Communication in Monetary Policy Committees

Jan Marc Berk and Beata K. Bierut *

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

This paper models monetary policy decisions as being taken by an interacting group of heterogeneous policy makers, organized in a MPC. We show that communication between members generally improves the quality of monetary policy by increasing knowledge about uncertain future economic developments. Interestingly, we find that it is sometimes beneficial to restrict communication to a subset of MPC members. We also show that the optimal size of a communicating MPC is generally smaller than otherwise. Compared with expanding the MPC, communication is a cost-effective way of increasing the quality of monetary policy. (JEL E58, D71, D78)

Keywords: monetary policy committees, deliberations, voting

1 Introduction

Most monetary policy decisions are nowadays taken not by a single individual, but by a monetary policy committee (henceforth: MPC). This collective decision-making procedure might have implications for the policy actually adopted. An approach that has been used in the previous literature is to assume that members are identical in terms of decisional skills but differ in

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preferences, thereby introducing strategic behaviour, see *inter alia* von Ha- 
gen and Stippel (1994), Hefeker (2003) and Sibert (2003). This paper follows 
a different route, by assuming that members share preferences but differ in 
competence, for instance due to informational differences. When members 
convene for the MPC meeting, they communicate and learn from each other, 
thereby increasing their knowledge and decisional skills. 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). Both of 
these MPC’s are of a ‘hub-and-spokes’ nature, comprising of representatives 
of the center (‘hub’) and the regions (‘spokes’). The contribution this paper 
makes is that it contains an analysis of the effects of communication in a 
hub-and-spokes MPC. As we argue below, our concept of communication is 
richer than used in most of the existing literature. In combination with ex-

cplicitly taking the hub-and-spokes nature of MPC’s into account, 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).1

The structure of the paper is as follows. We start, in section two, by de-
scribing the communication and learning process in a committee. In section 
three, we present our analytical framework, which formalizes the effects of 
communication and learning at an individual level. In this section, we also 
show how individual skills increase as a result of information sharing. Next 
(section four), we turn to an investigation of the effects of communication 
and learning on the quality of collective decisions. We derive and compare 
the accuracy of committee decisions reached under several decision-making 
scenarios, including the optimal decision-making rule, and for different com-
mittee members’ characteristics. Section five discusses the optimal size and 
decision time of the committee, under the assumption that collective decision 
making entails costs. Section six concludes.

Similar to the no-communication case (see Berk and Bierut, 2005), the 
optimal decision-making rule for a learning MPC with heterogeneous mem-

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1We would like to make clear at the outset, however, that our analysis is highly stylized 
and contains some important caveats. This should be kept in mind when interpreting our 
results. An example of such a caveat is that in our simple set-up the only value added the 
hub provides is in terms of improving the quality of decision making in the committee. 
This is clearly a simplification of reality, where hub-and-spokes committees tend to be 
motivated by other arguments (see Chappell et al., 2005, for the US experience). Other 
important caveats include the single-shot nature of our analysis, which clearly is at odds 
with the fact that monetary policy decisions are taken on a regular basis, so that the 
intertemporal dimension may be relevant for the current setting of interest rates. We plan 
to take up the latter issue in future research.
bers involves weighting. However, weighting is seldom found in monetary policy committees. This may be due to the fact that it is politically infeasible (as it could be seen as running counter to democratic principles), or difficult to implement in practice. We show that by implementing simpler decision-making rules, which do not require weighting, the optimal outcome can be well approximated. Depending on the degree of heterogeneity of skills, this approximation implies an unweighted averaging of information shared by all committee members or limiting information sharing to a pre-meeting where only the more-skilled committee members are present. Another finding is that the optimal size of a MPC that interacts is smaller than a MPC that does not interact. An alternative interpretation of the latter result is that allowing for communication is a cost-effective way of increasing the quality of monetary policy.

2 Communication and learning

A common approach in the literature on the effects of communication on collective decision making (see, for example, Coughlan, 2000, Gerardi and Yariv, 2003), is to model an exchange of views as members sending simultaneous messages regarding their preferred outcome, which are then aggregated into a single recommendation for the collective decision. The recommendation depends on the number of messages received for each alternative. This setup counts the messages, and therefore adds very little - in terms of the quality of monetary policy - to a simple majority voting rule. We argue that interaction of members of a MPC is more complicated as it involves a more extensive exchange of views regarding the current and future state of the economy, the transmission mechanism, etc. Communication thus implies an exchange of information that increases the total knowledge available to the MPC. Put differently, it allows for the possibility that the knowledge available to a MPC member just before the vote on interest rates is higher than his initial level of skills, i.e. available to him when entering the MPC meeting. However, communication also means that you augment your initial 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. We are interested in investigating the conditions un-

\footnote{With the more-skilled committee members having a larger say in the collective decision.}

\footnote{If the quality of information shared during communication would always imply an improvement upon a individual vote based solely on one’s initial views, Blackwell’s (1951) result guarantees that the collective outcome always benefits from communication. See}
der which communication improves the quality of the collective decision, (ex hypothesis) made by simple majority voting.

Communication in a MPC involves an informative exchange of views regarding the current and expected future state of the economy. Communication entails both speaking and listening. That is, communication is informative in the sense that when some committee member talks, other members listen and incorporate the received information into their assessment of the state of the economy. We label this process as 'learning'. Learning thus requires that at least one committee member speaks during the meeting. 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 and to speak the truth. As soon as at least one member speaks, all other members listen and learn. If nobody speaks, nobody can listen and nobody can learn: each committee member then decides based only on his own views ('initial skills'). Before deciding on their vote, each committee member averages all the information available to them (i.e. their own initial assessment and, when relevant, the information that they obtained during the meeting). In the following section we formalize this description.

