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On the optimality of decisions made by hub-and-spokes monetary policy committees

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Abstract

Most monetary policy committees decide on interest rates using a simple majority voting rule. Given the inherent heterogeneity of committee members, this voting rule is suboptimal in terms of the quality of the interest rate decision, but popular for other (political) reasons. We show that a clustering of committee members into 2 subgroups, as is the case in a hub-and spokes systems of central banks such as the Fed or the ESCB, can eliminate this suboptimality whilst retaining the majority voting rule.

JEL codes: D71, D78, E58

Key words: central banks' policies, decision-making under uncertainty, committees, decision-making processes

1 Introduction

> "...Improving the quality of decision-making by eliminating certain sources of error that prevent a group from achieving its goals can be expected to have good social consequences for policy-making groups that have good goals..."[1]

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[1] Janis (1982), p. 274

Most textbooks on monetary policy are based, either implicitly or explicitly, on the assumption that policy decisions are taken by a homogenous entity, often denoted by 'the' central bank. However, in reality these decisions are the competence of a group of persons, organized in the form of a committee. Prominent examples include the Federal Open Market Committee (FOMC) of the Federal Reserve System and the Governing Council of the European Central Bank (ECB). As noted by, inter alia, Blinder (1998) and Chappell et al. (2003), the fact that monetary decision-making is conducted by a committee could have implications for the way policy is conducted.

In this paper we focus on issues stemming from the unavoidable heterogeneity among committee members, in particular the heterogeneity in the accuracy with which they are able to correctly judge the prevailing (economic) conditions, and therefore their ability to take the (ex ante) correct interest rate decision. Intuitively, one would like to have more-skilled committee members to have a larger say in the collective decision. Indeed, it can be shown (see Ben-Yashar and Nitzan, 1997) that a weighted voting rule is optimal in terms of the quality of the collective decision. Although weighted voting rules can be found in real life[2], it 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. It would for example require the ex ante precise quantification of expertise, and it would require constant adjustments according to the evolution of individual expertise.

The main contribution of this paper is that we show that a certain institutional setup of a committee is able to both retain the simple majority voting rule[3] and to eliminate the inefficient use of information implied by the fact that individual members have different levels of expertise. We propose to divide the committee into two sub-groups according to skills of members, allow the more-skilled group to meet prior to the actual policy meeting and be allowed to produce a consensual position regarding the appropriate stance of monetary policy. Subsequently, the two groups should jointly take a vote on interest rates. In addition to an efficient use of the available information, our solution has additional advantages, as it combines several prescriptions suggested by Irving Janis to prevent a detrimental concurrence-seeking group

[2] Prominent examples include decision-making in the Council of the European Union and the presidential elections in the United States. In both cases, votes are weighted according to size of the region in question.

[3] Simple majority as we use throughout the text has 2 defining characteristics: the principle of one person one vote, and the majority of 50% + 1 votes is required to adopt a certain decision.

dynamics, labelled as groupthink.[4] The relevance of our proposal becomes clear once one looks at two of the most influential central banks in the world, i.e. the Federal Reserve System in the US and the European System of Central Banks in Europe (more specifically, in the euro area). Both central banks have two-tier monetary policy committees, which is related to the structure of the corresponding central bank, characterized by a main office in central location with additional regional offices throughout the currency area. We label this as a 'hub-and-spokes' system. As a consequence, the FOMC consists of the members of the Board of Governors (hub) as well as the presidents of the Federal Reserve Banks (spokes). The Governing Council of the European Central Bank includes members of the Executive Board of the ECB ('hub') as well as governors of all euro area national central banks ('spokes'). If, for whatever reason, members of the Board of Governors (ECB Executive Board) are in a better position to identify the 'true' state of the economy from the evidence presented then are other members of the FOMC (Governing Council), our analysis indicates that the adopted structure actually improves the quality of monetary policy.

In the literature on monetary policy, modelling the behaviour of the central bank has been predominantly along the lines of Barro and Gordon (1983) and Rogoff (1985). Hefeker (2003) and Sibert (2003) constitute recent examples of the shift in research attention to the investigation of the behaviour of individuals that together form a monetary policy committee. Our work differs from theirs in that we want to focus on the effects of the decision rule on the quality of monetary policy, and therefore sidestep the issue of differences in preferences of committee members. Given this objective, we also employ a different methodology and use models of collective decision-making under uncertainty, as frequently used in the jury literature. In fact, to our knowledge, jury models are as yet not frequently used in the analysis of monetary policy, which makes our paper interesting from the methodological point as well. A prominent exception is the recent paper by Persico (2004). Although related, this paper differs in terms of objective, i.e. it focusses on the role of information gathering.

Section 2 below describes the basic model and illustrates the suboptimality of simple majority voting in a monetary policy committee with heterogenous members. Section 3 proposes an alternative, and explores the (rationality of the) voting behaviour of members in this alternative regime. Section 4 presents the consequences of our alternative structure of the monetary policy committee for the quality of monetary policy, and section 5 concludes. Proofs of propositions can be found in the appendix.

[4] Janis (1982)

2 E¤ects of a sub-optimal decision rule

In a monetary policy committee, members are presented with evidence concerning the state of the economy. Their interpretation of the evidence may di¤er. Each member assesses the evidence, and on the basis of her interpretation votes either to change the policy interest rate or to leave it unchanged. In deciding how to vote, each member has to consider the costs of changing interest rates when the economy in fact requires leaving them unchanged, or of leaving the policy stance unchanged when the economy actually requires a change in rates. The committee member must also consider the likely e¤ect of her vote on the …nal outcome, which depends on the votes of other members. Thus an answer to the question how a committee member will vote requires considering the strategic interaction between committee members. Decision-making in a monetary policy committee may therefore modelled using Bayesian game theory, see for example Osborne (2004) and Hirschleifer and Riley (1992).

Our setup is a modi…cation of the seminal work of Austen-Smith and Banks (1996) and Feddersen and Pesendorfer (1998) on juries.[5] We investigate interest rate decision-making by a monetary policy committee faced with uncertainty about the prevailing economic conditions. We model this uncertainty by assuming that the economy can be in either of two states of the world: in state a economic conditions require a change of the policy rate (decision A), in state b the appropriate decision (labelled decision B) is to keep rates unchanged. We assume that committee members have identical prior beliefs regarding the appropriate monetary policy stance, and do not have an 'intrinsic preference' regarding monetary policy, i.e. we preclude 'doves' or 'hawks'.[6] Of course the (ex hypothesi equal) prior belief may and in general will be modi…ed by the evidence on the state of the economy presented in the meeting. We model the possibility that committee members interpret the evidence di¤erently 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

[5] See Persico (2004) for a comprehensive overview of the related literature.

[6] This assumption, formalised by symmetric priors: $8i : P_i(a) = P_i(b) = 0.5$, is commonly made in the jury literature. In contrast, most of the literature on monetary policy commitees (see the Introduction) analyses the e¤ects of a prior bias, that moreover di¤ers between committee members. In our defense, as the objective of the paper is to study the e¤ects of a voting rule and committee structure on the quality of the collective outcome, it seems appropriate not to attribute prior bias to individual members. For an analysis of heterogenous priors, see Hao, Rosen and Suen (1999).

directly into a higher probability of making the correct individual decision, i.e. voting for a change in interest rates in state a and voting for unchanged rates in state b:

$$\begin{aligned} P_i(\text{vote } A|a) &= P_i(\text{vote } B|b) = q_i \\ P_i(\text{vote } B|a) &= P_i(\text{vote } A|b) = 1 - q_i \end{aligned}$$

We label the q_i's as individual decisional skills. Suppose furthermore it is possible to cluster committee members into 2 subgroups such that the average skill level between both groups differ. In hub-and-spokes systems of central banks such as in the US or the euro area, such a clustering might coincide with the 'institutional' clustering of the center versus the regions. We will return to this issue later. We model this clustering as follows: m more-skilled and n less-skilled individuals, such that individual skills q_i are independently drawn from the following (normal) distributions:[7]

$$\begin{aligned} \forall i &\in M : q_i \sim N(q_M, \frac{q_M(1 - q_M)}{m}) \\ \forall i &\in N : q_i \sim N(q_N, \frac{q_N(1 - q_N)}{n}) \\ q_M &\geq q_N \\ \forall i &: 0.5 \leq q_i \leq 1 \end{aligned}$$

We furthermore assume that everybody knows in which group he or she falls, and also in which group other committee members fall. The monetary policy committee only convenes a single time, and decides only on interest rates, via a simultaneous voting procedure.

