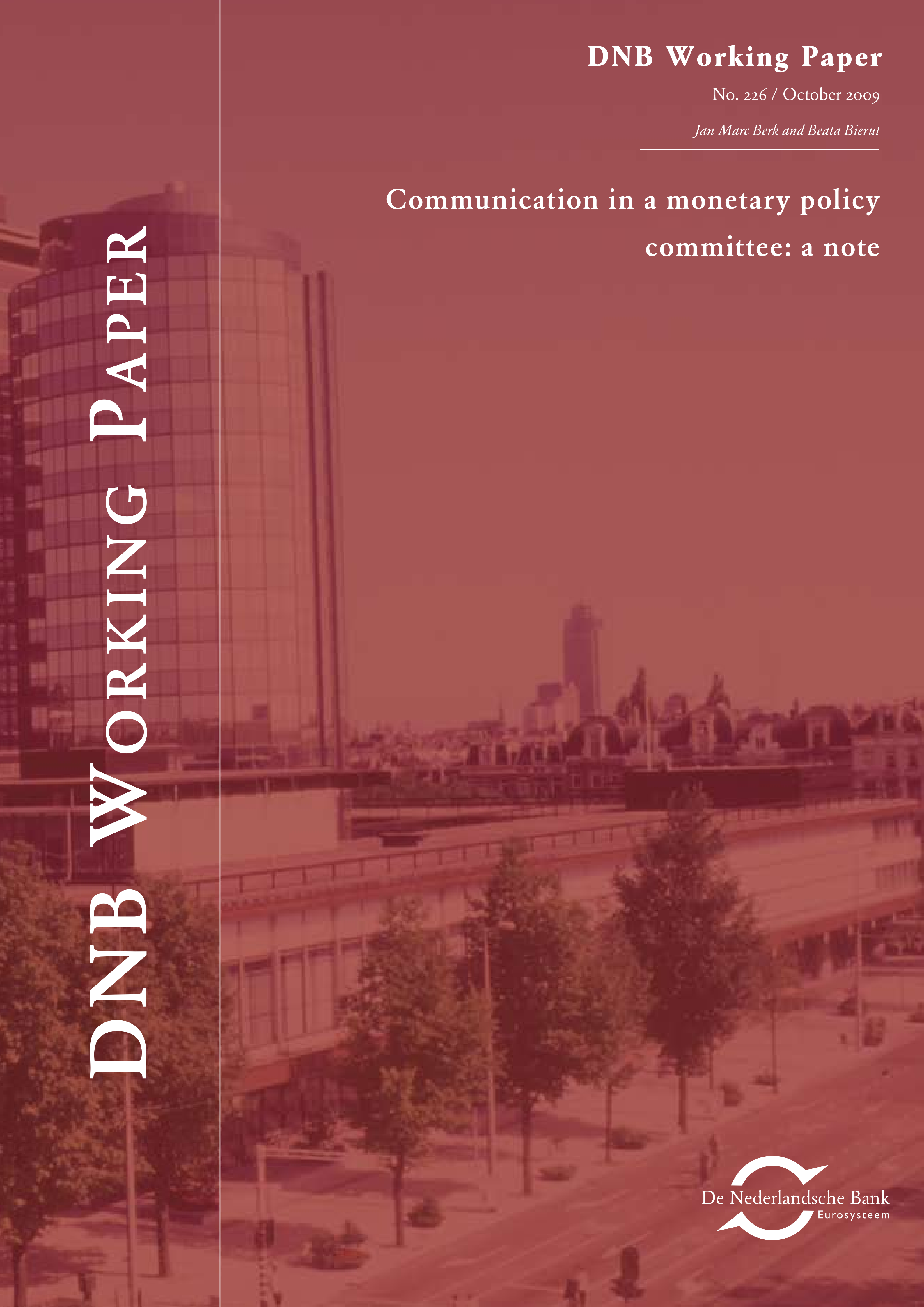

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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Communication in a monetary policy committee: a note

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October 14, 2009

Abstract

This paper models monetary policy decisions as being taken by an interacting group of heterogeneous policy makers, organized in a committee. Disclosing the premises on which an individual view on the interest rate is based is likely to provide value added in terms of the quality of the collective decision over-and-above simultaneous voting on interest rates. However, this is not generally true, as communication also involves a trade-off in the quality of views of committee members, which can lead to a reduction in the quality of collective decisions below the outcome achieved under simple majority voting. Still, communication is a relatively effective way to implement the 'knowledge pooling' argument pro collective decision-making, compared to expanding the size of the MPC. *(JEL E58, D71, D78)*