3 Analytical framework

The model is based on Berk and Bierut (2005). Consider the case where interest rate decisions are taken under uncertainty: the economy can be in either of two states of the world: economic conditions are such that a change in policy rates is required (state \( a \)) or not (state \( b \)). Committee 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

also Bielinska-Kwapisz (2003).
rates in state $a$ and voting for unchanged rates in state $b$:\footnote{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. If $q_i = 0.5$, then the decision could be taken by tossing a coin. In the case $0 < q_i < 0.5$ the results would be analogous, except that the actual decision should be the opposite to the one chosen by the committee.} 

\[ P(v_i = A|a) = P(v_i = B|b) = q_i \]  
and consequently:

\[ P(v_i = B|a) = P(v_i = A|b) = 1 - q_i \]  

We label the $q_i$’s as individual decisional skills. We impose some structure on the skill heterogeneity by assuming that it is possible to cluster committee members into 2 subgroups such that the average skill level between both groups differ. We follow the literature (see, e.g. Mayer, 2001, Chappell et al. 1993, 1995) that suggests that in hub-and-spokes MPC’s like the FOMC and the ECB Governing Council, the above-mentioned clustering coincides with the division between the hub and the spokes. On average, the hub has a higher skill level than the spokes. Arguments include the fact that the hub is usually entrusted with preparing the MPC meetings (a task that requires a relatively larger knowledge base in the hub). Moreover, and this is especially visible in the US, hub-and-spokes MPC’s also reflect a political compromise between the center and the regions.\footnote{Schwartz (2005) for example stresses the fact that regional Federal Reserve presidents are currently selected using criteria other than skills needed to participate in (and add value to) discussions regarding the appropriate stance of US monetary policy.}

Skills are linked to the following, stylized description of the economy (see also Gerlach-Kristen, 2003b). The evolution of inflation is captured by the following reduced-form equation:

\[ \pi_{t+1} = \pi_t - \alpha r_t + e_{t+1} \]  

where $\pi_t$ is the inflation rate at time $t$, $r_t$ is the real interest rate and $e_{t+1}$ is a normal iid error. The central bank’s instrument - the interest rate $i_t$ - is related to inflation via the Fisher equation:

\[ r_t = i_t - E_t \pi_{t+1} \]  

Each committee member $i$ believes the model (3)-(4) to be true but has his/her own idea about the strength of the transmission mechanism ($\alpha_t$) and
has his/her own forecast of future disturbances to the inflation rate \( E_{i,t}e_{t+1} \). Individual MPC members would like to set the following interest rate:

\[
i_{i,t} = \frac{1}{\alpha_i} (\pi_t + E_{i,t}e_{t+1}) + \frac{\alpha_i - 1}{\alpha_i} \pi^* \tag{5}\]

where \( \pi^* \) is the inflation target. The latter remains common to all MPC members.

An individual committee member \( i \) takes the correct interest rate decision when his/her estimate of future inflation shocks is within a certain (close) range of the actual outcome. Therefore we can define \( q_i \) as the probability

\[
q_i(x, \sigma_i) = P \left( \left| E_{i,t}e_{t+1} - e_{t+1} \right| \leq x \right) = P \left( -x \leq E_{i,t}e_{t+1} - e_{t+1} \leq x \right) = P \left( -\frac{x}{\sigma_i} \leq \frac{E_{i,t}e_{t+1} - e_{t+1}}{\sigma_i} \leq \frac{x}{\sigma_i} \right) = Z \left( \frac{x}{\sigma_i} \right) - Z \left( \frac{-x}{\sigma_i} \right) = \frac{1}{\sqrt{2\pi}} \int_{-x/\sigma_i}^{x/\sigma_i} e^{-z^2/2} dz \tag{6}\]

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

\[
\frac{\partial q_i(x, \sigma_i)}{\partial \sigma_i} \leq 0 \tag{7}\]

Figure 1 illustrates this, for \( x = 1 \). Individual skills \( q_i(1, \sigma_i) \) are measured by the size of the symmetric area under the standard normal DF \( z(z; 0, 1) \) between two vertical lines cutting through the points \( z = \{1/\sigma_i, -1/\sigma_i\} \). The thin lines in the figure define the area of 50%: \( q_i(1, \sigma_i) = 0.5 \), while the thick lines define the area of 80%: \( q_i(1, \sigma_i) = 0.8 \). The thin lines correspond to \( \sigma_i = 1.4826 \), the thick lines to \( \sigma_i = 0.78027 \).

Figure 2 presents the relation between the probability that the error made by an individual committee member in assessing the state of economy does not exceed the bound of unity (i.e. \( q_i(1, \sigma_i) \)), as a function of the uncertainty of individual forecast, \( \sigma_i \).

\[6\] The size of the bound, \( x \), is arbitrary. However, it does define the magnitude of the
Without communication, a MPC using simple majority rule will adopt the median interest rate, that is:

\[ i_{m,t} = \text{Median} \left( \frac{1}{\alpha_i} (\pi_t + E_{i,t}e_{t+1}) + \frac{1 - \alpha_i}{\alpha_i} \pi^* \right) \]  \hspace{1cm} (8)

If committee members communicate about the likely developments in the economy and the transmission mechanism, voting will aggregate their views into the following interest rate:

\[ i_{d,t} = \text{Median} \left( \frac{1}{\alpha^d_i} (\pi_t + E^d_{i,t}e_{t+1}) + \frac{1 - \alpha^d_i}{\alpha^d_i} \pi^* \right) \]  \hspace{1cm} (9)

where \( \alpha^d_i \neq \alpha_i \) and \( E^d_{i,t}e_{t+1} \neq E_{i,t}e_{t+1} \) if committee members incorporate the information provided by their colleagues into their proposed interest rate. This illustrates the difference between our concept of communication as opposed to the one commonly used in the (jury) literature. In the latter, committee members communicate their preferred interest rate \( i_{i,t} \) only. In contrast, MPC members in our framework not only communicate their preferred interest rate with their colleagues, but also share their knowledge regarding future shocks to inflation and the strength of the monetary transmission mechanism. As a result their expertise improves.

variances of individual forecast errors, since \( q_i(x, \sigma_i) \) is fixed between 0.5 and 1. For the sake of simplicity we will use \( x = 1 \) throughout and denote the skills as \( q_i(\sigma_i) \).
Figure 2: The relation between individual decisional skills and the uncertainty of individual forecast of future inflation shocks

The following illustrates the improvement in the decision skills due to learning. Suppose that each more-skilled committee member gets 1 unit of time allocated to speak, listening occurs instantaneous as speaking occurs, there are $t$ time units available for communication (as speaking and listening), and none of the less-skilled members speak. We moreover abstain from uncertainty related to the transmission mechanism in order to focus on future shocks to the inflation rate. If every more-skilled committee member (and there are $m$ of them in total) incorporates the information obtained by listening to his/her colleagues into his/her original estimation of the future inflation disturbance, the new estimate becomes:

$$
E_{i \in M,t}^d e_{t+1} = \frac{1}{t + 1} \left( \sum_{j=1, j \neq i}^{t} E_{j \in M,t} e_{t+1} + E_{i \in M,t} e_{t+1} \right)
$$