Each committee member wishes to contribute to the appropriate monetary policy, i.e. the interest rate setting that is called for by the state of the economy. She is indifferent between changing rates or leaving them unchanged, as long as the choice is appropriate given the economic situation. Each committee member strictly prefers these two outcomes to one in which interest rates are set inappropriately. Moreover, each member considers an inappropriate change in interest rates as bad as inappropriately leaving the policy stance unchanged. These preferences are represented by the following Bernoulli payoffs for each committee member:[8]

$$u_i(X|x) = \begin{cases} 1 \text{ if } X = B \text{ and } x = b \text{ or if } X = A \text{ and } x = a \\ 0 \text{ if } X = A \text{ and } x = b \text{ or if } X = B \text{ and } x = a \end{cases} \quad (1)$$

[7] The important assumption here is that the distribution of individual skills has second and higher moments that are negligible. This allows us to express the probability that the collective decision is correct in terms of average decisional skills instead of individual skills. Our choice of normal distribution follows the literature, see Grofman et al. (1983).

[8] This utility specification implies that all committee members want to take the correct

It is well-known (see e.g. Ben-Yashar and Nitzan, 1997) that, if committee members have asymmetric skills (and there is no clustering of members into subgroups), the optimal decision rule is weighted majority, with higher weights assigned to higher-skilled individuals. Weighted majority maximizes the gains from aggregating individual expertise. However, in most real-life situations, and in particular in monetary policy committees, the votes are not weighted according to decisional skills. The decisions are taken by simple majority. It can be shown[9] that under this voting rule it is rational for the individual member to base her vote only on her interpretation of the evidence regarding the state of the economy, i.e. to vote informatively. However, despite maximizing individual expected utility, informative voting is not enough to prevent the accuracy of the collective decision from deteriorating under a suboptimal decision rule. This result is illustrated in figure 1 below, which presents on the vertical axis the quality of the monetary policy decision (represented by the conditional probability that the committee takes a correct decision, denoted by P) under both simple majority[10] (dotted lines) and the optimal rule, i.e. weighted majority[11] (solid lines). We assume

decision. However, they may have different opinions on what actually is the correct decision, since they have different information and skills. This specification, therefore, does not imply that they all prefer the same interest rate.

[9] Because voting is simultaneous, the skill heterogeneity does not provide additional information for individual members that is relevant for the collective decision. That is, we can use the results of Austin-Smith and Banks (1996), derived under identical skills. The intuition behind their rationality proof is straightforward: under a simple majority voting rule, an individual vote is pivotal (i.e. can change the collective outcome) only when votes of other committee members are equally divided. Such a situation does not provide any additional information about the state of the economy, and an individual is left to trust his or her private information. That is, she will vote for A (B) if a signal to that effect is received. See also Coughlan (2000).

[10] We can write the conditional probabilities as: $P^{SM}(B|b) = P^{SM}(A|a) = \sum_{s_M=0}^{m} \binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \sum_{s=\frac{n+m+1}{2}-s_M}^{n} \binom{n}{s} q_N^{s} (1-q_N)^{n-s}$.

[11] That is $P^{FB}(B|b) = \sum_{s_M=0}^{m} \left(\binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \sum_{s=\frac{n}{2}+\left(\frac{m}{2}-s_M\right)\frac{w_M}{w_N}}^{n} \binom{n}{s} q_N^{s} (1-q_N)^{n-s} \right)$ $= P^{FB}(A|a)$, where $w_M = \ln\frac{q_M}{1-q_M}$ and $w_N = \ln\frac{q_N}{1-q_N}$ denote the optimal weights to be attributed to the votes of more- and less-skilled individuals (see also proof to proposition 1 in the appendix). FB refers to the first best decision rule, i.e. weighted majority.

$q_M = 0.8 \geq q_N$, $m = 6$, $n = 3$ (thin lines) or $n = 13$ (thicker lines).

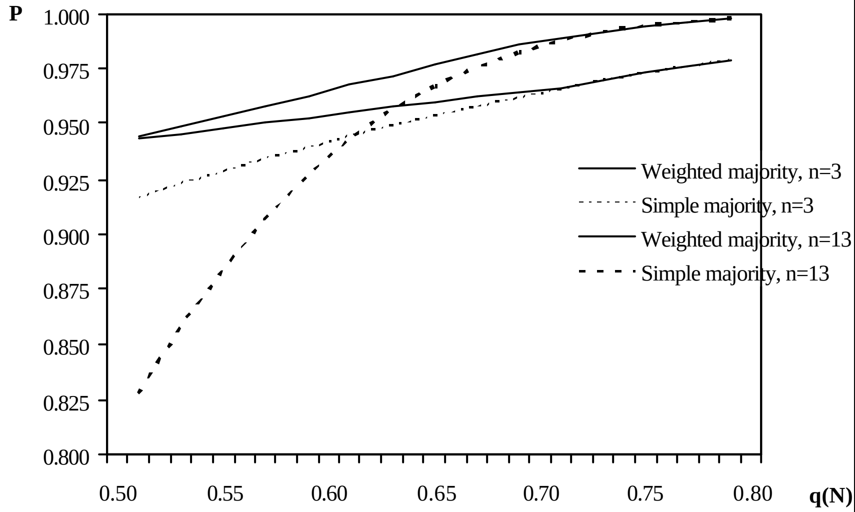


Figure 1. The accuracy of the collective interest rate decision
(Simple and weighted majority)

Compared to the optimal outcome, the loss in accuracy of the interest rate decision can be quite substantial, especially if the skills are very asymmetric within the committee and/or if the lower-skilled group dominates the committee in size. In the following section we will investigate possible solutions to this problem.

3 Individual voting behaviour

Our main result, to be stated more precisely below, is that the above-mentioned informational inefficiency can be resolved by allowing the subgroup that is better in interpreting the available economic evidence (i.e. the subgroup characterized by a higher average skill level) to meet prior to the full committee meeting and allow them to take a collective stand regarding the appropriate interest rate action. We assume that both the subgroup and the full committee decide using a simple majority voting rule,[12] and that both decisions are made by a simultaneous vote. We start by assuming that the common position of the subgroup (if any, see below) is not disclosed prior to the vote in the full committee. We subsequently relax this assumption, allowing for communication.

[12] The assumption of simple majority voting in the full committee obviously is essential. The same does not apply for the subgroup, we use the assumption $k_M = \frac{m}{2} + 1$ mainly for reasons of simplicity.

