ESSAYS ON THE MAKING AND IMPLEMENTATION OF MONETARY POLICY DECISIONS

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Essays on the Making and Implementation of Monetary Policy Decisions

Essays over het nemen en uitvoeren van monetaire beleidsbeslissingen

Thesis

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I will not be original in acknowledging that many people contributed to the success of this project.

Some people took a gamble by giving me the chance to do it in the first place, some provided enthusiastic guidance and support, some lent their ears to my frustrations, some supplied powerful boosts of energy, confidence and inspiration, some worked hard on reshaping my views (not only on economics), some simply bore with me in a loving way.

I cannot even assume to be able to mention everybody by name.

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Chapter 1

Introduction

According to the recent book by Professor Alan S. Blinder "The Quiet Revolution. Central Banking Goes Modern" published in 2004 "...one of the hallmarks of the quiet revolution in central banking practice has apparently been a movement toward making decisions by committee, whereas previously the dictatorial central bank governor was more the norm..." (Blinder (2004), p. 35). To put this conclusion in numbers: a study carried out by the Bank of England has shown that 79 out of 88 (that is 90%) central banks have committees (Fry et al. (2000)).

The transition to collective decision making requires that central banking in general and monetary policy in particular should be analyzed in a number of additional dimensions. As interest rate decisions are no longer taken by a single individual, a number of issues arise, related for example to an appropriate and efficient aggregation of diverse preferences, diverse beliefs about models of the economy and likely future developments. This puts yet another question to the validity of the "...traditional economic analysis [that] takes the behavior of policy makers, in particular the behavior of monetary policy makers, as exogenous..." (as argued earlier by Cukierman (1992), p. 1)

The behavior of policy makers has been traditionally analyzed by political economy. According to Cukierman (1992), in the 1980s 'new political economy' emerged, characterized by the use of modern tools such as game theory and econometrics. The change produced a number of highly influential ideas regarding the proper design of a monetary institution.[1] One of the earlier proposals was to delegate monetary policy to an independent

[1] For a comprehensive review of monetary policy institutions, see e.g. Persson and Tabellini (1999).

and conservative central banker (Rogoff (1985)). Its impact cannot be underestimated: according to Maxfield (1997), 34 countries have increased operational independence of their central banks between 1989 and 1999, compared to only 3 such changes in the 1980s (see also Cukierman (1998)). A more recent idea is assigning an explicit (inflation) target to a central bank (Svensson (1997)). Such a target can be enforced in a number of ways, from imposing certain transparency requirements to including a clause in the contract offered to a central bank governor, which stipulates his dismissal in case the target should be missed (as is the case in New Zealand). Explicit inflation targeting has become increasingly popular over the 1990s: according to Fry et al. (2000) 6 out of 84 (7%) central banks had inflation targets in 1990 and only 1 (New Zealand) had a sole inflation target, while eight years later the proportion was 54 out of 94 (57%), with 11 sole inflation targeters.

The above solutions have been designed to improve policy outcomes by producing the following two effects: (1) raising the cost of a deviation from the pre-announced policy path: under rational expectations, public anticipation of such deviation produces undesirable macroeconomic outcomes ('biases'), and, at the same time, (2) allowing for a safe degree of 'constrained discretion', which is necessary in the ever more complicated world where all possible future states cannot be foreseen (see e.g. Fischer (1995) and King (2004)). Still, successful as they are, these solutions stem from an analysis that is limited to investigating interactions between one economic and one political party, and they do not account for the fact that an economic party constitutes of a number of individuals.

It seems plausible to presume that political economy is entering yet another stage in its development, dominated by an analysis of interactions between individuals comprising an economic party, such as a monetary policy committee. The main contribution from this stage could be a set of rules for a proper design of a committee, such that it would foster the safe degree of 'constrained discretion' which monetary institutions are supposed to provide. Uncertainty characterizing our environment makes a committee inarguably valuable as the means to aggregate necessarily diffuse expertise; instituting efficient procedures and decision rules for the committee makes it possible to obtain monetary policy decisions which are superior in terms of accuracy to the ones taken by an individual. There is already some evidence available on the superiority of collective decisions, in the form of laboratory experiments. Blinder and Morgan (forthcoming) have tested two hypotheses in order to provide the reason behind the observed proliferation of collective decision making in monetary policy: (i) Are group decisions (on average) more accurate than individual decisions? and (ii) Does the collective character of the process affect (read: increase) the delay with which decisions are reached? The experiments have shown that not only groups did make better decisions, they also did not require more data (and time) to reach them. As a matter of fact, as experiment participants improved their knowledge of the game they played, groups have become statistically significantly faster in reacting to events.