(10)

$$
E_{i \in M,t}^d e_{t+1} \rightarrow N \left(e_{t+1}, \frac{\sigma_M^2}{t + 1} \right)
$$

if individual $i \in M$ does not speak (but he learns as others speak), and

$$
E_{i \in M,t}^d e_{t+1} = \frac{1}{t} \left( \sum_{j=1, j \neq i}^{t-1} E_{j \in M,t} e_{t+1} + E_{i \in M,t} e_{t+1} \right)
$$

(11)

$$
E_{i \in M,t}^d e_{t+1} \rightarrow N \left(e_{t+1}, \frac{\sigma_M^2}{t} \right)
$$
if individual \( i \in M \) does speak. The statistical behaviour of the updated estimates can be determined using the assumptions made earlier with respect to individual forecasts \( E_{t,t} e_{t+1} \rightarrow IIN(e_{t+1}, \sigma_i^2) \).

The less-skilled committee members (\( n \) in total) listen to their more-skilled colleagues and update their forecasts of the future inflation shock in the following way:\(^7\)

\[
E_{i \in N,t}^d e_{t+1} = \frac{1}{t+1} \left( \sum_{j=1}^{t} E_{j \in M,t} e_{t+1} + E_{i \in N,t} e_{t+1} \right)
\]

\[
E_{i \in N,t}^d e_{t+1} \rightarrow N(e_{t+1}, \frac{t \sigma^2_M + \sigma^2_N}{(t+1)^2})
\]

As a result, the average decisional skills of both sub-groups of committee members increase. Put differently, final skills (i.e. the level after the exchange of views, just before the vote on interest rates) are higher than initial skills:\(^8\)

\[
\frac{(m+1) \sigma^2_M}{m(t+1)} \leq \sigma^2_M : q_M \left( \sigma_M \sqrt{\frac{m+1}{m(t+1)}} \right) \geq q_M \left( \sigma_M \right)
\]

\[
\frac{t \sigma^2_M + \sigma^2_N}{(t+1)^2} \leq \sigma^2_N : q_N \left( \frac{\sqrt{t \sigma^2_M + \sigma^2_N}}{t+1} \right) \geq q_N \left( \sigma_N \right)
\]

Figure 3 depicts the development of the average decisional skills of two subgroups, more- and less-skilled committee members, as a function of time available for communication. As before, we assume that only more skilled members speak. But all committee members hear the interventions. As a result, all committee members incorporate the new information into their forecasts, and the average decisional skills of both subgroups increase. This process is similar to the learning curves found in psychology, where a subject’s rate of learning is very rapid at first and subsequently slows down, see e.g. Goldstein et al. (1993). The solid line represents the learning curve of the more-skilled members, the dotted one the learning curve of the less-skilled members. The initial average skill levels are (for expositional reasons) fixed at

\(^7\)The forecasts could be aggregated in the form of a weighted average, i.e. those forecasts that are less uncertain (i.e. have lower \( \sigma_i^2 \)) should have a higher weight in the average \( E_{i \in I}^d e_{t+1} \). We will return to this issue later.

\(^8\)If not all more-skilled members are able to speak (i.e. if \( t < m \)), the average uncertainty in their inflation-disturbance forecasts is given as: \( t \sigma^2_M + (m-t) \sigma^2_M \frac{m+1}{m(t+1)} \). If all more-skilled members could share their knowledge, then they would come to a common idea about the future disturbances to inflation with the average uncertainty of \( \frac{1}{m} \sigma^2_M \).
\( q_M(\sigma_M) = 0.8 \) and \( q_N(\sigma_N) = 0.6 \). Note that, after all more-skilled members have spoken, at the end of the time allotted for interventions, they all must have formed the same forecast of the future inflation disturbance. This is not the case for the less-skilled members. Notwithstanding the fact that their skills increase due to listening to their colleagues, their initial assessments of the state of the economy differ and remain private.

Figure 3: Learning curves for the more- and less-skilled committee members

Figure 3 also illustrates two learning effects, documented by experimental evidence (Lombardelli et al., 2002): (1) catching-up, i.e. the fact that the less-skilled committee members update their knowledge by learning from their more-skilled colleagues and, as a result, average skill levels converge (although not necessarily perfectly: if the time available is, for whatever reason, limited, then average skills may still differ substantially when the committee moves to voting on interest rates); (2) knowledge creation: learning is not limited to members with relatively low skills, as during communication the more-skilled committee members also update their forecasts of future developments and increase their expertise.\(^9\)

\(^9\)In (Lombardelli et al., 2002), learning shows as an increase in the average accuracy of individual decision-makers with the number of (monetary policy) games played (see Chart 3). Catching-up effect shows in the fact that the initially worst decision-makers improve their scores relatively the most; knowledge creation shows as an increase in the scores of the best players (Chart 4).
4 Quality of collective interest rate decisions

We now turn to the implications of communication for the quality of monetary policy, where the latter is represented by the probability that the committee makes the correct decision on interest rates. Throughout the analysis, we assume that the committee decides using a simple majority voting rule.10 We allow for the possibility of a subgroup of the full MPC to meet prior to the vote on interest rates. As mentioned earlier, this is likely to occur in hub-and-spokes MPC’s like the FOMC in the US and the ECB Governing Council in the euro area. See Meyer (2004) for evidence that such a pre-committee meeting of a subgroup, in this case the Board of Governors, is relevant for the US. The outcome of the prior meeting may or may not be announced to the other members of the MPC prior to the interest rate decision. For simplicity, we assume that during communication either all members of a subgroup speak, or none of them does so. This gives us four possible situations: (i) nobody speaks; (ii) only more-skilled members speak; (iii) only less-skilled members speak; (iv) all members speak. Assuming that the total time available for communication is scarce so that it is not possible for all members to hold interventions, it is intuitive to let the more-skilled members speak first. For this reason, we do not consider case (iii). The table below lists the specific cases we investigate.