Keywords: committees, deliberations, correlated votes, simple majority voting

1 Introduction

Most monetary policy decisions are nowadays taken not by a single individual, but by a monetary policy committee (henceforth: MPC). When members convene for the MPC meeting, they communicate with each other. This process of communication is an important characteristic of real-life committee decision-making such as by the FOMC in the US or the ECB Governing Council in the euro area (Goodfriend (1999), De Nederlandsche Bank (2000)). Interaction among MPC members involves an extensive exchange of views regarding the current and future state of the economy, the transmission mechanism and the appropriate interest rate decision. Communication thus implies an exchange of information that increases the total knowledge available to the MPC (Berger et al. (2008)). However, communication also implies augmenting one's initial

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views with those heard from others. The latter might be qualitatively less than the former, so the impact of communication on the collective decision is not clear a priori. The paper aims to investigate the conditions under which communication improves the quality of the collective decision, (ex hypothesi) made by simple majority voting. By doing so, we are able to provide a theoretical rationale for some of the results found in the recent empirical literature on MPC's, such as Gerlach-Kristen (2003a,b), Meade and Sheets (2005) and Chappell et al. (2005).

Our findings indicate that an exchange of views within monetary policy committees will, in general, be beneficial for the quality of decision-making even though it increases correlation in members' voting behaviour. Hence, we contradict the results of Ladha (1992), who - on statistical grounds - argued that a high positive correlation of votes above a certain threshold can substantially reduce the accuracy of simple majority decisions (in the limit, the majority will even do worse than an average voter). We show that an exchange leading to a single view on the correct decision yields collective outcomes inferior to the simultaneous simple majority voting only when decisional skills are very unevenly distributed among committee members. In other cases, communication increases the quality of monetary policy and is more effective doing so, the lower the average of MPC members' skills. It is also more effective than enlarging an MPC that does not communicate with new members.

The structure of the paper is as follows. We start, in section two, by briefly describing our analytical framework. In section three, we formalize the effects of communication on the quality of collective decisions taken by an MPC and investigate them in an MPC consisting of members with identical skills. An MPC consisting of members with heterogeneous skills is considered in section four. Section five concludes.

2 Analytics

We start with a simple binomial simultaneous voting model (e.g. Austen-Smith and Banks (1996)), as adapted for MPC context in Berk and Bierut (forthcoming), where details can be found. We assume that the MPC members' sole collective objective is to take the correct interest rate decision, conditional on the state of the economy. The economy can be in either of two states of the world: economic conditions are such that a change in policy rates is required (which we label 'state a') or not ('state b'). The members $i = 1, \ldots, n$ have to assess the state using available information. They have identical prior beliefs regarding the appropriate monetary policy stance. Of course this prior belief may be modified by the evidence on the state of the economy presented in the meeting. We model the possibility that committee members interpret the evidence differently by assuming that this interpretation represents a private signal each member receives and that is imperfectly correlated with the true state of the economy. The higher the quality of this interpretation, the larger the probability that the member receives the correct signal. This translates directly into a higher probability of making the correct individual decision, i.e. voting for a change in interest rates (decision A) in state a and voting for unchanged rates (decision B) in state b:[1]

$$P(v_i = A|a) = P(v_i = B|b) = q_i \tag{1}$$

and consequently:

$$P(v_i = B|a) = P(v_i = A|b) = 1 - q_i \tag{2}$$

We label the q_i's as individual decisional skills. For an elaboration of this concept, which is akin to Blinder's (2007) 'mind set', see Berk and Bierut (2009). See Vandenbussche (2006) for an elaborate motivation of focusing on skill differences between committee members instead of preference differentials. If the skills are independent the conditional probability that the decision d chosen by committee's simple majority will be correct is:

$$P(d = A|a) = P(d = B|b) = \sum_{\substack{S \subset N \\ s \geq \frac{n+1}{2}}} \prod_{i \in S} q_i \prod_{i \notin S} (1 - q_i) \tag{3}$$

where the sums are taken over all subsets S of the set of committee members $N = \{1, 2, 3, ..., n\}$, such that s (the number of members in S) is at least $\frac{n+1}{2}$ (for simplicity, we assume that the committee's size n is odd). If skills are homogeneous, i.e. $q_i = q$ for all $i = 1, \ldots, n$, the above simplifies to the familiar Condorcet formula:

$$P(d = A|a) = P(d = B|b) = \sum_{s=\frac{n+1}{2}}^{n} \binom{n}{s} q^s (1 - q)^{n-s} \tag{4}$$