As the formal monetary policy decision has to be taken by the full committee, the subgroup has the option to decide 'not to decide'. The meeting of the subgroup thus can generate three outcomes, depending on the distribution of opinions among the subgroup members. If there is a majority in favour of either A or B, this majority view is adopted. If not, no prior position is adopted and the subgroup members will vote individually in the full committee.[13] We formalize the outcome of the subgroup meeting in terms of probabilities that a certain alternative is selected, conditional on the available information on the state of the economy. The three possible outcomes: (1) consensus for a correct decision (e.g. status quo in state b: $P(CB|b)$), (2) consensus for an incorrect decision (e.g. a change in interest rates in state b: $P(CA|b)$), and (3) no consensus (i.e. $P(NC|b)$) are given by:

$$P(CB|b) = P(CA|a) = \sum_{\substack{S_M \subset M \\ s_M \geq \frac{m}{2}+1}} \prod_{i \in S_M} q_i \prod_{i \notin S_M} (1 - q_i) \tag{2}$$

$$P(CA|b) = P(CB|a) = \sum_{\substack{S_M \subset M \\ s_M \geq \frac{m}{2}+1}} \prod_{i \in S_M} (1 - q_i) \prod_{i \notin S_M} q_i \tag{3}$$

$$P(NC|b) = P(NC|a) = 1 - P(CB|b) - P(CA|b) \tag{4}$$

where the sums are taken over all subsets S_M of the set $M = \{1, 2, 3, ..., m\}$, such that s_M (the number of members in S_M) is at least $\frac{m}{2} + 1$. Under the assumptions made in the previous section, we can write conditional probabilities of the subgroup taking either of the three actions as:

$$P(CB|b) = P(CA|a) = \sum_{s_M = \frac{m}{2}+1}^{m} \binom{m}{s_M} q_M^{s_M} (1 - q_M)^{m - s_M} \tag{5}$$

$$P(CA|b) = P(CB|a) = \sum_{s_M = \frac{m}{2}+1}^{m} \binom{m}{s_M} q_M^{m - s_M} (1 - q_M)^{s_M} \tag{6}$$

$$P(NC|b) = P(NC|a) = \binom{m}{\frac{m}{2}} q_M^{\frac{m}{2}} (1 - q_M)^{\frac{m}{2}} \tag{7}$$

The outcome of the subgroup meeting obviously has consequences for the number of other committee members that have to be in favour of each policy alternative in order to get it passed in the full committee. If opinions in the subgroup are divided, one half of the subgroup members will vote for one alternative and the other half will vote against. If the subgroup has a common position which in fact is the incorrect policy option, then the full committee can still take the correct decision, if $\frac{n+m+1}{2}$ out of n less-skilled

[13] See Meade and Sheets (2002) for indications of dissenting behaviour within monetary policy committees of actual central banks.

members vote for it. If the subgroup has voted in favour of the correct alternative, then only $\frac{n+m+1}{2} - m$ less-skilled committee members have to be of the same opinion and the correct decision will be passed.

The quality of the monetary policy decision in our two-tier setup is then represented by the conditional probability that the monetary policy committee takes the correct decision:

$$P(B|b) = P(B \cap CB|b) + P(B \cap CA|b) + P(B \cap NC|b) \tag{8}$$

where:

$$
\begin{aligned}
P(B \cap CB|b) &= P(CB|b) \sum_{\substack{S \subset N \\ s \geq \frac{n+m+1}{2} - m}} \prod_{i \in S} q_i \prod_{i \notin S} (1 - q_i) && (9) \\
P(B \cap CA|b) &= P(CA|b) \sum_{\substack{S \subset N \\ s \geq \frac{n+m+1}{2}}} \prod_{i \in S} q_i \prod_{i \notin S} (1 - q_i) && (10) \\
P(B \cap NC|b) &= P(NC|b) \sum_{\substack{S \subset N - M \\ s \geq \frac{n+1}{2}}} \prod_{i \in S} q_i \prod_{i \notin S} (1 - q_i) && (11)
\end{aligned}
$$

S denotes subsets of the set N of less-skilled committee members, whose number s is large enough to obtain the committee majority for the correct decision. All conditional probabilities can be expressed using average decisional skills of committee members, q_M and q_N, analogously to formulas (5)-(7) for the subgroup.

Equations (8)-(11) characterize the decision on interest rates by the monetary policy committee, assuming that individual members base their vote on their interpretation of the evidence on the state of the economy. This assumed voting behaviour (i.e. voting informatively) actually constitutes a Nash equilibrium in the two-tier voting game, as we now show.

Each committee member i chooses a voting strategy that maximizes her expected utility, calculated over all states of the world as well as the actions chosen by other members (since they affect the collective outcome and therefore utility of i).[14] The latter complicates the analysis. In particular, there are two types of situations that may occur: (1) votes of other committee members will be divided in such a way that one of the alternatives will receive at least the required majority (in our case of simple majority: $\frac{n+m+1}{2}$ or more votes), and (2) votes of other committee members will be divided in an indecisive way (in our case: $\frac{n+m-1}{2}$ votes for decision A and $\frac{n+m-1}{2}$ for decision B). In the former cases, the action (i.e. the vote) of individual i is immaterial for the collective outcome and therefore for her expected utility

[14] See Osbourne (2004) for a further discussion of Bayesian games.

(see equation 1). In the latter cases, the vote of individual i changes the collective outcome (i.e. is pivotal) and therefore affects directly her utility from the collective decision. This implies that an utility maximizing committee member i will restrict her voting strategy to the cases when her vote matters. The optimal voting strategy of a rational committee member is to vote for the alternative that is more likely to be correct, based on her information set.[15] The latter consists of her own signal and the information deduced from the fact that her vote is pivotal.[16] Informative voting constitutes a rational choice if the following conditions are met:[17]

$$P_{i \in N}(b|B, \text{pivotal}) \geq 0.5 \tag{12}$$
$$P_{i \in N}(a|A, \text{pivotal}) \geq 0.5 \tag{13}$$

where

$$P_{i \in N}(b|B, \text{pivotal}) = \frac{P_i(b) q_i P_{i \in N}(\text{pivotal}|b)}{P_i(b) q_i P_{i \in N}(\text{pivotal}|b) + P_i(a)(1 - q_i) P_{i \in N}(\text{pivotal}|a)} \tag{14}$$
$$P_{i \in N}(a|A, \text{pivotal}) = \frac{P_i(a) q_i P_{i \in N}(\text{pivotal}|a)}{P_i(a) q_i P_{i \in N}(\text{pivotal}|a) + P_i(b)(1 - q_i) P_{i \in N}(\text{pivotal}|b)} \tag{15}$$

Furthermore, informative voting constitutes a Nash equilibrium if the conditions (12)-(13) hold when the probabilities are evaluated under the assumption that all (other) committee members vote informatively.

Analyzing the game backwards, we start with the choice facing a less-skilled member when she is to cast a vote for or against a change in interest rates: her vote is pivotal when the votes of other committee members are

[15] If we denote $r_i = P(b|\text{information set})$, then the expected utility from voting B is $P(B) r_i$ and the expected utility from voting A is $P(A)(1 - r_i)$. An individual will vote A if $P(a)(1 - r_i) > P(b) r_i$, or (given the assumption of $P(a) = P(b) = 0.5$), if $r_i < 0.5$.

[16] The informational content of the fact that i is pivotal is determined by the voting rule. In the case of simple majority, being pivotal does not provide additional information. This is not true for the case of unanimity. Assuming that no change in interest rates is the default option and the change requires unanimity, the only situation when an individual vote will be pivotal is when all other committee members will have voted for a change in interest rates. In that case, and assuming that all other committee members have voted informatively, state A is more likely to be true than state B and therefore option A is more likely to be the correct decision.