<table>
<thead>
<tr>
<th>Case</th>
<th>Meeting</th>
<th>More-skilled members</th>
<th>Less-skilled members</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Prior meeting</td>
<td>– no talk</td>
<td>– no talk</td>
</tr>
<tr>
<td></td>
<td>MPC meeting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Prior meeting</td>
<td>– talk and learn</td>
<td>– talk and learn</td>
</tr>
<tr>
<td></td>
<td>MPC meeting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Prior meeting</td>
<td>no talk</td>
<td>– no talk</td>
</tr>
<tr>
<td></td>
<td>MPC meeting</td>
<td>announcement</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Prior meeting</td>
<td>talk and learn</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>MPC meeting</td>
<td>announcement</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Prior meeting</td>
<td>no talk</td>
<td>– no talk</td>
</tr>
<tr>
<td></td>
<td>MPC meeting</td>
<td>no talk</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Prior meeting</td>
<td>talk and learn</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>MPC meeting</td>
<td>no talk</td>
<td></td>
</tr>
</tbody>
</table>

10 Whether or not the decision-making process is aptly summarised by the voting rule or voting records is open for discussion, see Chappell et al. (2005). For instance, Meyer (2004) argues that dissenting votes are seen as a revolt to the leadership of the chairman, thus signalling more than a stance on interest rates.
We subsequently group the above cases, depending on the extent of communication and learning:

1. **no communication (the maximum of cases 1, 3 and 5)**

   This corresponds to the cases studied in Berk and Bierut (2005). They show that the accuracy of the interest rate decision achieved under the optimal but infeasible decision rule, i.e. weighted majority voting, can be approximated by using a simple majority voting rule and splitting the MPC in two sub-groups. Depending on the difference in the skill levels and the relative size of the subgroups, the more-skilled subgroup (the hub) should (i) convene prior to the MPC meeting, vote on a common position and then announce it in the MPC meeting (case 3), (ii) convene, vote, but not reveal their common position (case 5), and (iii) not convene prior to the MPC meeting (case 1). Note that case 3 includes a simple exchange of information in the form of an announcement. We however do not classify this as communication, because it is inherently unidirectional. When investigating the effects of communication on the quality of the collective decision, we will use the maximum of cases 1, 3 and 5 to represent the 'no communication case', i.e. the maximum achievable accuracy across the three scenarios under the particular combination of the average skill levels ($q_M (\sigma_M)$ and $q_N (\sigma_N)$).

2. **learning limited to the prior meeting of the more-skilled committee members (the maximum of cases 4 and 6)**

   In these cases, the more-skilled committee members form a common view on the future shocks to inflation. But this common view is now based on an exchange of views. That is, all members present at the prior meeting participate in the discussion by talking and listening to each other. As a result they form a common view on the future inflation developments and a common position regarding the appropriate policy decision, they may announce it before the vote in the full MPC (case 4) or not (case 6), depending on whether or not it will increase the accuracy of the MPC decision. Again we use the maximum of both cases for comparison purposes.

3. **learning in the full MPC meeting, when all committee members learn (case 2)**

   Communication can involve all MPC members talking, provided there is enough time for all members to hold interventions and share their insights. In this case they form a common idea about the future risks to
inflation (just like the more-skilled members did in the previous case). The collective forecast is a simple (unweighted) average of individual forecasts of all committee members:

\[
E_{C,t}e_{t+1} = \frac{1}{m+n} \sum_{i=1}^{m+n} E_{i \in (M \cup N),t} e_{t+1}
\]

The collective forecast is a simple (unweighted) average of individual forecasts of all committee members:

\[
E_{C,t}e_{t+1} \rightarrow N \left( e_{t+1}, \frac{m\sigma_M^2 + n\sigma_N^2}{(m+n)^2} \right)
\]

The probability that the committee will make the correct decision is given as:

\[
q_C \left( \frac{\sqrt{m\sigma_M^2 + n\sigma_N^2}}{m+n} \right).
\]

4. learning in the full MPC meeting, when all committee members learn (case 2)

Finally, we re-consider case 2, i.e. the case when there is no prior meeting, and communication and learning takes place in the MPC meeting, involving all members. However, now we assume that individual information entering the common estimate of future inflation risks can be optimally weighted. As a result the collective forecast is given as:

\[
E^{w}_{C,t}e_{t+1} = \frac{\sum_{i=1}^{m+n} w_i E_{i \in (M \cup N),t} e_{t+1}}{\sum_{i=1}^{m+n} w_i}
\]

\[
E^{w}_{C,t}e_{t+1} \rightarrow N \left( e_{t+1}, \left( \frac{1}{nw_N + mw_M} \right)^2 \left( nw_N^2 \sigma_N^2 + mw_M^2 \sigma_M^2 \right) \right)
\]

where \(w_N \) and \(w_M \) denote the weights given to the individual estimates of the less- and more-skilled committee members. The probability that the committee will make the correct decision is in this case given as:

\[
q_C \left( \frac{\sqrt{nw_N^2 \sigma_N^2 + mw_M^2 \sigma_M^2}}{nw_N + mw_M} \right).
\]

The determination of the optimal weights is explained in proposition 1 below.

Figures 4 and 5 illustrate the effects of communication on the accuracy of monetary policy. The graphs plot the probability that the MPC takes the correct decision \((P)\) as a function of the uncertainty surrounding the forecasts of future shocks to inflation made by the less-skilled committee members \( (\sigma_N) \). Recall from figure 1, that this uncertainty is inversely related to the individual decisional skills. The range of \(\sigma_N\) between 0.7803 and 1.4826 corresponds to \(q_N (\sigma_N)\) between 0.8 and 0.5 \((q_M (\sigma_M)\) is fixed at 0.8). Thus, moving from left to right along the horizontal axis implies an increasing skill differential between the hub and the spokes. The figures are drawn for two
committee sizes: 9 and 19. In the first MPC, the more-skilled sub-group of 6 members is in majority, in the second in minority. The latter case may therefore be interpreted as relevant for the ECB Governing Council and the former as relevant for the FOMC.

The solid and dotted lines represent the accuracy of the collective decision in the case when all committee members have spoken. In the first case, individual information is weighted optimally, in the latter the information is not weighted. The dot-dashed line relates to the situation in which a prior meeting occurs before the MPC meeting. During the prior meeting the more-skilled individuals communicate and learn, and the outcome may or may not be announced to the full MPC prior to its vote on interest rates (we show the situation that gives the highest accuracy of the collective decision). Finally, the dashed line represents the maximum achievable quality of the monetary policy decision in all institutional set-ups without communication. In the small committee case, this line is not shown, as it generated (for all values of \( q_N (\sigma_N) \)) an accuracy far below the other alternatives.

