t-2} + \gamma \mathbf{R}_{M,t-1}^{-1} \mathbf{X}_{M,t-1} (\omega_{t-1}^M - \mathbf{X}_{M,t-1}' \widehat{\mathbf{m}}_{t-2}) \quad (37)$$

where $\widehat{\mathbf{m}}_t = (\widehat{m}_{1,t}, \widehat{m}_{2,t})'$ and $\mathbf{X}_{M,t-1}$ is defined as

$$\mathbf{X}_{M,t-1} = (\text{Median} [\omega_{1,t-1}, \omega_{2,t-1}, \dots, \omega_{N,t-1}, \omega_{CH,t-1}], \omega_{CH,t-1})' \quad (38)$$

and $\mathbf{R}_{M,t-1}$ evolves as follows over time:

$$\mathbf{R}_{M,t-1} = \mathbf{R}_{M,t-2} + \gamma (\mathbf{X}_{M,t-1} \mathbf{X}_{M,t-1}' - \mathbf{R}_{M,t-2}). \quad (39)$$

From the definition of constant gain learning and the updating processes of the coefficient estimates, (33), (35), (37) and (39), it can be seen that the smaller γ , the larger is the number of data points that are being used by the public. Thus the quality of the coefficient estimates will be decreasing in the size of the constant gain.

Therefore, the larger is γ , the more limited is the public in its ability to evaluate information efficiently and the greater is the public's degree of imperfect knowledge of the coefficients of equations (17) and (23).

The public's expectation of inflation in period t can be written as

$$\pi_t^e = \pi^* + \frac{1 - \omega_{tit-1}^{P,k}}{\omega_{tit-1}^{P,k}} y^* \quad (40)$$

for $k = C, M$. This takes into account the consensus based approach to decision-making where $k = C$ and the individualistic approach to decision-making where $k = M$.

Substituting the private sector's expectation into (19) and (22), gives the resulting output gap under both a consensus based and individualistic approach to decision-making:

$$y_t = y^* \frac{(\omega_{tit-1}^{P,k} - \omega_t^k)}{\omega_{tit-1}^{P,k}} - \omega_t^k \eta_t. \quad (41)$$

for $k = C, M$. Furthermore substituting (40) and (41) into (20) and (24) yields the resulting inflation rate under consensus and majority voting:

$$\pi_t = \pi^* + y^* \left(\frac{1 - \omega_t^k}{\omega_{t|t-1}^{P,k}} \right) + (1 - \omega_t^k)\eta_t \quad (42)$$

for $k = C, M$. It can be seen that the output gap is minimized when $\omega_{t|t-1}^{P,k}$ is equal to ω_t^k , that is when the aggregated committee preferences are fully predictable. Thus predictability in our model leads to less fluctuations in output. The variances of the output gap and inflation can be linearly approximated via a Taylor series expansion¹⁰:

$$\text{Var}(y_t) \approx (y^*)^2 \left[\frac{1}{\omega^2} \left(\sigma_{e_{P,k}}^2 + \sigma_{e,k}^2 \right) \right] + \sigma_\eta^2 \omega^2$$

and

$$\text{Var}(\pi_t) \approx (y^*)^2 \left[\frac{(1 - \omega)^2}{\omega^4} \sigma_{e_{P,k}}^2 + \frac{1}{\omega^2} \sigma_{e,k}^2 \right] + \sigma_\eta^2 (1 - \omega)^2$$

for $k = C, M$.

C. Imperfect Communication Of Preferences

Committee members can communicate their preferences to the public imperfectly before the policy decision is made in the form of speeches. The private sector receives the following signals on committee members' preferences:

$$\xi_{\omega,j,t} = \omega_{jt} + \psi_{j,t} \quad (43)$$

where $\psi_{j,t}$ is i.i.d. with variance $\sigma_{\psi,j}^2$ for $j = 1, \dots, N + 1$. The private sector can use these signals and combine them with the prediction of committee members' preferences formed from the publication of voting records and policy minutes in the previous period. We will first analyze a situation in which the private sector is already aware of the precision of these signals before considering perpetual learning about the variances of this public information.

¹⁰The linear approximation via a Taylor series expansion gives the approximate variance of (Y/X) where Y and X are random variables as:

$$\text{Var}\left(\frac{Y}{X}\right) \approx \frac{(E(Y))^2}{(E(X))^4} \text{Var}(X) + \frac{1}{(E(X))^2} \text{Var}(Y) - 2 \frac{E(Y)}{(E(X))^3} \text{Cov}(X, Y).$$

C.1 No uncertainty about the precision of public information

In this case the public will face a Kalman filtering problem with

$$\nu_{jt} = \rho_j \nu_{jt-1} + \varepsilon_{jt} \quad (44)$$

as the state equation and

$$\xi_{\omega,j,t} = \omega + \nu_{jt} + \psi_{j,t} \quad (45)$$

as the observation equation for each committee member, $j = 1, 2, \dots, N + 1$. The public is assumed to know the variances of both the state and the observation equation.

The solution to the signal extraction problem is¹¹:

$$\omega_{jtit} = \omega_{jtit-1} + \frac{\sigma_{\varepsilon,j}^2}{\sigma_{\varepsilon,j}^2 + \sigma_{\psi,j}^2} [\xi_{\omega,j,t} - \omega_{jtit-1}] \quad (46)$$

for $j = 1, 2, \dots, N + 1$. Thus, the more precise the information provided before the policy meeting is, the more weight the private sector will optimally attach to it.

Given those estimates of committee members' preferences, the private sector can form inflation expectations using the same methods as in Section IV.B.

C.2 Imperfect knowledge of the precision of public information

The assumption that the public knows the precision of the public signals is now relaxed and thus the value of the signal extraction parameter, $\frac{\sigma_{\varepsilon,j}^2}{\sigma_{\varepsilon,j}^2 + \sigma_{\psi,j}^2}$, becomes unknown. If its unknown value is denoted by β_j , then the estimate of the public for member j 's preference for inflation stabilization in period t is

$$\omega_{jtit} = \omega_{jtit-1} + \beta_j (\xi_{\omega,j,t} - \omega_{jtit-1}) \quad (47)$$

for $j = 1, 2, \dots, N + 1$. The weights, β_j , have to be determined by the relative historical forecasting performances of the prediction based on the state equation, ω_{jtit-1} , and the signal on committee members' preferences, $\xi_{\omega,j,t}$. The better $\xi_{\omega,j,t}$ performs in predicting ω_{jtit} in every period, the larger will be β_j . Let e_{1t} denote the forecast error of using ω_{jtit-1} to predict ω_{jtit} . Thus, $e_{1t} = \omega_{jtit} - \omega_{jtit-1}$. Similarly, the forecast error when using the public signal on preferences can be written as $e_{2t} = \omega_{jtit} - \xi_{\omega,j,t}$. The

¹¹For a detailed discussion of the Kalman filter formulae, see Hamilton (1994).

error of the combined forecast, ω_{jtt} , equals

$$\zeta_t = \omega_{jt} - \omega_{jtt} = e_{1t} + \beta_j(e_{2t} - e_{1t})$$

Rearranging the above expression gives

$$\omega_{jt} - \omega_{jtt-1} = \beta_j(\xi_{\omega,j,t} - \omega_{jtt-1}) + \zeta_t$$

where the composite error term is assumed to be serially uncorrelated with zero mean and variance σ_ζ^2 .