[17] As discussed in the previous footnote, in the case of a unanimous voting rule these conditions are not likely to be met. Pure considerations of a pivotal situation will lead committee member i to believe that state A is more likely to be true and to vote for a change in interest rates, regardless of her own information. In such a setup, informative voting is not a Nash equilibrium: the best response to informative voting of other committee members is to vote uninformatively (!). For a more detailed analysis of the effects of unanimous voting rules, see Feddersen and Pesendorfer (1998), Coughlan (2000) and Gerardi (2000).

split: $\frac{n+m-1}{2}$ votes for a change and $\frac{n+m-1}{2}$ votes against. Such a situation occurs in three cases, depending on the earlier decision of the more-skilled subgroup (see equations (8)-(11)). Since the decision rules both in the subgroup and in the full committee are symmetric, the probability of being pivotal if all other members vote informatively is the same in both states of the world, and is given by:

$$\begin{aligned} P_{i2N}(\text{pivotal}|b) &= P_{i2N}(\text{pivotal}|a) = P_{i2N}(\text{pivotal}) \\ &= P(CB|b)\binom{n-1}{\frac{n+m-1}{2}-m}\left(q_N^{\frac{n+m-1}{2}-m}(1-q_N)^{\frac{n+m-1}{2}}\right. \\ &\quad \left.+P(CA|b)\binom{n-1}{\frac{n+m-1}{2}}q_N^{\frac{n+m-1}{2}}(1-q_N)^{\frac{n+m-1}{2}-m}\right) \\ &\quad +P(NC|b)\binom{n-1}{\frac{n-1}{2}}q_N^{\frac{n-1}{2}}(1-q_N)^{\frac{n-1}{2}} \end{aligned} \quad (16)$$

Given this result and our assumption about the priors, we arrive at the following simplification of conditions (12)-(13):

$$P_{i2N}(b|B,\text{pivotal}) = P_{i2N}(a|A,\text{pivotal}) = q_{i2N} \quad (17)$$

By assumption $q_{i2N} \geq 0.5$ and therefore the optimal strategy for any less-skilled member is to vote informatively if all other committee members are assumed to vote informatively as well.

We now turn to the choices of the relatively higher skilled members. Under our assumptions, an individual subgroup member's vote is pivotal for the interest rate decision to be taken in the full committee in m cases. In these cases, her vote makes the difference between adopting a common group position or not, while the votes of other committee members are split in such a way that a common position of the subgroup wins if it is adopted and the other alternative wins if no common position is adopted.[18] This requires the following combination of votes: $\frac{m}{2}$ votes for B in the more-skilled group and between $\frac{n-1}{2}$ and $\frac{n-m+1}{2}$ votes (thus $\frac{m}{2}$ possible cases) for B among less-skilled committee members[19] or (symmetrically) $\frac{m}{2}$ votes for A in the more-skilled group and between $\frac{n-1}{2}$ and $\frac{n-m+1}{2}$ votes (again $\frac{m}{2}$ cases) for A among other committee members. The table below illustrates this for a 6-person subgroup where a member is pivotal for the final decision (to be

[18] Alternatively, a subgroup member that has the swing vote in the subgroup can be pivotal in the full committee as due to her swing vote, the outcome of the vote in the full committee changes.

[19] That implies $\frac{m}{2}-1$ votes for A in the sub-group and between $\frac{n+1}{2}$ and $\frac{n+m-1}{2}$ among other committee members.

taken by simple majority $\frac{n+7}{2}$):[20]

Case		Votes for B	Votes for A
	Sub-group	3	2
1	Other members	$\frac{n-1}{2}$	$\frac{n+1}{2}$
	i votes B	$\frac{n-1}{2}+6=\boxed{\frac{n+11}{2}}$	$\frac{n+1}{2}$
	i votes A	$\frac{n-1}{2}+3=\frac{n-5}{2}$	$\frac{n+1}{2}+3=\boxed{\frac{n+7}{2}}$
2	Other members	$\frac{n-3}{2}$	$\frac{n+3}{2}$
	i votes B	$\frac{n-3}{2}+6=\boxed{\frac{n+9}{2}}$	$\frac{n+3}{2}$
	i votes A	$\frac{n-3}{2}+3=\frac{n+3}{2}$	$\frac{n+3}{2}+3=\boxed{\frac{n+9}{2}}$
3	Other members	$\frac{n-5}{2}$	$\frac{n+5}{2}$
	i votes B	$\frac{n-5}{2}+6=\boxed{\frac{n+7}{2}}$	$\frac{n+5}{2}$
	i votes A	$\frac{n-5}{2}+3=\frac{n-1}{2}$	$\frac{n+5}{2}+3=\boxed{\frac{n+11}{2}}$

Case		Votes for B	Votes for A
	Sub-group	2	3
4	Other members	$\frac{n+1}{2}$	$\frac{n-1}{2}$
	i votes B	$\frac{n+1}{2}+3=\boxed{\frac{n+7}{2}}$	$\frac{n-1}{2}+3=\frac{n+5}{2}$
	i votes A	$\frac{n+1}{2}$	$\frac{n-1}{2}+6=\boxed{\frac{n+11}{2}}$
5	Other members	$\frac{n+3}{2}$	$\frac{n-3}{2}$
	i votes B	$\frac{n+3}{2}+3=\boxed{\frac{n+9}{2}}$	$\frac{n-3}{2}+3=\frac{n+3}{2}$
	i votes A	$\frac{n+3}{2}$	$\frac{n-3}{2}+6=\boxed{\frac{n+9}{2}}$
6	Other members	$\frac{n+5}{2}$	$\frac{n-5}{2}$
	i votes B	$\frac{n+5}{2}+3=\boxed{\frac{n+11}{2}}$	$\frac{n-5}{2}+3=\frac{n-1}{2}$
	i votes A	$\frac{n+5}{2}$	$\frac{n-5}{2}+6=\boxed{\frac{n+7}{2}}$

The corresponding probabilities that a member of the more-skilled subgroup

[20] The squares highlight the winning majority. It is therefore easy to see, that depending on i voting A or B, the winning alternative changes (i.e. i is indeed pivotal).

is pivotal for the interest rate decision are:

$$P_{i\in M}(\text{pivotal}|a) = \binom{m-1}{\frac{m}{2}}(1-q_M)^{\frac{m}{2}}q_M^{\frac{m}{2}-1}\sum_{x=\frac{n-m+1}{2}}^{n-1}\binom{n}{x}(1-q_N)^{n-x}q_N^x$$
$$+\binom{m-1}{\frac{m}{2}-1}(1-q_M)^{\frac{m}{2}-1}q_M^{\frac{m}{2}}\sum_{x=\frac{n+1}{2}}^{n+m-1}\binom{n}{x}(1-q_N)^{n-x}q_N^x \tag{18}$$

and

$$P_{i\in M}(\text{pivotal}|b) = \binom{m-1}{\frac{m}{2}}q_M^{\frac{m}{2}}(1-q_M)^{\frac{m}{2}-1}\sum_{x=\frac{n-m+1}{2}}^{n-1}\binom{n}{x}q_N^{n-x}(1-q_N)^x$$
$$+\binom{m-1}{\frac{m}{2}-1}q_M^{\frac{m}{2}-1}(1-q_M)^{\frac{m}{2}}\sum_{x=\frac{n+1}{2}}^{n+m-1}\binom{n}{x}q_N^{n-x}(1-q_N)^x \tag{19}$$

Again we have the result:

$$P_{i\in M}(\text{pivotal}|a) = P_{i\in M}(\text{pivotal}|b) = P_{i\in M}(\text{pivotal}) \tag{20}$$

and

$$P_{i\in M}(b|B,\text{pivotal}) = P_{i\in M}(a|A,\text{pivotal}) = q_{i\in M} \tag{21}$$

Since $q_{i\in M} \geq 0.5$ informative voting is rational for all more-skilled committee members, just as it is rational for all less-skilled committee members. Hence, informative voting constitutes a Nash equilibrium in this two-tier voting setup, provided that the interest rate decision is taken by simple majority.

4 The quality of monetary policy

The two-stage voting procedure defined above effectively replaces the optimal weighted voting rule as it reinforces the position of more-skilled committee members. This result is stated in proposition 1 below.