Figure 4 illustrates a trade-off involved in communication and learning: adopting the views expressed by others means to some extent giving up your own view.11 As long as the latter is qualitatively less than the former, the collective outcome improves.12 Figure 4 shows that allowing for learning across all members (dotted line) can imply a worse collective outcome than limiting learning to the relatively higher-skilled committee members (dot-dashed line). This is because in this hub-dominated committee, allowing for communication beyond the more-skilled members implies that the less-skilled sub-group influences the final outcome. In case the knowledge differential between the hub and the spokes is large, the quality of monetary policy will be less than in the case where learning is limited to the board and only the more-skilled sub-group is relevant for the final outcome.

Figure 5 illustrates the ‘monotonically increasing’ benefits of communication for the accuracy of collective decisions. By this we mean that the more members are involved in communication and learning, the higher the collective accuracy (especially if initial skills are highly heterogeneous). The size of the committee is thus important for the sensitivity of the accuracy of collective decisions to the extent of communication among committee members. In a small committee an inefficient aggregation of a large amount of information, accumulated via sharing among all committee members, can lead to worse results than limiting communication and learning to a sub-group of (highly-

11See also Swank and Wrasai, 2002.
12This illustrates that in our analysis ‘more (information) is not always better’, which precludes the use of Blackwell’s (1951) theorem.
Figure 4: Accuracy of the collective decision taken by a small committee with and without learning

Figure 5: Accuracy of the collective decision taken by a large committee with and without learning
skilled) committee members. In a large committee composed of individuals with comparable, high, expertise, communication allows for a collective decision that closely approaches the optimal accuracy. These conclusions prove to be quite general.

Proposition 1 Assume that individual decisional skills are heterogeneous, i.e. $q_M(x, \sigma_M) > q_N(x, \sigma_N)$. The optimal decision-making rule is information sharing among all committee members, with the collective forecast being a weighted average of individual forecasts.

Proof. See the appendix.

Proposition 2 Assume that individual decisional skills are heterogeneous, i.e. $q_N(x, \sigma_N) \to 0.5$ and $q_M(x, \sigma_M) > q_N(x, \sigma_N)$. Depending on the size of the skill asymmetry, the optimal decision-making rule could be approximated either by unweighted averaging of all individual forecasts (for a relatively low asymmetry) or by limiting information sharing to a pre-meeting by the more-skilled committee members (for a high skill asymmetry). Hence, in case of a high skill asymmetry, the less-skilled committee members are redundant.

Proof. See the appendix.

Proposition 3 If the skill asymmetry is very high, unweighted averaging of all individual forecasts may yield even worse results than the decision-making procedure which excludes a communication stage.

Proof. See the appendix.

It follows from proposition 1 that the optimal decision-making rule (or procedure) in a communicating MPC is characterized by weighting. The weights are positively related to the level of individual initial skills. However, as is the case with weighted voting in a non-learning MPC (see Berk and Bierut, 2005), this optimal procedure does not have to be applied in reality. Proposition 2 shows that implementing simpler decision-making rules, which do not require weighting, approximates the optimal outcome for a particular set of parameters.

There are other interesting and policy-relevant implications from our analysis. First, to the extent that a systematic difference in skills is unavoidable in hub-and-spokes MPC’s, ensuring that it is as small as possible is to be preferred, for a number of reasons. For one thing, the more symmetric MPC members’ skills, the higher the quality of monetary policy (this is assuming a given average level of skills: the higher this average, the higher the accuracy of monetary policy decisions). Moreover, the more symmetric
are initial skills, the better the optimal decision-making rule (weighting the information) can be approximated by an institutional set-up that includes communication and that might be easier to implement. Also, by maintaining a relatively small skill differential, it is always beneficial to have both the hub and the spokes participating in the monetary policy decision, and to allow communication between these subgroups. Finally, for both FOMC (figure 4) and ECB Governing Council (figure 5) type of MPC’s, communication in most cases is to be preferred. Proposition 3 indicates that communication is detrimental only in small MPC’s with large skill differentials.

5 Optimal committee size

The upshot from the preceding analysis is that communication by and large is beneficial for group decision making. However, communication takes time, and extending the time allotted to the committee to take a decision is costly (see below). Neither should we expect that individuals participate in decision-making bodies for purely altruistic motives. Their participation usually involves paying salaries. Therefore group decision making involves costs related to the size of the group as well as the time it requires to take a decision. Since the decisional quality also depends on both variables, we can calculate the optimal size and time allotted to communication of a committee, given its structure (i.e. having a prior meeting with or without announcement of its result), the initial level of skills and costs involved.

As before, the quality of the monetary policy decision will be measured by the probability that the committee takes the correct decision. The costs involved in making this decision will be captured by the following function:

\[ C(m + n, t) = \alpha (m + n) + \exp(\beta t) - 1 \] (18)

This form implies that the marginal cost of adding an extra committee member equals \( \alpha \) and is constant (see also Gradstein, Nitzan and Paroush, 1990) and equal for both more- and less-skilled committee members. The functional form is chosen for its simplicity, whilst capturing the essentials. We have experimented with alternatives that allow more-skilled members to be more expensive.\(^{13}\) The results turned out to be qualitatively similar to those reported below. Time costs are assumed to be nonlinear, with the parameter \( \beta \) governing the costs of learning; this assumption can be

\(^{13}\) Using the following cost function: \( C(m + n, t) = \alpha (q_M m + q_N n) + \exp(\beta t) - 1 \). It is however unlikely that paying a higher-skilled member a higher salary is politically feasible. The arguments against are similar to the ones put forward against weighted voting in monetary policy committees.
motivated by a real-life relevance. The meetings of the FOMC or the ECB Governing Council have a more or less pre-announced duration. Then, if a meeting exceeds the pre-announced deadline, economic agents may interpret this as a sign that the decision to be taken is a contentious one - possibly an indication of a disagreement among the decision-makers. In other words, financial markets may negatively interpret a longer-than-expected duration of the meeting, and may even question the quality of the decision taken (thus the credibility of the central bank is negatively affected). If one assumes that this type of effects is likely to accumulate with the duration of the meeting, then the time-related costs should be modelled in a nonlinear fashion.