This paper assumes that the private sector is perpetually learning about the economy. Thus, rather than using fixed weights for the above forecast combination, the private sector updates the weights each period as proposed by Diebold and Pauly (1987). At the beginning of period t , the private sector has observed the true individual preferences of members in period $t - 1$, ω_{jt-1} , as well as the signals communicated by committee members at the beginning of period $t - 1$ and it knows its own prediction of preferences using information from period $t - 2$, that is $\omega_{jt-1|t-2}$. The private sector recursively establishes β_{jt} by running the regression:

$$\omega_{jt-1} - \omega_{jt-1|t-2} = g_{jt-1}(\xi_{\omega,j,t-1} - \omega_{jt-1|t-2}) + \zeta_{t-1} \quad (48)$$

where

$$R_{t-1} = R_{t-2} + \gamma \left[(\xi_{\omega,j,t-1} - \omega_{jt-1|t-2})^2 - R_{t-2} \right]. \quad (49)$$

In every period t , the private sector then sets $\beta_{jt} = \widehat{g}_{jt-1}$ for $0 \leq \widehat{g}_{jt-1} \leq 1$ and $\beta_{jt} = 0$ for $\widehat{g}_{jt} < 0$ and $\beta_{jt} = 1$ for $\widehat{g}_{jt-1} > 1$ in order to make sure that $0 \leq \beta_{jt} \leq 1$.

Again, it can be noted that the larger γ , the fewer observations will be used by the public to estimate the precision of public information and thus the worse will the estimates of this precision be. In what follows, it will be argued that the larger γ , the more limited the public is in its ability to evaluate the precision of public information and thus the greater the degree of the public's imperfect knowledge.

In order to form inflation expectations, the private sector can make use of its different estimates of the preferences of member j , namely ω_{jtt} , using the same methods as in Section IV.B.

V. RESULTS

Section V.A. starts by exploring the simple case in which the private sector is fully rational and knows the parameters of equations (17) and (23)¹². This limiting case serves as a benchmark against which to consider the impact of imperfect knowledge and bounded rationality of the private sector. Section V.B. then investigates welfare under different institutional setups and communication strategies of the committee under the assumption that the public is perpetually learning.

In all the simulations, the error term of the Phillips curve has variance $\sigma_\eta^2 = 1$. In addition, $\sigma_\kappa^2 = \sigma_v^2 = 1$. Furthermore, π^* and y^* are set equal to 2. The model in this paper is highly stylized and as such the quantitative results are likely to depend on the parameter specifications. To illustrate this sensitivity and to assess the robustness of the qualitative results of the paper, the simulations are performed with different values for key parameters that are of economic interest and the results are shown in Section VI.

The effectiveness of communication is measured in terms of the accuracy of private sector expectations of the aggregated committee preference evaluated by their root mean squared error (RMSE). The more precise the private sector is in predicting the aggregated committee preference, the smaller is the root mean squared error of private sector inflation expectations¹³. When the public engages in perpetual learning, the economy is simulated over 160000 time periods. However, the first 80000 observations are discarded and the results are based on the second half of the sample and hence should not depend on the starting values used for the simulations. This procedure follows Dale et al (2008).

A. Perfect Knowledge Benchmark

When the committee is opaque, the private sector uses the mean preference of each committee member for inflation stabilization, ω . The expected squared deviation of this

¹²This assumption can be justified as a fully rational public is able to estimate the relevant parameters and variances using recursive least squares and thus estimates of the parameters will eventually converge to their rational expectations values (for more details on the RLS algorithm and the convergence of estimates to their rational expectations values, see Evans and Honkapohja (2001)).

¹³The accuracy of private sector expectations of inflation is given by $E_t(\pi_t^e - \pi_t)^2 = (y^*)^2 E_t \left[\frac{(\omega_t^k - \hat{\omega}_t^k)}{(\hat{\omega}_t^k)} \right]^2 + E_t(\eta_t(1 - \omega_t^k))^2$ for $k = C, M$ denoting both a consensus based and individualistic approach to decision-making and where $\hat{\omega}_t^k$ is the public's best prediction of the aggregated committee preference. $E_t(\pi_t^e - \pi_t)^2$ is increasing in the difference between ω_t^k and $\hat{\omega}_t^k$ and it is minimised when $\omega_t^k = \hat{\omega}_t^k$.

estimate from the true preferences of committee members is given by

$$E_t(\omega - \omega_{jt})^2 = \frac{\sigma_{\varepsilon,j}^2}{1 - \rho_j^2} \quad (50)$$

for $j = 1, \dots, N + 1$.

If voting records and policy minutes are published in period $t - 1$, the public's best prediction of committee member j 's preference for inflation stabilization in period t will be:

$$\omega_{j,t|t-1} = \omega + \rho_j \nu_{j,t-1} \quad (51)$$

for $j = 1, \dots, N + 1$. The expected squared deviation of these estimates from the true preferences of committee members can be written as

$$E_t(\omega_{j,t|t-1} - \omega_{jt})^2 = \sigma_{\varepsilon,j}^2 \quad (52)$$

for $j = 1, \dots, N + 1$.

Since $0 < \rho_j < 1$, the private sector's estimate of member j 's preference for inflation stabilization is more precise when voting records and minutes are published compared to the case when they are not published.

Furthermore, if the private sector is fully rational and able to process information efficiently, imperfect communication about committee members' preferences through speeches is always enhancing the predictability of members' preferences. It is straightforward to show that:

$$E_t(\omega_{j,t|t} - \omega_{jt})^2 = \frac{\sigma_{\varepsilon,j}^2 \sigma_{\psi,j}^2}{\sigma_{\varepsilon,j}^2 + \sigma_{\psi,j}^2} < \sigma_{\varepsilon,j}^2 = E_t(\omega_{j,t|t-1} - \omega_{jt})^2 \quad (53)$$

as long as $\sigma_{\varepsilon,j}^2 > 0$ for all $j = 1, \dots, N + 1$.