Proposition 1 If individual decisional skills are highly heterogeneous, the two-stage voting procedure described above perfectly approximates the accuracy of the collective decision that would be achieved in a committee dominated by the subgroup if a weighted voting rule would be applied. The accuracy of the collective decision taken by a committee where more-skilled members are in minority is also improved but not as much.

Proof. See appendix. ■

Figure 2 below illustrates proposition 1, using numerical assumptions identical to the ones underlying figure 1. Dotted lines refer to simple majority without a two-tier setup, solid lines to weighted majority, and dashed lines represent the quality of monetary policy formulated by a two-tier committee. Thin lines represent a small committee (6 + 3 members) and thicker lines a larger committee (6 + 13). The former is an illustration of a committee dominated by the hub, as in the Federal Reserve, and the latter illustrates a committee dominated by the spokes, as in the European Central Bank.

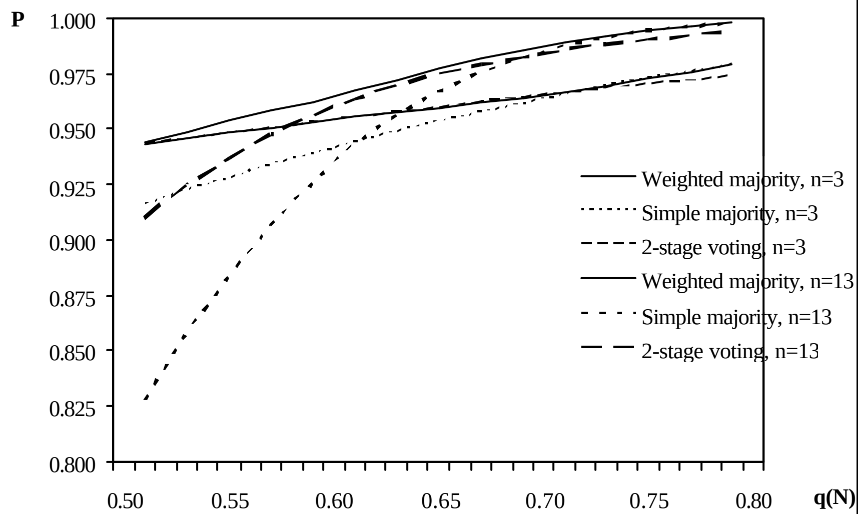


Figure 2. The accuracy of the collective interest rate decision (Simple majority, weighted majority and two-stage voting)

Creating a subgroup of more-skilled members improves the accuracy of the collective decision; this two-tier structure works particularly well in a relatively small committee. Consider the FOMC in the United States. This monetary policy committee, which is dominated (in terms of votes needed to secure a majority) by the Board, decides using a simple majority rule. The graph shows that if Board-FOMC members are substantially better in assessing the available evidence on the state of the economy, simple majority without allowing the Board to meet prior to the FOMC meeting and to take a common stand on interest rates, is far from optimal. The degree of inefficiency is measured by the difference between the thin solid and dotted lines. This inefficiency is completely eliminated once prior meeting is allowed (the thin solid and dashed lines overlap). For larger committees, this inefficiency is reduced, but not eliminated. However, if we extend the two-tier structure by allowing for communication prior to the decision in the full committee, the quality of monetary policy again closely resembles the first best rule (of weighted voting). By communication we mean that the higher-skilled members are required to announce their common position (if they have reached one) before the interest rate vote in the full committee. This announcement provides an additional common signal to other committee members.

Proposition 2 If individual decisional skills are highly heterogeneous, communication in a two-stage voting procedure increases the accuracy of the collective decision to be made by a committee where more-skilled members are in minority so that it is as high as if a weighted voting rule were applied. This is because communication changes the rational behavior of committee members: the less-skilled individuals choose to follow the common position of the more-skilled ones.

Proof. See appendix. ■

Again we illustrate the results from proposition 2 graphically in figure 3 below: we reproduce the lines from figure 2 drawn for the larger committee of 19 individuals and introduce a boxed line for the two-tier setup with communication stage.

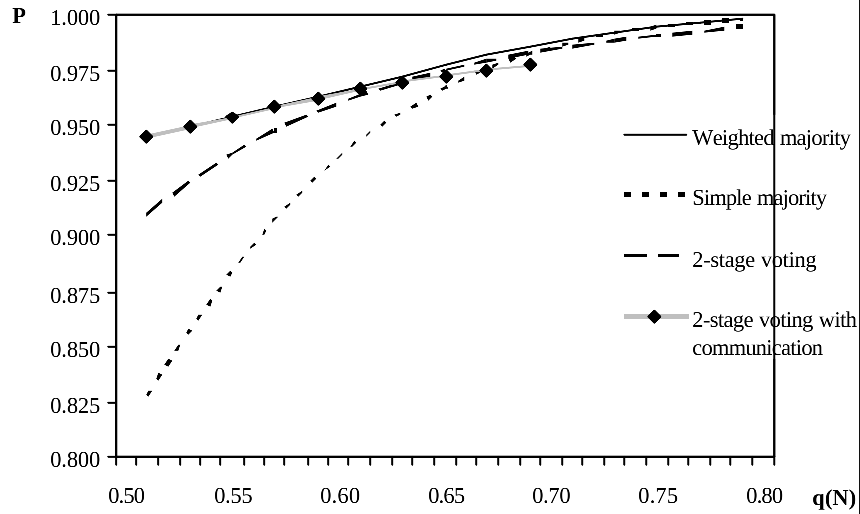


Figure 3. The accuracy of the collective interest rate decision (Simple majority, weighted majority and two-stage voting with and without communication)

Figure 3 illustrates the fact that communication yields the highest accuracy of the collective decision for the lowest average skills of the less-skilled members.[21] As we move to the right along the q_N axis the optimal decision

[21] The boxed line is shorter than other lines, because the two-tier set-up with communication is 'double-sided': it works very well if decisional skills are sufficiently heterogeneous between the two sub-committees, otherwise (see proposition 3 below) it performs badly.

procedure changes from two-tier voting with communication, through two-tier voting without communication, to simple majority voting. As a result the first best decision rule is closely approximated for every level of q_N. The ECB Governing Council can be taken as a real-life example of a larger committee, where the Executive Board is in minority. The Governing Council currently decides by simple majority. Only when Council members are nearly identical in terms of their ability to assess the true state of the economy of the euro area correctly from the available evidence will this voting rule imply the highest possible quality of the monetary policy decision. If it is the case that, say, the members of the Executive Board of the ECB are on average better informed or for some other reason are better skilled in identifying the true state of the economy, simple majority in the Council results in suboptimal monetary policy decisions, as it implies an inefficient use of information. The extent of this inefficiency depends on the size of the 'skill bias', as does the solution for improving the quality of the monetary policy decision. If governors of euro area national central banks on average are substantially worse in interpreting the evidence on the state of the economy in the euro area presented in the Council meeting, it would pay to allow the Board to meet prior to the Council meeting to discuss interest rates and to communicate the result of this meeting to the Council prior to the decision on interest rates. If this skill bias is relatively small, it still pays to allow the Board to meet prior to the Council meeting, but communication of the outcome of this meeting should be discouraged.

In fact, a word of caution is necessary. Knowledge of the size of the skill bias is essential, if one were to institutionally adjust the structure of the monetary policy committee composed of heterogenous members as to achieve the best possible monetary policy decision. A misjudgment regarding the skill bias might lead to a committee structure that actually results in a worse monetary policy outcome than the default of the committee taking the decision by simple majority after a simultaneous vote. We can observe this clearly in figure 3: for q_N larger than 0.69 the dotted line is drawn above the dashed line, i.e. simple majority yields higher accuracy in collective decision-making than the two-stage voting. As we show in proposition 3, an institutional structure in which the Board meets prior to the Council and communicates the outcome of this meeting to other Council members before the vote on interest rates takes place can be especially damaging if members are actually relatively homogenous in their decisional skills.