The above Condorcet specification of the group decision-making problem can be linked to a stylized macroeconomic description of the central bankers' problem in the following way. Assume that the central bank's committee loss function is given by:

$$L_t = E_t (\pi_{t+1} - \pi^*)^2 \tag{5}$$

implying that members have common preferences. The inflation target π^* is fixed and common knowledge. The evolution of inflation is captured by the following reduced-form equation (see also Gerlach-Kristen (2003b)):

$$\pi_{t+1} = \pi_t - \alpha r_t + e_{t+1} \tag{6}$$

where π_t is the inflation rate observed at time t, r_t is the interest rate set at time t and e_{t+1} is the future inflation shock. Each committee member i believes the model (6) to be true and shares the estimate of the transmission parameter

[1] We assume that individual expertise q_i ranges between 0.5 and 1. For a discussion of the assumption of $q_i > 0.5$, see Ladha (1992). Note that this assumption implies that each member receives enough but incomplete information about the true state of the economy.

α, but has her own forecast of the future inflation shock ($E_{i,t}e_{t+1}$). Hence, each MPC member would like to set the following interest rate $r_{i,t}$:[2]

$$r_{i,t} = \frac{1}{\alpha}\left(\pi_t + E_{i,t}e_{t+1} - \pi^*\right) \tag{7}$$

Individual interest rates $r_{i,t}$ deviate from the true rate r_t proportionally to the deviation of individual estimates of future inflation shocks from the actual outcome:

$$r_{i,t} - r_t = \frac{1}{\alpha}\left(E_{i,t}e_{t+1} - e_{t+1}\right) \tag{8}$$

An individual committee member is thus more likely to take the correct interest rate decision, the more accurate his/her estimate of future inflation shock. Define q_i as the probability $P\left(|E_{i,t}e_{t+1} - e_{t+1}| \leq x\right)$ where x is an arbitrarily chosen bound.[3] A larger variance of the individual information about the state of the economy (σ_i^2) implies that the individual forecast ($E_{i,t}e_{t+1}$) is more likely to diverge substantially from e_{t+1} lowering the accuracy of the individual vote. Formally, if individual forecasts are independent and accurate on average but differ in their uncertainty, $E_{i,t}e_{t+1} \to IIN\left(e_{t+1}, \sigma_i^2\right)$, then:

$$\begin{aligned} q_i(x, \sigma_i) &= P\left(|E_{i,t}e_{t+1} - e_{t+1}| \leq x\right) \\ &= P\left(-x \leq E_{i,t}e_{t+1} - e_{t+1} \leq x\right) \\ &= P\left(-\frac{x}{\sigma_i} \leq \frac{E_{i,t}e_{t+1} - e_{t+1}}{\sigma_i} \leq \frac{x}{\sigma_i}\right) \\ &= Z\left(x/\sigma_i\right) - Z\left(-x/\sigma_i\right) \end{aligned} \tag{9}$$

where $Z(.)$ denotes the standard normal CDF. Hence:

$$\frac{\partial q_i(x, \sigma_i)}{\partial \sigma_i} \leq 0 \tag{10}$$

Figure 1 illustrates the monotonic negative relation between individual decisional skills of a committee member $q_i(x, \sigma_i)$ and the uncertainty of her forecast σ_i.[4]

[2] There are alternative potential sources of heterogeneity between committee members, such as preferences, national backgrounds or particular views on the functioning of the economy. We decided to sidestep these sources in order to be able to derive analytical results. Moreover, in practice heterogeneity of preferences among MPC members is at odds with the fact that central banks nowadays have clearly specified objectives (like the ECB or the Bank of England).

[3] Whether the correct decision is to change interest rates (decision A) or to leave them unchanged (decision B) is determined by the magnitude of the future inflation shock e_{t+1}, relative to the realized shock e_t. This can be shown using equation 7: $r_{i,t} - r_{i,t-1} = \frac{1}{\alpha}\left(\pi_t - \pi_{t-1}\right) + \frac{1}{\alpha}\left(E_{i,t}e_{t+1} - E_{i,t-1}e_t\right)$, hence $E(r_{i,t} - r_{i,t-1}) = \frac{1}{\alpha}(e_{t+1} - e_t)$.