The tables below present the optimal combinations of committee size $m + n$, time available for learning $t$ and the average initial skills of the less-skilled committee members, together with the resulting accuracy of the collective decision and costs. The results are calculated under the assumption that average initial skills of the more-skilled committee members equal 0.8 ($q_M (\sigma_M) = 0.8$). We present 3 cases: no communication, learning limited to the higher-skilled members (with communication only in a prior meeting), and the case in which all MPC members learn without weighting. The first case applies our institutional set-up to the existing jury literature. The third case builds on Gerlach-Kristen (2003b). The second case is, to our knowledge, not yet dealt with. The table below therefore addresses the following question: given the institutional set up, the average level of initial skills of the more-skilled subgroup, what is the optimal size of the MPC, the time allowed for communication and the optimal average level of skills of the less-skilled subgroup.

Remember that learning is only possible when members listen to others. This in turn requires that other members speak. These interventions take time.

By assumption each intervention requires 1 unit of time. In the limited and unlimited learning case, every member attending the prior meeting or the full MPC meeting talks and learns. The optimal learning time thus is denoted by the optimal number of members (in the limited learning case: the optimal size of $m$).
<table>
<thead>
<tr>
<th></th>
<th>Optimum</th>
<th>Accuracy</th>
<th>Cost</th>
<th>Optimum</th>
<th>Accuracy</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001 0.001</td>
<td>(0.8; 0.8) 17</td>
<td>0.997</td>
<td>0.017</td>
<td>(0.8; NA) (6, 0)</td>
<td>0.998</td>
<td>0.012</td>
</tr>
<tr>
<td>0.001 0.01</td>
<td>(0.8; 0.8) 17</td>
<td>0.997</td>
<td>0.017</td>
<td>(NA; 0.8) (0, 15)</td>
<td>0.996</td>
<td>0.015</td>
</tr>
<tr>
<td>0.01 0.001</td>
<td>(0.8; 0.8) 7</td>
<td>0.967</td>
<td>0.070</td>
<td>(0.8; NA) (4, 0)</td>
<td>0.990</td>
<td>0.044</td>
</tr>
<tr>
<td>0.01 0.01</td>
<td>(0.8; 0.8) 7</td>
<td>0.967</td>
<td>0.070</td>
<td>(0.8; NA) (4, 0)</td>
<td>0.990</td>
<td>0.081</td>
</tr>
<tr>
<td>0.1 0.001</td>
<td>(0.8; 0.8) 3</td>
<td>0.896</td>
<td>0.300</td>
<td>(0.8; NA) (2, 0)</td>
<td>0.930</td>
<td>0.202</td>
</tr>
<tr>
<td>0.1 0.01</td>
<td>(0.8; 0.8) 3</td>
<td>0.896</td>
<td>0.300</td>
<td>(0.8; NA) (2, 0)</td>
<td>0.930</td>
<td>0.220</td>
</tr>
</tbody>
</table>

The numbers in the first row of the column 'optimum' reflect the average initial level of skills of the more-skilled and the less-skilled subgroup, respectively. The numbers in the second row of this column reflect the optimal size of the MPC, or, where relevant, the optimal size of the more-skilled and less-skilled subgroup, respectively.

A first observation from the table is that in the optimum, there is never a difference in the level of skills among the members. Even if we would make the participation of more-skilled members slightly more expensive (see footnote 12), it always pays off to have as high skilled members as possible. This result is due to a high non-linearity of the collective accuracy with...
respect to individual initial skills. Unless the cost function would also be highly nonlinear, the optimum will always yield a corner solution in terms of skill levels.

The no learning case gives the classic Condorcet result: if adding committee members is (almost) costless, and given that the lower bound of skills exceeds 0.5, the optimal committee size becomes very large (unbounded). However, as soon as we relax Condorcet’s assumption of independent voting and we allow for communication, the optimal committee size becomes bounded. The costs are reduced while the collective accuracy remains roughly the same. This is because an exchange of information leads to an improvement in individual skills which increases collective accuracy. Without communication and the possibility of learning the collective accuracy can be improved only by adding extra committee members (which is costly). The benefits of learning can also be seen from comparing the results for the no learning and unlimited learning cases in the last row of the table. For both, the optimal committee size and initial skill levels are the same. Still, the accuracy of the collective decision in the communicating committee, which can be interpreted as the final level of skills (just before taking the vote on interest rates) is much higher.

Another interesting observation is that, as the membership and time costs increase, communication and learning become more crucial for the accuracy of collective decisions. Looking at the last four rows of the table, we see that decision-making procedures involving learning yield higher accuracy of collective decisions than any procedure that excludes learning. In some cases they involve lower costs as well.

6 Conclusions

Our results have interesting implications for actual monetary policy making, when conducted in a committee. First of all, we show that what policy makers in real life indicate to be an important characteristic of monetary policy committees, interaction, is beneficial to the quality of interest rate decisions, since committee members learn from each other. By sharing information, MPC members improve their knowledge about future economic developments, which is beneficial to the monetary policy outcome. Gerlach-Kristen (2003a) and Meade and Sheets (2005) provide empirical support for this line of reasoning. More specifically, if, as these authors seem to suggest, members of the hub have a significant advantage vis-à-vis their colleagues in terms of knowledge and information, our results indicate that it is beneficial to communicate, at least among each other. Whether or not communication
should be extended to all committee members depends on the degree of skill asymmetry. If the asymmetry in initial skills is relatively large, this paper advises against extending the scope of communication to all MPC members. This is because learning, i.e. partially adopting the views expressed by others, means to some extent giving up your own view. As long as the latter is qualitatively less than the former, the collective outcome improves. Another implication for committee design is that there is a trade-off between communication and size in increasing the quality of the collective outcome. Without communication, the quality of monetary policy can only be improved by adding members. Alternatively, as it becomes more costly to add members to a MPC, communication and learning become more important to improve the collective outcome.

7 References


8 Appendix. Proofs to propositions

**Proposition 1:** Assume that individual decisional skills are heterogeneous, i.e. $q_M(x, \sigma_M) > q_N(x, \sigma_N)$. The optimal decision-making procedure is information sharing among all committee members, with the collective forecast being a weighted average of individual forecasts.

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

$$E_{C,t}^w e_{t+1} = \frac{\sum_{i=1}^{m+n} w_i E_{i(M\cup N),t} e_{t+1}}{\sum_{i=1}^{m+n} w_i}$$

(19)

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

$$Var\left(E_{C,t}^w e_{t+1}\right) = \left(\frac{1}{nw_N + mw_M}\right)^2 \left(nw_N^2 \sigma_N^2 + mw_M^2 \sigma_M^2\right)$$

(20)

where $\sigma_N^2$ and $w_N$ denote the uncertainty of the estimates made by the less-skilled committee members and the weight given to their estimates in computing the collective forecasts. Analogously, $\sigma_M^2$ and $w_M$ denote the uncertainty and the weight of the forecasts made by the more-skilled committee members.