Proposition 3 If individual decisional skills are relatively homogeneous, communication accentuates the adverse effects that the two-stage decision-making process has on the accuracy of the collective decision, as the rational choice of the ’less-skilled’ committee members is to vote against the consensual position of the ’more-skilled’ ones.

Proof. See appendix. ■

5 Discussion

The key idea underlying the analysis presented above is that members of monetary policy committees might di¤er systematically in their ability to interpret the economic evidence presented to them in the committee meeting. In hub-and-spokes central banks such as the FED or the ESCB, this may coincide with the division between the hub and the spokes. The hub (i.e. the Board of Governors of the Federal Reserve System and the ECB Executive Board) is usually entrusted with the preparation of the monetary policy discussions; for example, it prepares assessments of current macroeconomic conditions and provides forecasts under alternative policy scenarios. The execution of these tasks may require a knowledge base of the hub that is, on average, higher than that of the spokes. Also, the hub usually acts as liason between the currency area (the US or the euro area) and the outside world, and thereby gets access to private information that makes it better equipped to interpret the evidence on the state of the economy of the currency area (Chappell, Havrilesky and McGregor, 1993, 1995). Finally, it has been argued (see Hefeker, 2003) that hub-and-spokes central banks, and corresponding monetary policy committees, re‡ect a political compromise between regions, which insist on representation, and a board appointed by the central governing body. This may coincide with the hub being relatively more informed regarding the currency area as a whole, with the spokes having regional expertise.

So, in our view one cannot dismiss a priori the possibility that the there is a skill bias between members of the hub and the spokes in monetary policy committees similar in structure to those in the US and the euro area. This paper indicates that, if such a bias is indeed present and substantial in size, having a meeting of the full committee that decides on monetary policy by simple majority will result in monetary policy that is suboptimal. When implementing the optimal voting rule is either unwarranted (for democratic or political reasons for example) or infeasible, our results indicate that it is, in principle, possible to restructure the committee in such a way that it generates monetary policy outcomes that closely approximate the optimum.

However, the solution we propose is not without its dangers, i.e. the cure may actually be worse than the illness. This is especially true if there is substantial uncertainty regarding the extent of the skill bias between the hub and the spokes. In combination with the fact that hub-and-spokes systems of central banks tend to be motivated by more reasons than the quality of policy, see for example von Hagen and Süppel (1994), and Meade and Sheets (forthcoming), it may actually be preferable to strive for a maximal dissemination of knowledge and information across the hub and the spokes, as to prevent a skill bias from occurring.

We would like to conclude by stating that, while the main motivation of this research is based on real life, i.e. the 'hub-and-spokes' monetary policy committees of the Federal Reserve and the European Central Bank, 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 our setup allows only for a limited and specific form of interaction among members, reducing the scope for an exchange of arguments that would lead to a change of position. As noted by others, see, for example, DNB (2000) and Goodfriend (1999), this interaction, where a common vision on interest rates evolves from an exchange of views based on economic analysis, is an important characteristic of monetary policy decision making by real-life committees. Further research is warranted on this topic, and we plan to take this up in the future.

6 Appendix: Proofs to propositions

Proposition 1 If individual decisional skills are highly heterogeneous, the two-stage voting procedure described above perfectly approximates the accuracy of the collective decision that would be achieved in a committee dominated by the subgroup if a weighted voting rule would be applied. The accuracy of the collective decision taken by a committee where more-skilled members are in minority is also improved but not as much.

Proof. When individual decisional skills are heterogeneous, a weighted voting rule is optimal in terms of the quality of the collective decision. The weight should be calculated as $w_i = \ln\left(\frac{q_i}{1-q_i}\right)$. It can be shown that the weight calculated for the average skill level is a good (first-order) approximation of the average weight of votes of the members belonging to one of the sub-groups within the committee:

$$E_{i\in M}\left(\ln\left(\frac{q_i}{1-q_i}\right)\right) \simeq E_{i\in M}\left(\ln\left(\frac{q_M}{1-q_M}\right) + \frac{1}{q_M(1-q_M)}(q_i - q_M)\right) = \ln\left(\frac{q_M}{1-q_M}\right)$$

$$E_{i\in N}\left(\ln\left(\frac{q_i}{1-q_i}\right)\right) \simeq E_{i\in N}\left(\ln\left(\frac{q_N}{1-q_N}\right) + \frac{1}{q_N(1-q_N)}(q_i - q_N)\right) = \ln\left(\frac{q_N}{1-q_N}\right)$$

Therefore the votes of more-skilled committee members can be weighted with the weight $\ln\left(\frac{q_M}{1-q_M}\right)$ and the votes of less-skilled members with the weight $\ln\left(\frac{q_N}{1-q_N}\right)$.

If the skills of committee members are relatively homogeneous, i.e. if $q_N \to q_M$, then $w_N \to w_M$, and the weights can be normalized to unity. In this case standard results obtained in the literature for symmetric skills hold, i.e. the first best decision rule (FB) corresponds to simple majority (SM) and any modification to this rule results in inferior accuracy of the collective decision, i.e. $P^{SM}(B|b) = P^{FB}(B|b)$ and $P(B|b) \leq P^{SM}(B|b)$.

The departure from the first best therefore has the most pronounced effects on the voting outcomes when $q_N \to 0.5$ (see figure 1). In this case votes of the less-skilled individuals should be ignored: $w_N = \ln\frac{0.5}{1-0.5} = 0$. As a result the decisions should actually be taken by the subgroup of more-skilled members regardless of its size relative to the committee majority (provided this subgroup reaches consensus). Therefore the probability that the committee takes the correct decision is given by:

$$P^{FB}(B|b)|_{q_N \to 0.5} \to \sum_{s_M=\frac{m}{2}+1} \binom{m}{s_M} q_M^{s_M}(1-q_M)^{m-s_M} + 0.5\binom{m}{\frac{m}{2}}\left(q_M(1-q_M)\right)^{\frac{m}{2}}$$

Simple majority decision rule on the other hand yields the following results:

$$P^{SM}(B|b)|_{q_N \to 0.5} \to \left(\sum_{s_M=0} \binom{m}{s_M} q_M^{s_M}(1-q_M)^{m-s_M} \sum_{s=\frac{n+m+1}{2}-s_M} \binom{n}{s} 0.5^n\right)$$

whereas simple majority in our 2-tier set-up yields:

$$\begin{aligned} P(B|b)|_{q_N \to 0.5} \to & \sum_{s_M=0}^{\frac{m}{2}-1} \binom{m}{s_M} q_M^{s_M}(1-q_M)^{m-s_M} \sum_{s=\frac{n+m+1}{2}} \binom{n}{s} 0.5^n \\ & +0.5\binom{m}{\frac{m}{2}}\left(q_M(1-q_M)\right)^{\frac{m}{2}} \\ & + \sum_{s_M=\frac{m}{2}+1} \binom{m}{s_M} q_M^{s_M}(1-q_M)^{m-s_M} \sum_{s=\frac{n+m+1}{2}-m} \binom{n}{s} 0.5^n \end{aligned}$$

It is obvious that if $m > n-1$, i.e. if the subgroup dominates the committee, the last probability can be simplified to obtain:

$$\begin{aligned} P(B|b)|_{\substack{q_N \to 0.5 \\ m>n-1}} & \to \sum_{s_M=\frac{m}{2}+1} \binom{m}{s_M} q_M^{s_M}(1-q_M)^{m-s_M} + 0.5\binom{m}{\frac{m}{2}}\left(q_M(1-q_M)\right)^{\frac{m}{2}} \\ & = P^{FB}(B|b)|_{q_N \to 0.5} \end{aligned}$$