If the publication of voting records and policy minutes and speeches enables the private sector to predict more accurately the preferences of each committee member, then it follows that this has to be true of any function of the estimates of committee members' preferences by the public, such as the mean or median. Thus if decisions are made by consensus it directly follows that for a given N ,

$$\begin{aligned} E_t(\omega_{t|t}^{P,C} - \omega_t^C)^2 &= E_t(c_1 \text{mean}(\boldsymbol{\omega}_{t|t} - \boldsymbol{\omega}_t) + c_2(\omega_{CH,t|t} - \omega_{CH,t}))^2 \\ &< E_t(\omega_t^{P,C} - \omega_t^C)^2 = E_t(c_1 \text{mean}(\boldsymbol{\omega}_{t|t-1} - (\boldsymbol{\omega}_t)) + c_2(\omega_{CH,t|t-1} - \omega_{CH,t}))^2 \end{aligned} \quad (54)$$

where $\boldsymbol{\omega}_t$ denotes the vector of true preferences for $j = 1, 2, \dots, N + 1$ (including the chairman), and $\boldsymbol{\omega}_{t|t}$ denotes the vector of predicted preferences when policy minutes and speeches are published. Similarly, $\boldsymbol{\omega}_{t|t-1}$ denotes the vector of predicted preferences when only minutes are published.

If decisions are made by a committee with an individualistic approach to decision-making, it can be deduced that for a given N ,

$$\begin{aligned} E_t(\omega_{t|t}^{P,M} - \omega_t^M)^2 &= E_t(m_1(\text{median}(\boldsymbol{\omega}_{t|t}) - \text{median}(\boldsymbol{\omega}_t)) + m_2(\omega_{CH,t|t} - \omega_{CH,t}))^2 \\ &< E_t(\omega_t^{P,M} - \omega_t^M)^2 \end{aligned} \quad (55)$$

where

$$E_t(\omega_t^{P,M} - \omega_t^M)^2 = E_t(m_1(\text{median}(\boldsymbol{\omega}_{t|t-1}) - \text{median}(\boldsymbol{\omega}_t)) + m_2(\omega_{CH,t|t-1} - \omega_{CH,t}))^2.$$

Again $\boldsymbol{\omega}_t$ denotes the vector of true preferences for $j = 1, 2, \dots, N + 1$ (including the chairman), and $\boldsymbol{\omega}_{t|t}$ denotes the vector of predicted preferences when voting records and speeches are published. Similarly, $\boldsymbol{\omega}_{t|t-1}$ denotes the vector of predicted preferences when only voting records are published. These results are summarized in Proposition 1.

Proposition 1 *When the private sector does not face imperfect knowledge, it will always be beneficial to publish minutes and voting records of committee meetings. Policy minutes and voting records in this case perfectly reveal to the private sector the preferences of committee members for that period and can then be used to predict preferences in the next period. In addition, speeches by committee members before policy meetings enhance the predictability of preferences and thus welfare.*

It is also interesting to consider whether the predictability of preferences and thus inflation depends on the decision-making strategy of the committee. When only voting records and policy minutes are published, the expected squared deviation of the prediction of the mean preference (excluding the chairman) by the public from the true average preference of the committee can be expressed as

$$E_t(\text{mean}(\boldsymbol{\omega}_{j|t-1}) - \text{mean}(\boldsymbol{\omega}_{jt}))^2 = \frac{1}{N^2} [\sigma_{\varepsilon,1}^2 + \sigma_{\varepsilon,2}^2 + \dots + \sigma_{\varepsilon,N}^2] \quad (56)$$

and for the median preference as

$$\begin{aligned} &E_t(\text{median}(\boldsymbol{\omega}_{j|t-1}) - \text{median}(\boldsymbol{\omega}_{jt}))^2 \\ &= E_t \left[\begin{array}{c} \text{median}(\omega + \rho_1 \nu_{1,t-1}, \omega + \rho_2 \nu_{2,t-1}, \dots, \omega + \rho_N \nu_{N,t-1}) \\ - \text{median}(\omega + \nu_{1,t}, \omega + \nu_{2,t}, \dots, \omega + \nu_{N,t}) \end{array} \right]^2. \end{aligned} \quad (57)$$

Which one of the above expressions is smaller depends on the number of committee members and how heterogeneous committee members are regarding the variances of the error terms in the $AR(1)$ process governing their preferences, that is $\sigma_{\varepsilon,j}^2$. In what follows, the paper will refer to policymakers that share the same variance of the error term in the $AR(1)$ process governing their preferences, as 'homogeneous'. Strictly speaking, these policymakers still have heterogeneous preferences that feature the same $\sigma_{\varepsilon,j}^2$.

Figure 1 in the Appendix shows that when the variances of the $AR(1)$ processes governing committee members preferences are identical and equal to 1, making decisions by simple averaging is clearly preferable to making decision by majority voting. In addition, predictability under both a consensus based and individualistic approach to decision-making is increasing with committee size (for $N > 2$). The intuition for these results is as follows. When the variances of the $AR(1)$ process governing committee preferences are identical, then the preference of each committee member is equally predictable. Attaching the same weight to all predictions of members' preferences is optimal. Moreover, as N increases, predictability of preferences increases. This is because as N increases the preference of each policymaker will carry less weight under averaging. This can be easily seen for consensus based decision making from equation (56) under the assumption that $\sigma_{\varepsilon,1}^2 = \sigma_{\varepsilon,2}^2 = \dots = \sigma_{\varepsilon,N}^2$.

On the other hand, Figure 2 illustrates the RMSE of the public, when the variances of the $AR(1)$ process governing preferences are different in that $\varepsilon_{jt} \sim N(0, 1)$ for $j = 2, \dots, N$ and $\varepsilon_{1t} \sim N(0, 8)$. This figure shows that making decisions by majority voting yields higher predictability of preferences in this case. The difference in predictability under majority voting and decision-making by consensus is shown to be decreasing with committee size when members are heterogeneous. The intuition for these results is as follows. Under majority voting the public has to predict the preferences of the median policymaker and thus can ignore policymakers with very large variances, whose preferences are hard to predict. Thus, if the variances of preferences of committee members are diverse, then using majority voting will lead to greater predictability of preferences. In addition, as N increases, policymakers with high variances and whose preferences thus change by a large amount each period are given less weight under averaging, which improves predictability.