[4] The size of the bound, x, is arbitrary. However, it does define the magnitude of the variances of individual forecast errors, since $q_i(x, \sigma_i)$ is fixed between 0.5 and 1. For simplicity we will use $x = 1$ throughout and denote the skills as $q_i(\sigma_i)$.

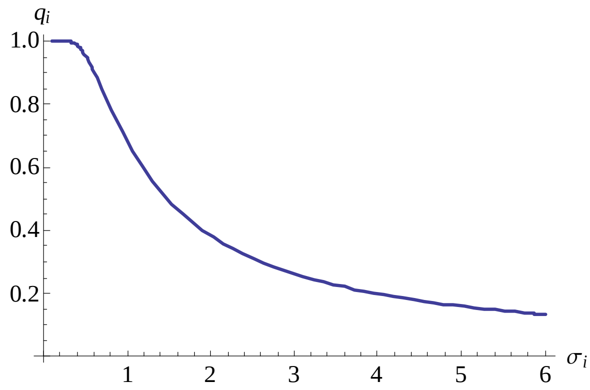

Figure 1: Relation between individual decisional skills and the uncertainty of individual forecast of future inflation shocks

3 Identical skills

Communication in an MPC involves an informative exchange of views regarding all elements relevant for the interest rate decision, such as the current and expected future state of the economy. Formally, we model communication as 'cheap-talk', meaning that the contents of speech do not enter the payoffs of the speakers. Still, since all committee members are interested in obtaining the best estimate of future inflation, this gives them incentives to share their information (see e.g. Crawford and Sobel (1982) or Austen-Smith (1990)). That is, it is rational for members to want to speak (truthfully). Before deciding on their vote, each committee member averages all the information available to them (i.e. their own initial assessment and the information heard during the meeting). We now formalize this description.

In our model communication implies that members discuss their estimates of future inflation shocks $E_{i,t}e_{t+1}$.[5] These estimates are then aggregated (by averaging) into a single estimate $E_{C,t}e_{t+1}$; hence communication results in a common view regarding the interest rate decision $r_{C,t}$:[6]

$$r_{C,t} = \frac{1}{\alpha}\left(\pi_t + E_{C,t}e_{t+1} - \pi^*\right) \tag{11}$$

[5] Which naturally follows from equation (7) and the fact that π_t is observed and π^* and α are common to all members.

[6] Communication thus makes the voting rule used less relevant. This is a well-known result since the work of Gerardi and Yariv (2007) who have shown that deliberations make collective outcomes independent of the voting rule used (except for unanimous voting rules), irrespective of information structure and preferences of MPC members.

with accuracy given by:

$$\begin{aligned} q_C(\sigma_C) &= P\left(|E_{C,t}e_{t+1} - e_{t+1}| \leq x\right) \\ &= \frac{1}{\sqrt{2\pi}} \int_{-x/\sigma_C}^{x/\sigma_C} e^{-\frac{z^2}{2}} dz \end{aligned} \tag{12}$$

where

$$\sigma_C = \frac{\sigma}{\sqrt{n}} \tag{13}$$

which follows from $E_{i,t}e_{t+1} \to IIN\left(e_{t+1}, \sigma_i^2\right)$ and $\sigma_i^2 = \sigma^2$ for all $i = 1, \ldots, n$. Since communication eliminates heterogeneity of views on the appropriate interest rate decision in the MPC, all MPC members will vote in favour of $r_{C,t}$. Therefore, with communication we have:

$$P(d = A|a) = P(d = B|b) = q_C(\sigma_C) \tag{14}$$

Our simple model of communication under majority voting thus touches on a general discussion of the discursive dilemma in collective decision-making, see Pettit (2001) and Claussen and Røisland (2007), i.e. a possible difference in collective outcomes depending on whether the committee directly aggregates individual views on the appropriate decision (the interest rate) or whether the committee first aggregates individual views on the premises on which the individual views are based (the inflation shock), and then lets the collective decision follow from the agreed premises.