However, if the group of relatively highly-skilled individuals forms a minority in the committee, the accuracy achieved under both 'ordinary' simple majority and simple majority in our 2-tier set-up is inferior to the first best decision rule:

$$P^{FB}(B|b)|_{q_N \to 0.5} - P^{SM}(B|b)|_{q_N \to 0.5} =$$

$$= -\sum_{s_M=0}^{\frac{m}{2}-1} \left(\binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \sum_{s=\frac{n+m+1}{2}-s_M} \binom{n}{s} 0.5^n \right)$$

$$+ \sum_{s_M=\frac{m}{2}+1} \left(\binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \left(1 - \sum_{s=\frac{n+m+1}{2}-s_M} \binom{n}{s} 0.5^n \right) \right) \geq 0$$

and

$$P^{FB}(B|b)|_{q_N \to 0.5} - P(B|b)|_{q_N \to 0.5} =$$

$$\sum_{s=\frac{n+m+1}{2}} \binom{n}{s} 0.5^n \left(\begin{array}{c} \sum_{s_M=\frac{m}{2}+1} \binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \\ -\sum_{s_M=\frac{m}{2}+1} \binom{m}{s_M} q_M^{m-s_M} (1-q_M)^{s_M} \end{array} \right) \geq 0$$

However, our 2-tier procedure still yields results superior to simple majority:

$$P(B|b)|_{q_N \to 0.5} - P^{SM}(B|b)|_{q_N \to 0.5} =$$

$$= \sum_{s_M=0}^{\frac{m}{2}-1} \left(\binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \left(\begin{array}{c} \sum_{s=\frac{n+m+1}{2}} \binom{n}{s} 0.5^n \\ -\sum_{s=\frac{n+m+1}{2}-s_M} \binom{n}{s} 0.5^n \end{array} \right) \right)$$

$$+ \sum_{s_M=\frac{m}{2}+1} \left(\binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \left(\begin{array}{c} \sum_{s=\frac{n+m+1}{2}-m} \binom{n}{s} 0.5^n \\ -\sum_{s=\frac{n+m+1}{2}-s_M} \binom{n}{s} 0.5^n \end{array} \right) \right) \geq 0$$

∎

Proposition 2 If individual decisional skills are highly heterogeneous, communication in a two-stage voting procedure increases the accuracy of the collective decision to be made by a committee where more-skilled members are in minority so that it is as high as if a weighted voting rule were applied. This is because communication changes the rational behavior of committee members: the less-skilled individuals choose to follow the common position of the more-skilled ones.

Proof. If communicated prior to the vote in the full committee, the position on interest rates taken by the subgroup implies an additional piece of information about the likely state of the economy for the less-skilled members. Therefore individual voting behavior of the committee members changes:

Knowing that the more-skilled members have agreed on option B and that she is pivotal, a less-skilled individual will vote informatively if and only if the following conditions are met:

$$P_{i\in N}(b|B, CB, \text{pivotal}) \geq 0.5$$
$$P_{i\in N}(a|A, CB, \text{pivotal}) \geq 0.5$$

where

$$P_{i\in N}(b|B, CB, \text{pivotal}) = \frac{q_i P(CB|b) q_N^{\frac{n+m-1}{2}-m}(1-q_N)^{\frac{n+m-1}{2}}}{\left(\begin{array}{c} q_i P(CB|b) q_N^{\frac{n+m-1}{2}-m}(1-q_N)^{\frac{n+m-1}{2}} \\ +(1-q_i)P(CB|a)(1-q_N)^{\frac{n+m-1}{2}-m} q_N^{\frac{n+m-1}{2}} \end{array}\right)}$$

$$P_{i\in N}(a|A, CB, \text{pivotal}) = \frac{q_i P(CB|a) q_N^{\frac{n+m-1}{2}}(1-q_N)^{\frac{n+m-1}{2}-m}}{\left(\begin{array}{c} q_i P(CB|a) q_N^{\frac{n+m-1}{2}}(1-q_N)^{\frac{n+m-1}{2}-m} \\ +(1-q_i)P(CB|b) q_N^{\frac{n+m-1}{2}-m}(1-q_N)^{\frac{n+m-1}{2}} \end{array}\right)}$$

Since the setup is symmetric, the same conditions define the optimal strategy of a less-skilled individual in case the consensual position is A, since $P_{i\in N}(b|B, CA, \text{pivotal}) = P_{i\in N}(a|A, CB, \text{pivotal})$ and $P_{i\in N}(a|A, CA, \text{pivotal}) = P_{i\in N}(b|B, CB, \text{pivotal})$. In case no consensual position is presented, the results of Austen-Smith and Banks (1996) apply and the optimal strategy is to vote informatively.

The conditions for the optimality of informative voting can be solved to yield the following restrictions on the relationship between average skill levels and sizes of the two subgroups:[22]

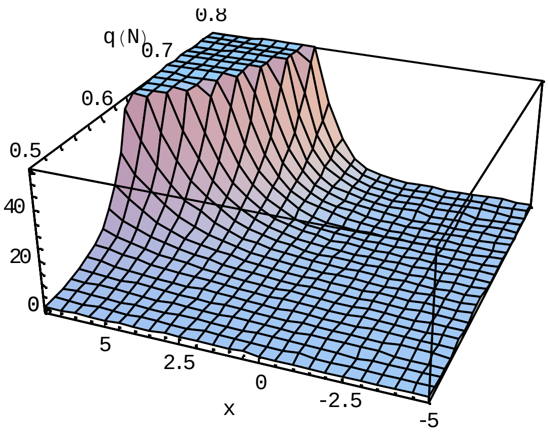
$$\left(\frac{q_N}{1-q_N}\right)^{1-m} \leq \frac{\sum_{s_M=\frac{m}{2}+1}^{m}\binom{m}{s_M} q_M^{s_M}(1-q_M)^{m-s_M}}{\sum_{s_M=\frac{m}{2}+1}^{m}\binom{m}{s_M} q_M^{m-s_M}(1-q_M)^{s_M}} > 1$$

$$\left(\frac{q_N}{1-q_N}\right)^{m+1} \geq \frac{\sum_{s_M=\frac{m}{2}+1}^{m}\binom{m}{s_M} q_M^{s_M}(1-q_M)^{m-s_M}}{\sum_{s_M=\frac{m}{2}+1}^{m}\binom{m}{s_M} q_M^{m-s_M}(1-q_M)^{s_M}} > 1$$

It is obvious that these conditions are not necessarily simultaneously satisfied. First, for $q_N \to 0.5$ (i.e. for highly heterogeneous skills), only the

[22] Assuming $q_i \to q_N$.

first condition will be satisfied, since $\left(\frac{q_N}{1-q_N}\right)\Big|_{q_N \to 0.5} \to 1$. Secondly, if q_N increases (and approaches q_M), $\left(\frac{q_N}{1-q_N}\right)^{1-m}$ quickly explodes (as can be seen in the figure below, where the expression $\left(\frac{q_N}{1-q_N}\right)^{x}$ is drawn) and violation of the first constraint becomes increasingly likely, while the second inequality becomes easily satisfied.



We therefore observe that for highly heterogeneous skills, the second condition for the optimality of informative voting is likely to be violated. In this case we have $P_{i \in N}(b|B, CB, \text{pivotal}) \geq 0.5$ and $P_{i \in N}(a|A, CB, \text{pivotal}) \leq 0.5$, and the optimal strategy for an individual $i \in N$ is to vote for B regardless of her private information, i.e. to follow the common position of the more-skilled members. Hence, informative voting is not the best response to informative voting by other players, and it is not a Nash equilibrium.

In searching for a Nash equilibrium we first note that following the position of the more-skilled members is the best response of a less-skilled individual if other less-skilled members have chosen to follow as well. In such a situation a less-skilled individual is never pivotal. Following the more-skilled members trivially becomes her optimal voting strategy.