In figures 1 and 2 the result for the RMSEs for different committee sizes under voting are non-monotonic. In this case, preferences are aggregated using the median. This is a more complex aggregating procedure than averaging, and from (57) it can be seen that the median of the predicted members' preferences might not correspond to the preference of the median committee member. The fact that in this case, the results are less smooth than under averaging was also demonstrated by Gerlach-Kristen (2006). Gerlach-Kristen (2006) examines whether voting or averaging performs better in terms of choosing the correct policy instrument under uncertainty about the state of the economy. She finds that if policymakers' skills are identical, averaging outperforms voting. However, if policymakers have different abilities, majority voting leads to a

monetary policy that is closer to the optimal monetary policy that would be conducted if there was no uncertainty about the economy. Our results do not investigate which decision-making process leads to better monetary policy but which decision rule leads to greater predictability of preferences and thus welfare. However, the results are similar in that greater heterogeneity between policymakers (be it about abilities or preferences) makes decision-making by majority more desirable.

B. Private Sector Imperfect Knowledge

The section first discusses the simulation results when the central bank communicates only its voting records and policy minutes and when the chairman has no particular influence. The section then analyses welfare when the chairman has added influence. Finally, the section considers the case in which the central bank publishes its voting records and policy minutes and communicates through speeches before policy meetings.

B.1 Voting records and policy minutes are published

The effect of publishing voting records and policy minutes under different constant gains of the public on the predictability of the aggregated committee preference for the weight given to inflation stabilization is shown in Figures 3 and 4. Those figures show the constant gain, which the public uses to learn about the parameters of the processes governing policymakers' preferences, (17) and (23), and the corresponding RMSE of the public in predicting the aggregated preference of the committee for inflation stabilization. In both figures, N is set equal to 9 and ρ_j is equal to 0.5 for $j = 1, 2, \dots, N + 1$. Furthermore, in Figure 3, $\varepsilon_{jt} \sim N(0, 1)$ for $j = 2, 3, \dots, N + 1$ and $\varepsilon_{1t} \sim N(0, 0.1)$ whereas in Figure 4, $\varepsilon_{jt} \sim N(0, 1)$ for $j = 1, 2, \dots, N + 1$. The coefficients c_1 and m_1 are set to 1.

Figures 3 and 4 illustrate that as the constant gain increases, the public uses less historical data to estimate the relevant model parameters and hence the quality of the prediction of the aggregated committee preference for the weight given to inflation stabilization decreases. By way of comparison, the RMSE of the public when the central bank does not publish its voting records or policy minutes is shown by the horizontal line. If there is no communication by the committee, the public will simply use the mean preference of committee members, ω , as the best estimate of the aggregated committee preference.

For both consensus based decision-making and majority voting, when the private sector gain is low, the predictability of the aggregated committee preference is increased when policy minutes and voting records are published. However as Figure 3 illustrates, when policymakers are heterogeneous in their preferences, an individualistic approach to decision-making leads to greater predictability and this means that the constant gain

beyond which central bank communication becomes suboptimal is larger than for a consensus based approach. Figure 4 shows that the opposite applies when policymakers are homogeneous in terms of their policy preferences.

The intuition for these results is as follows. The public learns about the coefficients of the process that aggregates the different preferences of committee members, that is (17) and (23). The lower is the constant gain that the public uses in order to form estimates of the coefficients, the more precise those estimates will be. This is because the smaller is γ the more observations the public uses to form these estimates. Thus, when γ is small, the public is able to use the information contained in minutes and voting records relatively efficiently leading to better predictions of the aggregated committee preference than using the mean preference, ω . In addition, the results of Section A. regarding the desirability of majority voting versus consensus continue to hold, in that if policymakers are heterogeneous, majority voting is preferable. This is because, in this case, the private sector needs to predict the policy preference of the median member and can ignore policymakers whose preferences are very variable and difficult to predict.

B.2 A chairman with added influence

It is often argued that the chairman can exert disproportionate influence on the committee decision (Blinder, 2004). In an empirical study on decision-making at the Federal Reserve Open Market Committee, Chappell et al (2004) estimate that the impact of the chairman on policy decisions corresponds to a voting weight of 40 to 50 percent. As Gerlach-Kristen (2008a) argues, this influence may come from the chairman's ability to influence the discussion and summarize the different views of committee members but it may also be the result of superior monetary policy making skills or due to the institutional setup of the committee.

The results for a consensus based approach to decision-making are shown in Figure 5 and for an individualistic approach to decision-making in Figure 6. In Figures 5 and 6, $N = 9$, $\rho_j = 0.5$ for $j = 1, 2, \dots, N + 1$. Furthermore, $\varepsilon_{jt} \sim N(0, 1)$ for $j = 1, 2, \dots, N$ and $\varepsilon_{N+1t} \sim N(0, 0.1)$. When the chairman has added influence c_1 and m_1 are set to 0.6 and c_2 and m_2 are set to 0.4. If all committee members have the same weight in the policy decision, then c_1 and m_1 are set to 1.

Figures 5 and 6 show that if the chairman has stable policy preferences having a chairman with added influence is beneficial. The presence of such a chairman enhances the overall predictability of the aggregated policy preference under both consensus and an individualistic approach to decision-making. In addition, the constant gain beyond which it becomes suboptimal to publish voting records and policy minutes is higher than without the presence of such a chairman.

The intuition for these results is as follows. If the policy preference of the chairman are very predictable, then the public is able to predict his voting behavior well from past

voting records. Thus if he has a significant influence on the policy decision, this enhances the predictability of the aggregated committee preference. Because, the RMSE of the public under private sector learning is generally smaller when an influential chairman whose preferences are predictable is present, central bank communication remains optimal for higher constant gains of the public.

The results of this paper may provide some explanation for the diverse communication practices of three major central banks, the Bank of England, the European Central Bank and the Federal Reserve. The Federal Reserve and the Bank of England release minutes along with individual votes. The European Central Bank on the other hand does not publish minutes. If policymakers are heterogeneous in their preferences, then it is more likely that the publication of individual votes will be welfare enhancing when decisions are made by majority voting as it is the case at the Bank of England than when decisions are made by consensus, as it is the case at the ECB. Furthermore, if the chairman is very stable in his preferences and carries significant weight, then this makes the publication of minutes and voting records more likely to be welfare enhancing. This may provide some explanation for why the Federal Reserve publishes minutes and individual votes since it is often argued that the chairman has significant influence on the decision-making process.

The results also provide some explanation for empirical findings, which generally show that transparency about policy deliberations in the form of voting records and minutes are scarce. For example, Geraats (2009) using a sample of 98 central banks shows that in 2006 only 10 of these central banks published their voting records. 5 of these 10 central banks published individual voting records, the others published unattributed voting patterns. Only 16 of those 98 central banks published minutes, which are generally non-verbatim and unattributed with the exception of the Swedish Riksbank, which publishes attributed minutes.