Figure 2 compares the accuracy of the committee decisions with and without communication (given by equations (4) and (14)), assuming that committee members have the same level of decision skills (i.e. $q_i = q \Leftrightarrow \sigma_i^2 = \sigma^2$ for all $i = 1, \ldots, n$). The figure plots the probability that the MPC (for illustrative purposes set at size 5) takes the correct decision (P) as a function of the decisional skills of its members ($q(\sigma)$). The dotted line represents the accuracy of the collective decision when committee members do not communicate but only vote (the classical Condorcet case), the dashed line represents the case when all members have spoken, exchanged their views and arrived at a common view on the interest rate decision (the communication case). Even though communication makes the votes of committee members perfectly correlated, figure 2 clearly illustrates benefits of communication in committees. This is because under communication policy is based on a broader information set (Gerlach-Kristen, 2006). More specifically, with communication each MPC member's estimate of inflation shock directly affects the interest rate decision – meaning that errors in individual estimates can at least partially average out - while under simple majority voting without communication only the median member's

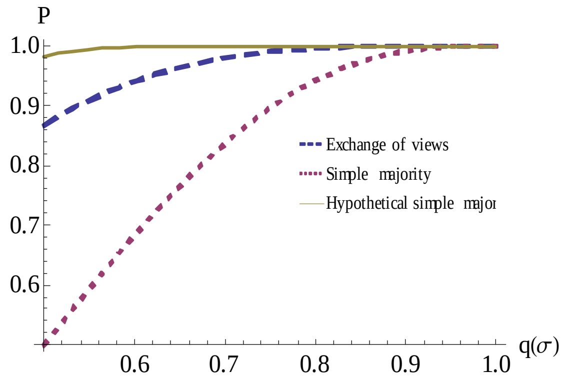

Figure 2: Accuracy of MPC decisions with and without communication, symmetric skills

estimate enters the decision.[7][8] Obviously, endowing the committee with a very high skill level to start with implies that the value added of communication in terms of the quality of the collective decision is significantly reduced, and this is shown by the solid line. This line illustrates the hypothetical case where all committee members intrinsically have the high level of skills illustrated by the dashed line and would simultaneously vote on the interest rate decision, without communicating.

The latter illustrates a more general point. One of the advantages of collective decision-making that is frequently mentioned in the literature (see, for example, Blinder (2004, 2007) and Vandenbussche (2006)) relates to the pool of knowledge available to a committee. This pool can, in principle, be enlarged by adding members with different views and simply letting them vote without communicating, or it can be enlarged by sharing and aggregating views of existing members. Figure 3 illustrates a trade-off between these two possibilities. Specifically, the line relates the number of members with skills q that must be taken on a non-communicating committee in order to achieve the same accuracy of collective decisions (taken by simultaneous simple majority voting) as a small committee of 5 members with skills q that shares and aggregates their knowledge. Figure 3 shows clearly that the lower the skills of individual members, the more efficient communication is in reaping the fruits of collective

[7] Put differently, our assumptions regarding preferences and views on the transmission mechanism among the MPC members imply that in our simple model aggregating decisions is equivalent to aggregating premises, provided that the same aggregation method is used (in principle both decisions and premises can be aggregated in either way: by voting or by communication). However, in line with the actual practice we assume that the MPC aggregates individual views on interest rates by voting, while the views on underlying expected inflation developments are aggregated through communication. The difference in collective outcomes thus partially originates from differences in aggregation methods.

[8] Note that we abstract from any noise or costs that communication may involve.

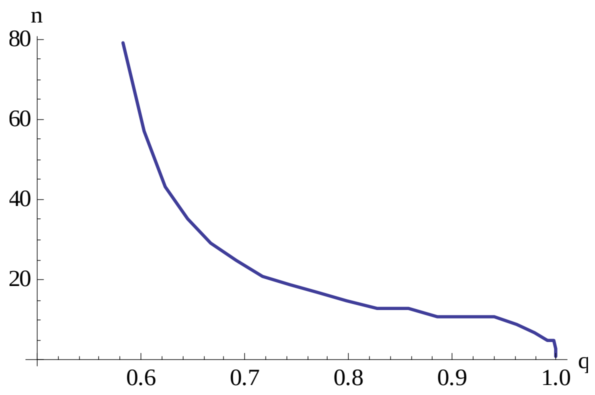

Figure 3: Trade-off in improving collective accuracy through communication or MPC size

decision-making – even if communication only means averaging individual views on future inflation shocks - compared to enlarging the MPC.

4 Heterogeneous skills

We now relax the assumption made in the previous section that committee members have identical skills. Indeed, diversity of views is believed to increase the benefits from collective decision-making. In real life MPCs, this heterogeneity is in many cases grounded in law. Take the US FOMC. Regarding the Board, the Federal Reserve Act states "...In selecting the members of the Board, not more than one of whom shall be selected from any one Federal Reserve district, the President shall have due regard to a fair representation of the financial, agricultural, industrial, and commercial interests, and geographical divisions of the country..." (Section 10). The Bank of England Act 1998, that created the Monetary Policy Committee of the Bank of England, stipulates the appointment of 4 external members to the Committee to ensure that the MPC benefits from thinking and expertise in addition to that gained inside the Bank of England.