Although the optimal strategy of less-skilled members obviously changes in response to the additional information, communication does not affect the strategy of more-skilled members, i.e. their optimal choice still is to vote informatively. This is because an individual board member's vote is pivotal in the same (m) cases, when his vote makes the difference between a common position or no common position in the subgroup and the votes in the full committee are split in such a way that in the case of no consensus in the subgroup the other alternative wins. In order to illustrate the fact that a more-skilled individual is pivotal in exactly the same cases as when there is no communication, we construct a table analogous to the one in section 3.1

with all cases when a member of a 6-person subgroup is pivotal for the final decision when communication is involved:

Case		Votes for B	Votes for A
	Sub-group	3	2
1	Other members	$\frac{n-1}{2}$	$\frac{n+1}{2}$
	i votes B	$\boxed{n+6}$	0
	i votes A	$\frac{n-5}{2}$	$\boxed{\frac{n+7}{2}}$
2	Other members	$\frac{n-3}{2}$	$\frac{n+3}{2}$
	i votes B	$\boxed{n+6}$	0
	i votes A	$\frac{n+3}{2}$	$\boxed{\frac{n+9}{2}}$
3	Other members	$\frac{n-5}{2}$	$\frac{n+5}{2}$
	i votes B	$\boxed{n+6}$	0
	i votes A	$\frac{n-1}{2}$	$\boxed{\frac{n+11}{2}}$

Case		Votes for B	Votes for A
	Sub-group	2	3
4	Other members	$\frac{n+1}{2}$	$\frac{n-1}{2}$
	i votes B	$\boxed{\frac{n+7}{2}}$	$\frac{n+5}{2}$
	i votes A	0	$\boxed{n+6}$
5	Other members	$\frac{n+3}{2}$	$\frac{n-3}{2}$
	i votes B	$\boxed{\frac{n+9}{2}}$	$\frac{n+3}{2}$
	i votes A	0	$\boxed{n+6}$
6	Other members	$\frac{n+5}{2}$	$\frac{n-5}{2}$
	i votes B	$\boxed{\frac{n+11}{2}}$	$\frac{n-1}{2}$
	i votes A	0	$\boxed{n+6}$

Comparison to the table in section 3.1. reveals that in all 6 cases the votes of all committee members other than member i are split in exactly the same way as when the communication stage is not included. As a result, the conclusions about optimal voting strategy made in section 3.1 hold in the setup enlarged by communication.

Therefore the equilibrium of the two-stage voting game with communication is: (1) informative voting of the more-skilled members and (2) informative voting/following the more-skilled members for the less-skilled individuals. As we have already indicated, this is an equilibrium if and only if the skills are sufficiently heterogeneous (the case of the less-than-sufficient heterogeneity will be dealt with in the next proposition).

Under this new equilibrium behaviour, the probability that the committee takes the correct decision is given by:

$$
\begin{aligned}
P^{COM}(B|b)|_{q_N \to 0.5} &\to \sum_{s_M=\frac{m}{2}+1}^{m} \binom{m}{s_M} q_M^{s_M}(1-q_M)^{m-s_M} + 0.5\binom{m}{\frac{m}{2}} q_M^{\frac{m}{2}}(1-q_M)^{\frac{m}{2}} \\
&= P^{FB}(B|b)|_{q_N \to 0.5}
\end{aligned}
$$

■

Proposition 3 If individual decisional skills are relatively homogeneous, communication accentuates the adverse effects that the two-stage decision-making process has on the accuracy of the collective decision, as the rational choice of the 'less-skilled' committee members is to vote against the consensual position of the 'more-skilled' ones.

Proof. Under the assumption of comparable average skills, i.e. $q_i \to q_N \to q_M$, the condition $P_{i \in N}(b|B, CB, \text{pivotal}) \geq 0.5$ will be violated and the condition $P_{i \in N}(a|A, CB, \text{pivotal}) \geq 0.5$ will hold (see the proof to proposition 2). It is thus optimal for the 'less-skilled' individuals to vote against the consensual position of the 'more-skilled' members, e.g. to vote A when the other group collectively supports decision B. As in the case $q_N \to 0.5$, the optimal voting strategy of the 'more-skilled' members remains unaffected by the subsequent communication. The table below again presents the cases when a member of 6-person subgroup is pivotal for the final decision:

Case		Votes for B	Votes for A
	Sub-group	3	2
1	Other members	$\frac{n+1}{2}$	$\frac{n-1}{2}$
	i votes B	6	$\boxed{n}$
	i votes A	$\boxed{\frac{n+7}{2}}$	$\frac{n+5}{2}$
2	Other members	$\frac{n+3}{2}$	$\frac{n-3}{2}$
	i votes B	6	$\boxed{n}$
	i votes A	$\boxed{\frac{n+9}{2}}$	$\frac{n+3}{2}$
3	Other members	$\frac{n+5}{2}$	$\frac{n-5}{2}$
	i votes B	6	$\boxed{n}$
	i votes A	$\boxed{\frac{n+11}{2}}$	$\frac{n+1}{2}$

Case		Votes for B	Votes for A
	Sub-group	2	3
4	Other members	$\frac{n-1}{2}$	$\frac{n+1}{2}$
	i votes B	$\frac{n+1}{2}$	$\boxed{\frac{n+7}{2}}$
	i votes A	$\boxed{n}$	6
5	Other members	$\frac{n-3}{2}$	$\frac{n+3}{2}$
	i votes B	$\frac{n+3}{2}$	$\boxed{\frac{n+9}{2}}$
	i votes A	$\boxed{n}$	6
6	Other members	$\frac{n-5}{2}$	$\frac{n+5}{2}$
	i votes B	$\frac{n+1}{2}$	$\boxed{\frac{n+11}{2}}$
	i votes A	$\boxed{n}$	6

Under the new kind of optimal voting behaviour of the 'less-skilled' committee members, the votes of all committee members other than member i are split in a somewhat different way than before. Nevertheless, it still holds that

$$P_{i2M}(\text{pivotal}|a) = P_{i2M}(\text{pivotal}|b) = P_{i2M}(\text{pivotal})$$

and hence

$$P_{i2M}(b|B, \text{pivotal}) = P_{i2M}(a|A, \text{pivotal}) = q_{i2M}$$

As a result, the new equilibrium behaviour is for the 'more-skilled' members to vote informatively and for the 'less-skilled' individuals to vote strategically: against the common position of the 'more-skilled' subgroup, should one be presented. The probability that the committee takes the correct decision is now given by:

$$\begin{aligned} P^{COM}(B|b)|_{q_N \to q_M} = & \sum_{s_M=\frac{m}{2}+1} \binom{m}{s_M} (1-q_M)^{s_M} q_M^{m-s_M} \\ & + \binom{m}{\frac{m}{2}} q_M^{\frac{m}{2}} (1-q_M)^{\frac{m}{2}} \sum_{s=\frac{n+1}{2}} \binom{n}{s} q_M^{s} (1-q_M)^{n-s} \end{aligned}$$

Communication, therefore, does more damage to the collective decision-making compared to our 2-tier set-up without communication, since $P(B|b)|_{q_N \to q_M} \geq P^{COM}(B|b)|_{q_N \to q_M}$:

$$\begin{aligned} & P(B|b)|_{q_N \to q_M} - P^{COM}(B|b)|_{q_N \to q_M} \to \\ + & \sum_{s_M=\frac{m}{2}+1} \binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \sum_{s=\frac{n-m+1}{2}} \binom{n}{s} q_M^{s} (1-q_M)^{n-s} \\ - & \sum_{s_M=\frac{m}{2}+1} \binom{m}{s_M} (1-q_M)^{s_M} q_M^{m-s_M} \sum_{s=\frac{n-m+1}{2}} \binom{n}{s} (1-q_M)^{s} q_M^{n-s} \geq 0 \end{aligned}$$

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