B.3 Voting records and speeches are published

Figure 7 shows the RMSE of the public under imperfect common knowledge of the precision of public information for a committee that makes decisions by majority. In this figure, $N = 9$ and $\rho_j = 0.5$ for $j = 1, 2, \dots, N + 1$. Furthermore, $\varepsilon_{jt} \sim N(0, 1)$ for $j = 2, 3, \dots, N + 1$ and $\varepsilon_{1t} \sim N(0, 0.1)$. The coefficients c_1 and m_1 are set to 1. Figure 7 shows that when committee members give speeches that imperfectly reveal their preferences, the public may not be able to attach a correct weight to this additional information, resulting in less predictability of preferences. Figure 7 also illustrates that the constant gain beyond which it becomes suboptimal to communicate with the markets prior to the committee meeting in addition to publishing voting records is smaller than the constant gain beyond which it is suboptimal to publish voting records.

The intuition for these results is as follows. If the committee only publishes its voting records, then in order to predict the aggregated committee preference, the public only

needs to learn about the coefficients in equations (17) and (23). If committee members in addition to voting records also communicate noisy information on their preferences before the committee meeting, then the private sector has to learn about the weights that it should attach to these two sources of information on members' preferences. Thus, when there are two sources of public information, there are two different learning processes by the public. If γ is sufficiently small, then the predictability of the aggregated committee preference is enhanced by noisy communication of preferences through speeches and the publication of voting records because the private sector is able to process this information relatively efficiently. As γ increases, both the quality of the estimates of the variances of the public information and the estimates of the coefficients in equations (17) and (23) decrease. The interaction of those learning processes implies that the RMSE of the public rises by more as γ increases if there is communication in the form of speeches prior to meetings compared to the case when only voting records are published.

These results illustrate that the release of vague information by the central bank can be welfare reducing. If there are limits to how much information the public can digest effectively, some communication might still be useful but the central bank has to be careful not to confuse the markets with extra communication that they cannot efficiently process. The results correspond to the findings of Dale et al (2008) who conclude that the usefulness of communication depends on the public's ability to assess the quality of the central bank's communication. They are also related to the results by Morris and Shin (2002) who show that communication by the central bank could generate lower welfare when agents overreact to the public signal.

VI. CONCLUSION

Recently there has been a growing interest in the communication strategies of central banks. This paper provides a first attempt to analyze how the optimal communication strategy of a central bank depends on the nature of its decision-making process and the structure of its monetary policy committee, a question that has been barely touched on in the existing literature on central bank communication.

The paper considers the optimal communication strategies of committees with different decision-making structures in a model of imperfect knowledge and learning. The main policy implications are that there may be costs to communication if the public is boundedly rational. In addition, when committee members are heterogeneous, welfare is greater under majority voting than under a consensus based approach to decision-making. Furthermore with the public engaged in perpetual learning, when committee members are heterogeneous, central bank communication is more likely to be welfare enhancing under majority voting. However, under both majority voting and a consensus based approach to decision-making, if the public faces a significant degree of imperfect knowledge due to uncertainty about the preference aggregation process of the

committee and the precision of public information, then communication by the central bank reduces welfare. Furthermore, a chairman with stable policy preferences who carries significant weight in the policy decision-making process is welfare-enhancing.

The model presented is highly stylized. However, it does provide some rationale for why monetary policy committees with different structures and institutional setups should communicate differently and why central banks may want to be careful when communicating noisy information to the public. Some useful directions for future research should also be noted. This paper does not consider strategic behavior of committee members. However, it is plausible that with different policy preferences, coalitions among policymakers are formed. In addition, the paper abstracts from any political pressures on committee members, which may also affect the voting behavior of committee members and hence the decision-making process of the committee. These issues are left to be explored in future research.

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APPENDIX A: FIGURES

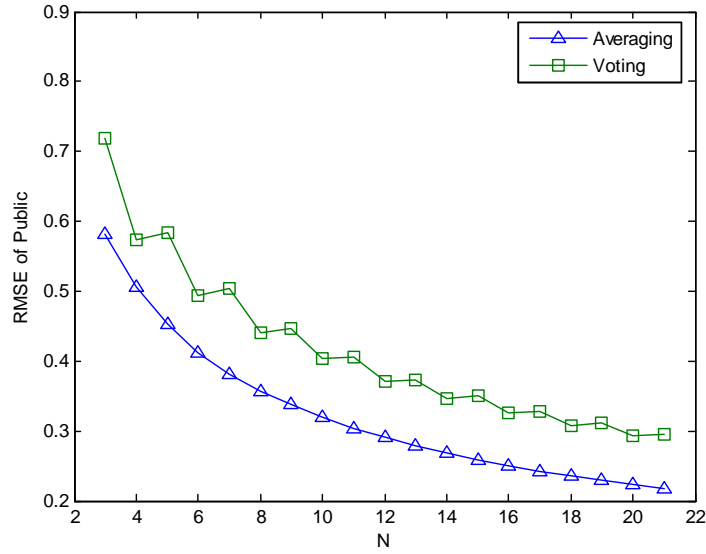


Figure 1: RMSE of the public under averaging and voting: 'homogeneous' policymakers.

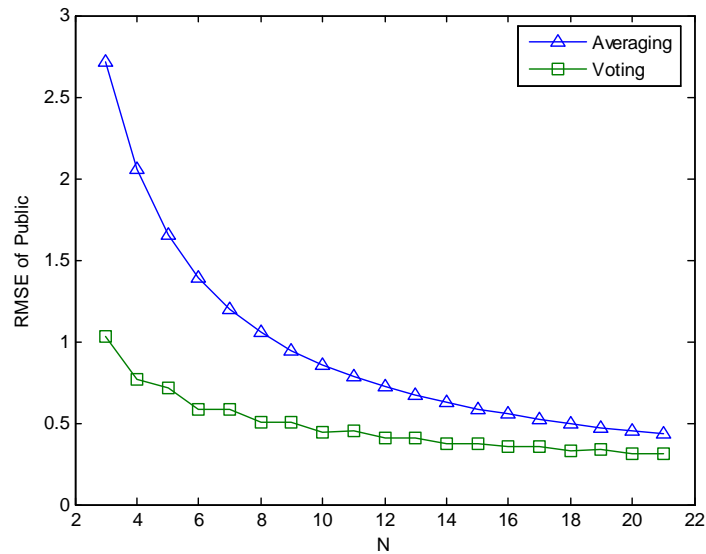


Figure 2: RMSE of the public under averaging and voting: 'heterogeneous' policymakers.