It is also well-known (see for example Ben-Yashar and Nitzan (1997)) that, in a non-communicating committee consisting of members having different skills, the optimal voting rule is weighted majority, with higher weights assigned to higher-skilled individuals.[9] However, in most real-life monetary policy committees this voting rule is not applied, and simple majority is used instead. Similarly, with communication, the optimal collective premise should be a weighted average of individual estimates of inflation shocks, with the weights positively related to the accuracy of individual estimates (see the appendix for a proof). Still, in real-life situations aggregate estimates need not be (correctly) weighted

[9] Using the formula $w_i = \ln\left(\frac{q_i}{1-q_i}\right)$.

averages of individual estimates. Instead, they could be simple averages (as in the previous section).

Heterogeneity in skills among members implies that the results from the previous section need not hold: specifically, sharing individual views on premises need not improve the quality of the collective decision, in particular when skills are highly asymmetric (see the appendix for a proof). Figure 4 below, again drawn for a committee of 5 but now composed of two types of members ($n_1 = 3$ members with skills $q_1 = 0.5$ and $n_2 = 2$ members with skills q_2), illustrates that when one group of members has rather poor decisional skills while the other group is highly skilled, the quality of collective decisions is improved by simply voting, without communication and aggregation of knowledge. This illustrates a trade-off involved in communication: incorporating the views expressed by others, with different quality, means to some extent giving up (on) the quality of one's own views.[10] If the former is qualitatively less than the latter, the accuracy of the collective outcome may suffer.[11]

Despite the fact that Figure 4 illustrates that communication is not always better, it is generally more robust to skill heterogeneity. In other words: the loss in accuracy of collective decisions due to not weighting individual views or votes according to levels of skills is more likely to be higher in the absence of communication. Figure 5 is again drawn for the committee of 5 and depicts the difference (i.e. the loss) in the accuracy of collective decisions under simultaneous voting with and without weighted votes (checked gray surface) and the difference under communication with and without weighted forecasts (black surface). In general, the higher the asymmetry of skills, the larger the loss from using unweighted decision-making procedures; however, for the same combinations of skills, the loss is more frequently higher in the absence of communication.

5 Conclusions

In this paper, we have highlighted a number of results with important implications for actual policy-making, when conducted in a committee. First, communication is most likely to be beneficial for the quality of interest rate decisions. Only when knowledge is very unevenly distributed among members will communication be detrimental to the quality of policy decisions. Through communication MPC members improve their common knowledge about future economic developments, i.e. the premises for the interest rate decision, which is beneficial for the quality of policy decisions. Secondly, communication can be a more efficient way of improving the quality of policy decisions than increasing the MPC size. Moreover, communication and aggregation of views is less likely to suffer from a lack of weighting of different views with varying accuracy than simple voting. The latter illustrates the fact that deliberations make collective outcomes more robust to the voting rule used. Using the classification of Blinder

[10] See also Swank and Wrasai (2003).

[11] This illustrates that in our analysis 'more (information) is not always better', which precludes the use of Blackwell's (1951) theorem.

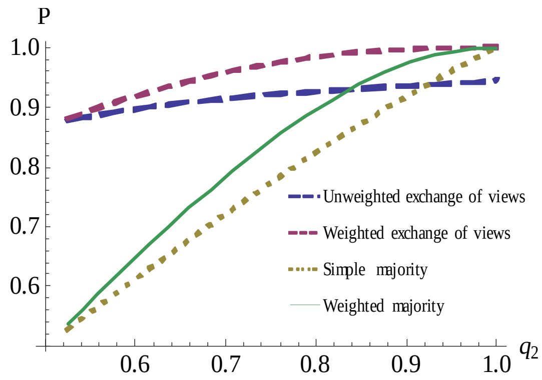

Figure 4: Accuracy of MPC decisions with and without communication, asymmetric skills