Under the normalizing assumption $nw_N + mw_M = m + n$,\(^{16}\) we can compute the weights $w_N$ and $w_M$ that minimize the variance $Var\left(E_{C,t}^w e_{t+1}\right)$. They are given as:

$$w_M = \frac{(m + n) \sigma_N^2}{n\sigma_M^2 + m\sigma_N^2}$$

(21)

$$w_N = \frac{(m + n) \sigma_M^2}{n\sigma_M^2 + m\sigma_N^2}$$

(22)

\(^{16}\)This assumption allows for a natural comparison with the case of no weighting, i.e. the case where $w_N = w_M = 1$. 

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Note that the weights are equal only if \( \sigma_N^2 = \sigma_M^2 \), i.e. if \( q_M(x, \sigma_M) = q_M(x, \sigma_N) \). If \( q_M(x, \sigma_M) > q_M(x, \sigma_N) \), implying \( \sigma_N^2 > \sigma_M^2 \), we have \( w_M > w_N \).

**Proposition 2:** Assume that individual decisional skills are heterogeneous, i.e. \( q_N(x, \sigma_N) \to 0.5 \) and \( q_M(x, \sigma_M) > q_N(x, \sigma_N) \). Depending on the size of the skill asymmetry, the optimal decision-making procedure could be approximated either by unweighted averaging of all individual forecasts (for a relatively low asymmetry) or by limiting information sharing to a pre-meeting by the more-skilled committee members (for a high skill asymmetry). Hence, in case of a high skill asymmetry, the less-skilled committee members are redundant.

**Proof:** The optimal decision-making procedure yields the following accuracy of the collective decision:

\[
P^W_C(B|b) = q^W_C \left( x, \frac{\sigma_M \sigma_N}{\sqrt{m \sigma_M^2 + m \sigma_N^2}} \right)
\]

If the individual forecasts are not weighted, the collective accuracy is given as:

\[
P_C(B|b) = q_C \left( x, \frac{\sqrt{m \sigma_M^2 + m \sigma_N^2}}{m + n} \right)
\]

In the case of communication and learning limited to the pre-meeting, the collective accuracy becomes:

\[
P_{LC}(B|b) = \text{Max} \left\{ P_{LC}^{NA}(B|b), P_{LC}^{A}(B|b) \right\}
\]

where \( P_{LC}^{NA}(B|b) \) refers to the situation when the more-skilled sub-group does not announce their common position before voting in the MPC, and is given as:

\[
P_{LC}^{NA}(B|b) = q_M \left( x, \frac{\sigma_M}{\sqrt{m}} \right) \sum_{s=\frac{n+m+1}{2}}^{n} \binom{n}{s} (q_N(x, \sigma_N))^s (1 - q_N(x, \sigma_N))^{n-s} + \left( 1 - q_M \left( x, \frac{\sigma_M}{\sqrt{m}} \right) \right) \sum_{s=\frac{n+m+1}{2}}^{n} \binom{n}{s} (q_N(x, \sigma_N))^s (1 - q_N(x, \sigma_N))^{n-s}
\]

and \( P_{LC}^{A}(B|b) \) refers to the situation when the common position is announced, and is given by:

\[
P_{LC}^{A}(B|b) = q_M \left( x, \frac{\sigma_M}{\sqrt{m}} \right)
\]
If \( q_N (x, \sigma_N) \to 0.5 \), we have

\[
P^{NA}_{LC}(B|b) = q_M \left( x, \frac{\sigma_M}{\sqrt{m}} \right) \sum_{s = \frac{n-m+1}{2}}^{n} \binom{n}{s} 0.5^n + \left( 1 - q_M \left( x, \frac{\sigma_M}{\sqrt{m}} \right) \right) \sum_{s = \frac{n-m+1}{2}}^{n} \binom{n}{s} 0.5^n
\]

It can be shown that, for \( q_N (x, \sigma_N) \to 0.5 \), \( P^{A}_{LC}(B|b) \geq P^{NA}_{LC}(B|b) \):

\[
P^{A}_{LC}(B|b) \geq P^{NA}_{LC}(B|b) \iff q_M \left( x, \frac{\sigma_M}{\sqrt{m}} \right) \sum_{s = \frac{n-m+1}{2}}^{n} \binom{n}{s} 0.5^n + \left( 1 - q_M \left( x, \frac{\sigma_M}{\sqrt{m}} \right) \right) \sum_{s = \frac{n-m+1}{2}}^{n} \binom{n}{s} 0.5^n \geq \frac{q_M \left( x, \frac{\sigma_M}{\sqrt{m}} \right) \sum_{s = \frac{n-m+1}{2}}^{n} \binom{n}{s} 0.5^n}{1 - \sum_{s = \frac{n-m+1}{2}}^{n} \binom{n}{s} 0.5^n}
\]

Since \( \sum_{s = \frac{n-m+1}{2}}^{n} \binom{n}{s} 0.5^n \leq 0.5 \leq \sum_{s = \frac{n-m+1}{2}}^{n} \binom{n}{s} 0.5^n \), the last inequality is certainly true for \( q_M \left( x, \frac{\sigma_M}{\sqrt{m}} \right) \geq 0.5 \). Hence, for \( q_N (x, \sigma_N) \to 0.5 \):

\[
P_{LC}(B|b) = P^{A}_{LC}(B|b) = q_M \left( x, \frac{\sigma_M}{\sqrt{m}} \right)
\]