Note: In Figure 1, the errors of the AR(1) process governing preferences were simulated using 20000 draws with $\varepsilon_{jt} \sim N(0, 1)$ for all $j = 1, \dots, N$. In Figure 2, the errors of the AR(1) process governing policy preferences have been simulated using 20000 draws with $\varepsilon_{jt} \sim N(0, 1)$ for all $j = 2, \dots, N$ and $\varepsilon_{1t} \sim N(0, 8)$ for one policymaker.

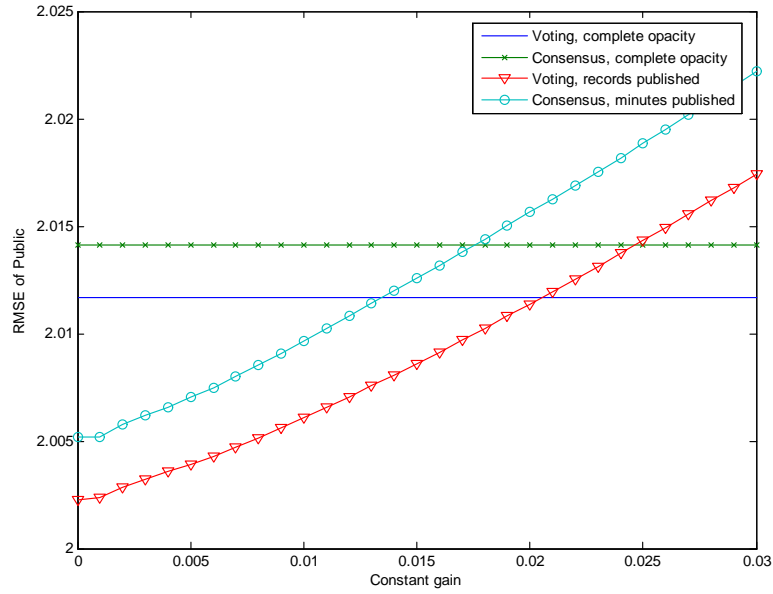


Figure 3: RMSE of the public with heterogeneous policymakers for different constant gains.

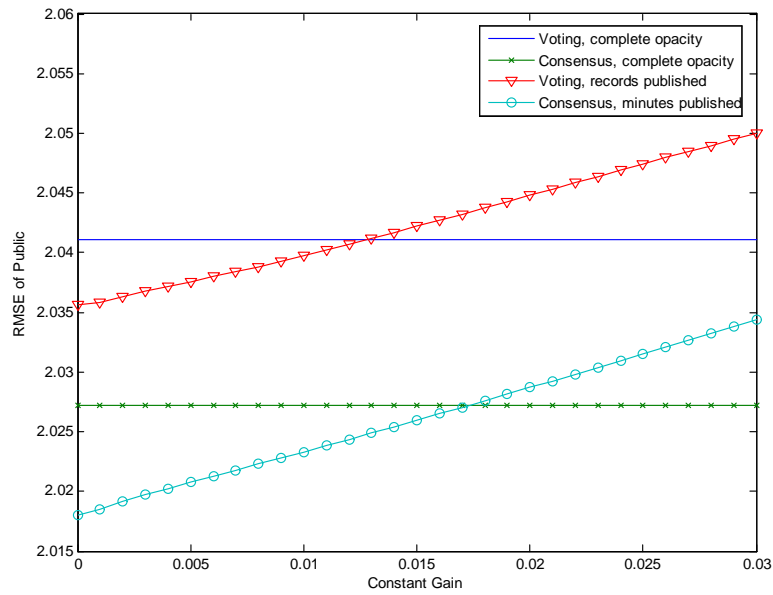


Figure 4: RMSE of the public with 'homogeneous' policymakers for different constant gains.

Notes: In figures 3 and 4 we set $N = 9$, c_1 and $m_1 = 1$, c_2 and $m_2 = 0$ and $\rho_j = 0.5$ for all $j = 1, \dots, N + 1$. Figure 3 assumes that $\varepsilon_{jt} \sim N(0, 1)$ for $j = 2, 3, \dots, N + 1$ and $\varepsilon_{1t} \sim N(0, 0.1)$ whereas in Figure 4 $\varepsilon_{jt} \sim N(0, 1)$ for all $j = 1, \dots, N + 1$.

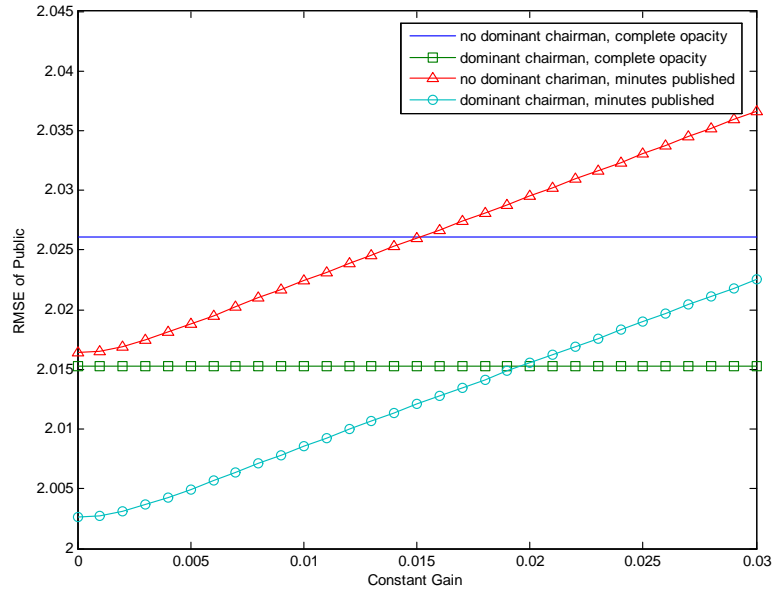


Figure 5: RMSE of the public under consensus with special influence of the chairman.