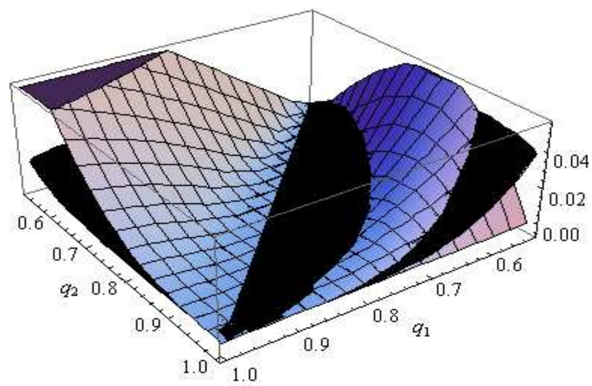

Figure 5: Relative loss in collective accuracy due to unweighted procedures, with and without communication

(2007), the more individualistic and less collegial a committee, the more important the voting rule for the quality of policy. If an MPC is genuinely collegial, the voting rule is largely immaterial for the collective outcome. This puts the criticism on the consensus-based procedure used by the Governing Council of the ECB, an MPC that extensively communicates and where no voting takes place (see Issing, 1999, for details), into perspective.

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Appendix

Proposition 1. *Assume that individual decisional skills are heterogeneous. The optimal procedure to aggregate the information shared among all committee members into a collective forecast is weighted averaging of individual forecasts with weights positively dependent on the level of individual decisional skills.*

Proof: Assume that the collective estimate of the future shock to inflation can be computed as a weighted average:

$$E_t^C e_{t+1} = \frac{\sum_{i=1}^n w_i E_{i,t} e_{t+1}}{\sum_{i=1}^n w_i} \tag{15}$$

The variance of the estimate $E_t^C e_{t+1}$ is given by:

$$\begin{aligned} E\left(E_t^C e_{t+1} - e_{t+1}\right)^2 &= E\left(\frac{\sum_{i=1}^n w_i \left(E_{i,t} e_{t+1} - e_{t+1}\right)}{\sum_{i=1}^n w_i}\right)^2 \\ &= \left(\frac{1}{\sum_{i=1}^n w_i}\right)^2 E\left(\sum_{i=1}^n w_i \left(E_{i,t} e_{t+1} - e_{t+1}\right)\right)^2 \\ &= \left(\frac{1}{\sum_{i=1}^n w_i}\right)^2 \sum_{i=1}^n w_i^2 E\left(E_{i,t} e_{t+1} - e_{t+1}\right)^2 = \frac{\sum_{i=1}^n w_i^2 \sigma_i^2}{\left(\sum_{i=1}^n w_i\right)^2} \end{aligned} \tag{16}$$

where we use the independence assumption: $E_{i,t} e_{t+1} \rightarrow IIN\left(e_{t+1}, \sigma_i^2\right)$.

$$\begin{aligned} \frac{\partial E\left(E_t^C e_{t+1} - e_{t+1}\right)^2}{\partial w_i} &= \frac{2 w_i \sigma_i^2 \left(\sum_{i=1}^n w_i\right)^2 - 2\left(\sum_{i=1}^n w_i\right)\left(\sum_{i=1}^n w_i^2 \sigma_i^2\right)}{\left(\sum_{i=1}^n w_i\right)^4} \\ \frac{\partial E\left(E_t^C e_{t+1} - e_{t+1}\right)^2}{\partial w_i} &= 0 \Rightarrow w_i \sigma_i^2 \left(\sum_{i=1}^n w_i\right) = \left(\sum_{i=1}^n w_i^2 \sigma_i^2\right) \end{aligned}$$

Hence the optimal weight w_i is given by:

$$w_i = \frac{\sum_{i=1}^n w_i^2 \sigma_i^2}{\sigma_i^2 \left(\sum_{i=1}^n w_i\right)} \tag{17}$$

and is negatively related to the individual uncertainty σ_i^2:

$$\begin{aligned} \frac{\partial w_i}{\partial \sigma_i^2} &= \frac{w_i^2 \sigma_i^2 \left(\sum_{i=1}^n w_i\right) - \left(\sum_{i=1}^n w_i\right)\left(\sum_{i=1}^n w_i^2 \sigma_i^2\right)}{\sigma_i^4 \left(\sum_{i=1}^n w_i\right)^2} \\ &= \frac{w_i^2 \sigma_i^2 - \left(\sum_{i=1}^n w_i^2 \sigma_i^2\right)}{\sigma_i^4 \left(\sum_{i=1}^n w_i\right)} \leq 0 \end{aligned} \tag{18}$$

Proposition 2. *Assume that individual decisional skills are highly heterogeneous, i.e. $q_1 \rightarrow 1$ and $q_2 \rightarrow 0.5$. In this case the collective accuracy may be reduced by allowing for an exchange and aggregation of views among members* *relative to simple majority voting outcome, depending on the composition of the committee.*