As a result, the comparison of the accuracy of the collective decisions achieved under each of the three procedures boils down to comparing three standard deviations: \( \sqrt{\frac{\sigma_N \sigma_M}{\sqrt{n \sigma_M^2 + m \sigma_N^2}}} \) and \( \sigma_M \sqrt{\frac{1}{m \sigma_M^2 + n \sigma_N^2}} \):

\[
\frac{\sigma_N \sigma_M}{\sqrt{n \sigma_M^2 + m \sigma_N^2}} = \sqrt{\frac{m \sigma_M^2 + n \sigma_N^2}{m + n}} = \frac{\sigma_N \sigma_M - \sqrt{\sigma_N^2 (m \sigma_M^2 + n \sigma_N^2) + m \sigma_M^2 \sigma_N^4}}{(m + n) \sqrt{\sigma_M^2 + \sigma_N^2}} \leq 0
\]

\[
\Rightarrow P^W_C (B|b) \geq P_C (B|b)
\]

\[
\frac{\sigma_M \sigma_N}{\sqrt{n \sigma_M^2 + m \sigma_N^2}} = \frac{\sigma_M}{\sqrt{m \sigma_M^2 + n \sigma_N^2}} = \sigma_M \sqrt{\frac{1}{m \sigma_M^2 + n \sigma_N^2}} \leq 0
\]

\[
\Rightarrow P^W_C (B|b) \geq P_{LC} (B|b)
\]
The comparison between the two sub-optimal decision-making rules is less straightforward and depends on the degree of skill asymmetry:

\[
\frac{\sqrt{m\sigma^2_M + n\sigma^2_N}}{m+n} - \frac{\sigma_M}{\sqrt{m}} = \sqrt{\frac{m(\sigma^2_M + n\sigma^2_N)}{m+n}} - (m + n) \frac{\sigma_M}{\sqrt{m}}
\]

\[
\sigma^2_M \rightarrow \sigma^2_N : \sigma_M \sqrt{\frac{m(m+n) - (m+n)}{\sqrt{m}(m+n)}} \leq 0
\]

\[
\sigma^2_M \rightarrow 0 : \frac{\sigma_N\sqrt{mn}}{\sqrt{(m+n)}} \geq 0
\]

Hence, if the asymmetry in skills is low, the unweighted averaging procedure yields the collective accuracy which is higher than limited deliberations:

\[P_{LC}(B|b) \leq P_C(B|b) \leq P^W_C(B|b)\]

and, if the asymmetry is high, limited deliberations with announcement yield higher accuracy than unweighted averaging. In this case, the less-skilled committee members are redundant, as the collective decision is solely determined by the position of the more-skilled committee members:

\[P_C(B|b) \leq P_{LC}(B|b) \leq P^W_C(B|b)\]

**Proposition 3:** If the skill asymmetry is very high, unweighted averaging of all individual forecasts may even yield worse results than the decision-making procedure which excludes a communication stage.

**Proof:** The accuracy of the collective decision without communication is the maximum of simple majority voting, two-tier voting with more-skilled committee members holding a pre-meeting, and two-tier voting with more-skilled committee members announcing the decision they reached in the pre-meeting to other committee members:

\[P(B|b) = Max \left\{ P_{SM}(B|b), P^{NA}(B|b), P^A(B|b) \right\} \quad (28)\]

where

\[P_{SM}(B|b) = \sum_{s_M=0}^{m} \left( \binom{m}{s_M} (q_M(x,\sigma_M))^{s_M} (1 - q_M(x,\sigma_M))^{m-s_M} \right) \sum_{s=\frac{m-s_M}{2}}^{n} \binom{n}{s} (q_N(x,\sigma_N))^{s} (1 - q_N(x,\sigma_N))^{n-s_N} \quad (29)\]
\[ P_{NA}(B|b) = \left( \sum_{s_{M}=\frac{m}{2}+1}^{m} \binom{m}{s_{M}} (q_{M}(x, \sigma_{M}))^{s_{M}} (1 - q_{M}(x, \sigma_{M}))^{m-s_{M}} \right) \]

\[ + \left( \sum_{s_{M}=n+1}^{n} \binom{n}{s_{M}} (q_{N}(x, \sigma_{N}))^{s_{M}} (1 - q_{N}(x, \sigma_{N}))^{n-s_{M}} \right) \]

\[ + \left( \sum_{s_{M}=n+1}^{\frac{m}{2}} \binom{m}{s_{M}} (q_{M}(x, \sigma_{M}))^{s_{M}} (1 - q_{M}(x, \sigma_{M}))^{m-s_{M}} \right) \frac{n}{2} \sum_{s=n+1}^{\frac{m}{2}} \binom{n}{s} (q_{N}(x, \sigma_{N}))^{s} (1 - q_{N}(x, \sigma_{N}))^{n-s_{N}} \] (30)

and

\[ P_{A}(B|b) = \sum_{s_{M}=\frac{m}{2}+1}^{m} \binom{m}{s_{M}} (q_{M}(x, \sigma_{M}))^{s_{M}} (1 - q_{M}(x, \sigma_{M}))^{m-s_{M}} + \]

\[ \left( \binom{m}{2} (q_{M}(x, \sigma_{M}))^{\frac{m}{2}} (1 - q_{M}(x, \sigma_{M}))^{\frac{m}{2}} \right) \sum_{s=n+1}^{\frac{m}{2}} \binom{n}{s} (q_{N}(x, \sigma_{N}))^{s} (1 - q_{N}(x, \sigma_{N}))^{n-s_{N}} \] (31)

In the case of highly asymmetric skills, i.e. \( q_{N}(x, \sigma_{N}) \to 0.5 \) and \( q_{M}(x, \sigma_{M}) \to 1 \), \( P(B|b) = P_{A}(B|b) \) (see Berk and Bierut (2005)), and:

\[ P(B|b)|_{q_{N}(x, \sigma_{N}) \to 0.5 \atop q_{M}(x, \sigma_{M}) \to 1} \to 1 \]

\[ P_{C}(B|b)|_{q_{N}(x, \sigma_{N}) \to 0.5 \atop q_{M}(x, \sigma_{M}) \to 1} \to q_{C} \left( x, \frac{1.4826\sqrt{n}}{m+n} \right) \]

The figure below presents the difference \( P(B|b)|_{q_{N}(x, \sigma_{N}) \to 0.5 - P_{C}(B|b)|_{q_{N}(x, \sigma_{N}) \to 0.5 \atop q_{M}(x, \sigma_{M}) \to 1} \) for \( m \) between 2 and 20, and \( n \) between 1 and 29. It shows clearly that in
smaller committees $P(B|b)\big|_{q_N(x,\sigma_N)\to 0.5} > P_C(B|b)\big|_{q_N(x,\sigma_N)\to 0.5}$.

$$p\Theta g_{(B|b)}^q N(x,\sigma N) \to 0.5$$

$$p\Theta g_{(B|b)}^q M(x,\sigma M) \to 1.$$
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