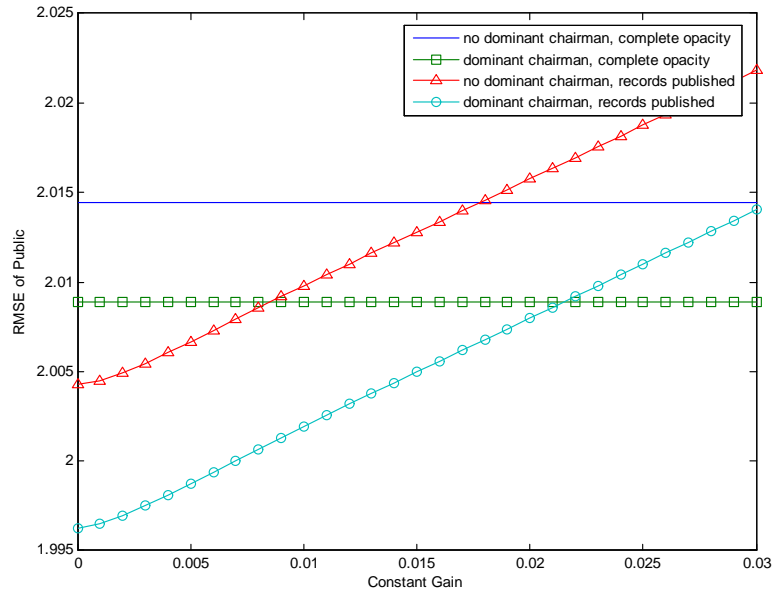


Figure 6: RMSE of the public under majority voting with special influence of the chairman.

Note: In figures 5 and 6 we set $N = 9$ and $Var(\varepsilon_{jt}) = 1$ for $j = 1, \dots, N$ and $Var(\varepsilon_{N+1t}) = 0.1$. Furthermore $\rho_j = 0.5$ for all $j = 1, \dots, N + 1$. We let c_1 and $m_1 = 1$ and c_2 and $m_2 = 0$ when there is no dominating chairman and c_1 and $m_1 = 0.6$ and c_2 and $m_2 = 0.4$ when the chairman has special influence on the committee decision.

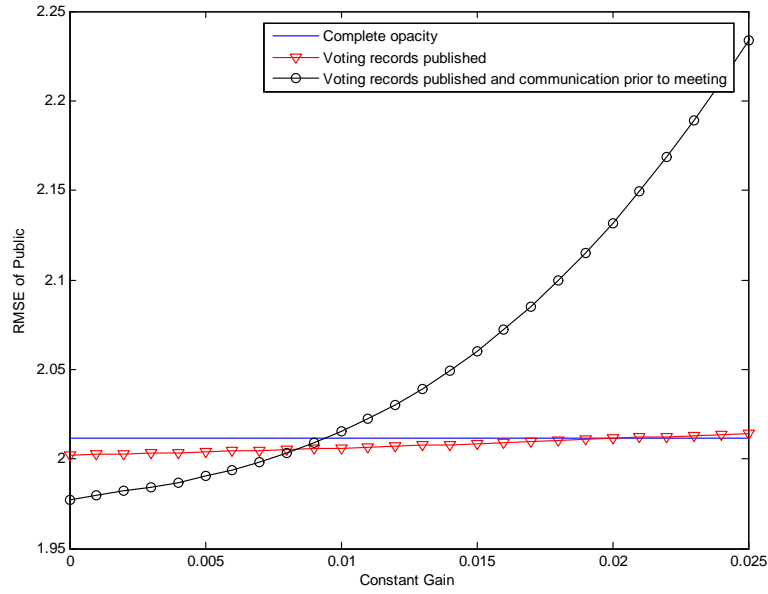


Figure 7: RMSE of the public under majority voting with imperfect knowledge of precision of public information.

Note: In Figure 7 we set $N = 9$ and assumed that $E_t(\varepsilon_{jt}) = 0$ and that $Var(\varepsilon_{jt}) = 1$ for $j = 2, \dots, N$ and $Var(\varepsilon_{1t}) = 0.1$. Furthermore $\rho_j = 0.5$ for all $j = 1, \dots, N + 1$. We let c_1 and $m_1 = 1$ and c_2 and $m_2 = 0$.

APPENDIX B: SENSITIVITY ANALYSIS

First, the effect of varying the persistence of committee members' preferences, ρ_j , on the results in Section B. is analyzed. Two alternative values are considered - $\rho_j = 0.2$ and $\rho_j = 0.8$ for all $j = 1, 2, \dots, N + 1$ - compared with the benchmark case of $\rho_j = 0.5$. The results for $\rho_j = 0.2$ and $\rho_j = 0.8$ are summarized in Tables 1 to 3 where $\varepsilon_{jt} \sim N(0, 1)$ for $j = 1, 2, \dots, N + 1$ and $\varepsilon_{1t} \sim N(0, 0.1)$, $c_1 = m_1 = 1$ and $N = 9$. The qualitative results are broadly the same as in Figures 3 and 7. However, it is interesting to note that reducing the persistence of preferences decreases the gain beyond which communication is no longer beneficial. This is intuitive. When committee members are opaque and ω is used as an estimate of preferences, then the expected squared deviation of this estimate from the true preference of member j is given by (50). This expression is clearly increasing in ρ_j . The less persistent preferences are, the better does ω as an estimate of member j 's preference. When voting records and minutes are published, then (52), shows that the expected squared deviation of using this information from period $t - 1$ to predict preferences in period t does not depend on ρ_j . This is because a decrease ρ_j reduces the ability of the public to predict preferences in period t using information from period $t - 1$, but it also decreases the variance of preferences thereby making them more predictable overall.

$\rho_j = 0.2$ γ	Voting records and minutes		Voting records, minutes and speeches	
	RMSE, voting	RMSE, consensus	RMSE, voting	RMSE, consensus
0.001	2.0050	2.0098	2.0042	2.0095
0.002	2.0059	2.0107	2.0055	2.0108
0.003	2.0068	2.0115	2.0069	2.0112
0.004	2.0077	2.0123	2.0083	2.0126
0.005	2.0085	2.0131	2.0098	2.0140
0.006	2.0092	2.0139	2.0114	2.0155
0.007	2.0100	2.0146	2.0129	2.0171

Table 1: Private sector RMSEs, preferences less persistent than in benchmark case

$\rho_j = 0.8$ γ	Voting records and minutes		Voting records, minutes and speeches	
	RMSE, voting	RMSE, consensus	RMSE, voting	RMSE, consensus
0.01	2.0068	2.0257	2.0048	2.0232
0.02	2.0166	2.0336	2.0158	2.0392
0.03	2.0252	2.0404	2.0262	2.0464
0.04	2.0335	2.0473	2.0446	2.0609
0.05	2.0422	2.0545	2.0626	2.0761
0.06	2.0511	2.0613	2.0861	2.0925
0.07	2.0605	2.0686	2.1092	2.1103

Table 2: Private sector RMSEs, preferences more persistent than in benchmark case

It is also possible to evaluate how the quantitative results depend on the variances of

Complete opacity, heterogeneous members		
	$\rho_j = 0.2$	$\rho_j = 0.8$
RMSE, voting	2.0063	2.0509
RMSE, consensus	2.0105	2.0544

Table 3: Private sector RMSEs, complete opacity, different persistence of preferences of committee members

the error terms in equations (17) and (23). In the baseline simulations, these variances were both set equal to 1. Two alternative values are considered- $\sigma_\kappa^2 = \sigma_v^2 = 0.5$ and $\sigma_\kappa^2 = \sigma_v^2 = 1.5$. The results for these alternative parameter specification are shown in Table 4 where $\varepsilon_{jt} \sim N(0, 1)$ for $j = 1, 2, \dots, N + 1$ and $\varepsilon_{1t} \sim N(0, 0.1)$, $c_1 = m_1 = 1$ and $N = 9$. It can be seen that the qualitative results are broadly the same as in the benchmark case. However, the larger are the variances of the error terms in the preference aggregation equations, the larger is the RMSE of the public in general. This is because the larger are these variances, the worse does ω perform as an estimate of the committee preference. In addition, when voting records and minutes are published, the larger are those variances, the less precise are the private sector estimates of the aggregated committee preferences, (31) and (36).