Proof: The accuracy of collective decisions under simple majority voting with heterogeneous skills is given by:

$$P(d=A|a)=\sum_{s_1=0}^{n_1}\left(\binom{n_1}{s_1}q_1^{s_1}\left(1-q_1\right)^{n_1-s_1}\sum_{s_2=\frac{n_2+n_1+1}{2}-s_1}^{n_2}\binom{n_2}{s_2}q_2^{s_2}\left(1-q_2\right)^{n_2-s_2}\right) \tag{19}$$

where n_1 (n_2) is the number of committee members with skills q_1 (q_2), hence $n_1+n_2=n$; and $s_1(s_2)$ is the number of sub-group members that received a correct signal about the state of the world, hence $s_1+s_2=s\geq\frac{n+1}{2}$.

For $q_2\to 0.5$ we have:

$$q_2^{s_2}\left(1-q_2\right)^{n_2-s_2}\to 0.5^{n_2}$$

For $q_1\to 1$ we have:

$$q_1^{s_1}\left(1-q_1\right)^{n_1-s_1}\to\begin{cases}1\Leftrightarrow s_1=n_1\\ 0 \text{ otherwise}\end{cases}$$

Hence:

$$P(d=A|a)_{|q_2\to 0.5,\ q_1\to 1}=0.5^{n_2}\sum_{s_2=\frac{n_2+n_1+1}{2}-n_1}^{n_2}\binom{n_2}{s_2}$$

Note that for $s_2\leq 0$ or $n_2\leq n_1-1$ we have $\sum_{s_2=\frac{n_2+n_1+1}{2}-n_1}^{n_2}\binom{n_2}{s_2}=2^{n_2}$ and hence:

$$n_2\leq n_1-1\Rightarrow P(d=A|a)_{|q_2\to 0.5,\ q_1\to 1}\to(0.5*2)^{n_2}=1 \tag{20}$$

Under an exchange and aggregation of views, the accuracy of collective decisions is given by:

$$P(d=A|a)=q_C(\sigma_C),\ \text{where } \sigma_C=\sqrt{\frac{n_1\sigma_1^2+n_2\sigma_2^2}{\left(n_1+n_2\right)^2}} \tag{21}$$

The conditions $q_2\to 0.5$ and $q_1\to 1$ are equivalent to $\sigma_2\to 1.4826$ and $\sigma_1\leq 0.1989$ (i.e. not necessarily $\sigma_1\to 0$, see also figure 1 in the main text). They thus jointly imply:

$$\sigma_C\leq\sqrt{\frac{n_1\left(0.1989\right)^2+n_2\left(1.4826\right)^2}{\left(n_1+n_2\right)^2}}$$

For $q_C(\sigma_C)\to 1$, we need $\sigma_C\leq 0.1989$ or

$$\sqrt{\frac{n_1\left(0.1989\right)^2+n_2\left(1.4826\right)^2}{\left(n_1+n_2\right)^2}}\leq 0.1989$$

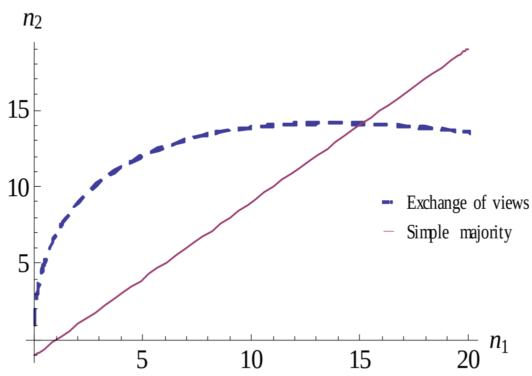

Figure 6: Cut-off lines for conditions (20) and (22)

Hence:

$$n_2 \geq 0.5 - n_1 + 7.38661\sqrt{0.00458194 + n_1} \Rightarrow q_C(\sigma_C)_{|q_2 \to 0.5, \atop q_1 \to 1} \to 1 \qquad (22)$$

The two cut-off conditions (20) and (22) are illustrated in figure 6. Condition (20) is satisfied below the solid line. Condition (22) is satisfied above the dashed line. Hence, there exists a region in the lower right-hand corner below both lines where, for $q_2 \to 0.5$ and $q_1 \to 1$, $q_C(\sigma_C) < 1$ while $P(d = A|a) \to 1$.

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