Voting records and minutes published				
	$\sigma_\kappa^2 = \sigma_v^2 = 0.5$		$\sigma_\kappa^2 = \sigma_v^2 = 1.5$	
γ	RMSE, voting	RMSE, consensus	RMSE, voting	RMSE, consensus
0.005	1.0746	1.0846	2.5139	2.5218
0.010	1.0759	1.0857	2.5167	2.5239
0.015	1.0778	1.0874	2.5196	2.5258
0.020	1.0799	1.0892	2.5228	2.5291
0.025	1.0821	1.0911	2.5263	2.5322
0.030	1.0843	1.0931	2.5300	2.5354
0.035	1.0865	1.0950	2.5340	2.5389
0.040	1.0887	1.0970	2.5381	2.5426
0.045	1.0909	1.0989	2.5425	2.5465
0.050	1.0931	1.1008	2.5470	2.5505
Complete opacity	1.0926	1.0960	2.5180	2.5233

Table 4: Effects of changing the variance of the noise in the committee preference aggregation equation

As a further sensitivity analysis, the effect of varying N on the results in Section B. is considered. Two alternative values are considered - $N = 3$ and $N = 15$ - compared to the benchmark case of $N = 9$. The results are summarized in Tables 5 and 6 where $c_1 = m_1 = 1$ and $\rho_j = 0.5$. In addition, in Table 5, $\varepsilon_{jt} \sim N(0, 1)$ for $j = 2, 3, \dots, N$ and $\varepsilon_{1t} \sim N(0, 0.1)$ whereas in Table 6, $\varepsilon_{jt} \sim N(0, 1)$ for $j = 1, 2, \dots, N + 1$. It can be seen

that the qualitative results are broadly the same as in Figures 3 and 4. However, it is interesting to note that reducing the number of committee members increases the differences between majority voting and consensus. This is not surprising. Figure 2 shows that under perfect knowledge, the difference in the RMSE of the public between majority voting and consensus is decreasing in the number of committee members. This is because under a consensus based approach, as the number of committee members increases, policymakers whose preferences are very variable are given less weight. This improves predictability and from Figure 2 it can be seen that as a consequence the difference between the RMSE under consensus and voting decreases as N increases.

Voting records and minutes published				
	$N = 3$		$N = 15$	
γ	RMSE, voting	RMSE, consensus	RMSE, voting	RMSE, consensus
0.005	2.0389	2.0580	2.0052	2.0115
0.010	2.0405	2.0603	2.0090	2.0152
0.015	2.0427	2.0632	2.0124	2.0186
0.020	2.0453	2.0663	2.0168	2.0218
0.025	2.0478	2.0696	2.0203	2.0248
0.030	2.0503	2.0730	2.0237	2.0278
0.035	2.0528	2.0765	2.0271	2.0310
0.040	2.0552	2.0801	2.0304	2.0341
0.045	2.0577	2.0839	2.0338	2.0371
0.050	2.0601	2.0878	2.0372	2.0403
Complete opacity	2.0525	2.0702	2.0091	2.0118

Table 5: Effects of varying N , heterogeneous members

Finally, the paper also assesses the predictability of preferences, when all committee members have different variances of preferences, that is $\sigma_{\varepsilon,j}^2 \neq \sigma_{\varepsilon,k}^2$ for $j \neq k$. The results are summarized in Tables 7 and 8 for $N = 9$, $\rho_j = 0.5$ and $c_1 = m_1 = 1$. It is assumed that $Var(\varepsilon_{1t}) = 0.1$ and that for $j = 2, 3, \dots, N + 1$, $Var(\varepsilon_{jt}) = Var(\varepsilon_{j-1t}) + 0.1$. Again, the qualitative results are broadly similar to Figures VI. and VI.. However, the RMSE of the public is now generally smaller, since there is a larger number of committee members with $Var(\varepsilon_{jt}) < 1$ than in the benchmark case.

Voting records and minutes published				
	$N = 3$		$N = 15$	
γ	RMSE, voting	RMSE, consensus	RMSE, voting	RMSE, consensus
0.005	2.1313	2.0939	2.0257	2.0197
0.010	2.1348	2.0976	2.0295	2.0240
0.015	2.1386	2.1015	2.0331	2.0280
0.020	2.1424	2.1055	2.0364	2.0317
0.025	2.1463	2.1094	2.0395	2.0354
0.030	2.1501	2.1133	2.0425	2.0390
0.035	2.1539	2.1172	2.0455	2.0426
0.040	2.1576	2.1210	2.0484	2.0463
0.045	2.1613	2.1247	2.0514	2.0500
0.050	2.1650	2.1285	2.0543	2.0538
Complete opacity	2.1518	2.1178	2.0304	2.0280

Table 6: Effects of varying N, 'homogeneous' members

γ	Voting records and minutes		Voting records, minutes and speeches	
	RMSE, voting	RMSE, consensus	RMSE, voting	RMSE, consensus
0.005	1.9881	1.9917	1.9866	1.9895
0.010	1.9904	1.9950	1.9899	1.9951
0.015	1.9928	1.9980	1.9925	1.9983
0.020	1.9953	2.0010	1.9952	2.0015
0.025	1.9978	2.0040	1.9979	2.0046
0.030	2.0004	2.0069	2.0007	2.0078
0.035	2.0030	2.0100	2.0035	2.0110
0.040	2.0057	2.0131	2.0064	2.0143
0.045	2.0085	2.0162	2.0094	2.0196
0.050	2.0115	2.0194	2.0129	2.0297

Table 7: Private sector RMSEs, different variances of committee members' preferences

Complete opacity, heterogeneous members	
RMSE, voting	2.0028
RMSE, consensus	2.0034

Table 8: Complete opacity, different variances of committee members' preferences