Blinder and Morgan (forthcoming) have also touched on issues related to the design of a committee: decision rules and deliberations. Their experiment has shown that "... for whatever reason, majority decisions quickly evolved into unanimous decisions..." (p. 20). The authors have compared the results of experiments with theoretical predictions from a number of models: the whole is equal to the average of its parts, the median voter theory, and 'may the best man win'. None of them provided a satisfactory explanation: the accuracy of group decisions exceeded both the average of individual scores and the median score that would be obtained under pure simultaneous voting. Another experiment, carried out at the Bank of England, provides other valuable insights into collective decision making processes. Lombardelli et al. (2002) found that "...collective decision making appears to give more weight to the better and less weight to the worse committee members - as judged by their scores when playing the game as individuals..." (p. 7). For this reason simple averaging of individual scores falls short of collective outcomes. The authors have also documented "...evidence that committees do more than this, enabling all members to improve their performance by sharing information and learning from each other..." (p. 7).

The results summarized in the last paragraph teach us that "...not all committees are created equal..." (Blinder (2004), p. 54). Hence, a particular design of the institution of a monetary policy committee is likely to affect its performance and the quality of decisions that it delivers. In chapters 2 and 3 of this thesis we will investigate the consequences of committee structure and decision rules on the accuracy of its decisions and we will provide recommendations regarding different procedures and possible trade-offs involved. In particular, in chapter 2 we will discuss the most efficient design of a monetary policy committee structure, such that it gives the appropriate attention to differences in individual decision makers' beliefs, information and skills. We will also show that attaching different weights to different opinions as well as following opinions of other committee members may be perfectly rational, and, more importantly, quality-improving, choices. In chapter 3 we will formally assess the effects of sharing and pooling diverse information and expertise that the committee has at its disposal.

In the final chapter of this thesis we will look at another institutional aspect of monetary policy making: we will investigate central bank control of short-term interest rates. By focusing on the implementation of monetary policy decisions, this study nicely complements the analysis presented in chapters 2 and 3.

In the last ten to fifteen years, monetary policy implementation has entered a new stage: "...an approach which is new in its clarity, theoretical foundation, and acceptance by almost all central banks..." (Bindseil (2005), pp. 234-235). The 'new view' has broken up with the tradition of controlling quantitative measures of money supply and put forward a short-term interest rate as the appropriate operational target. This target has been postulated to be universal and independent of the monetary strategy chosen by the central bank. Moreover, the 'new view' considers standing facilities, open market operations and required reserves as the appropriate instruments for steering short-term interest rates.

The design of the operating framework has been and will be affected by innovations in financial markets. However, the 'new view' is likely to remain relatively robust to some developments, for example to the possible disappearance of the demand for central bank's reserves. Woodford (2001), among others, argues that in such a case the 'corridor' system set by official interest rates on central bank's standing facilities will still remain effective in steering the short-term interest rate towards the desired level. Within such framework, central banks can still choose the mix of the level and characteristics of reserve requirements, the type and frequency of open market operations and the width of the corridor (Bindseil (2005)). Indeed, in chapter 4 we will show and analyze an example of two largely different operating frameworks used by the European Central Bank and the Federal Reserve which deliver comparable precision of interest rate control. The European Central Bank has a symmetric wide corridor set by interest rates on standing facilities, relatively large reserve requirements with averaging provisions and weekly open market operations. The Federal Reserve operates under an asymmetric corridor (i.e. with only one interest rate), no reserve requirements and daily open market operations.

This thesis consists of two connected parts, each contributing to our understanding of a particular institutional aspect of modern monetary policy making, where a **committee** of policy makers decides on a short-term **interest rate**, and this decision is subsequently implemented in the money market with the use of **open market operations** and other instruments.

Chapter 2

Hub-and-spokes monetary policy committees

[1]

> "...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..."[2]

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 as '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. Blinder (2004) argues that individual committee members might differ in their (voting) behavior due to differing preferences, different models, different forecasts or different capabilities to process information.

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

[1] This chapter is a version of a paper published as a DNB Working Paper, No. 27, January 2005, co-authored by Jan Marc Berk.

[2] Janis (1982), p. 274

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[3], 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.

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[4] 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 to produce a common 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 Janis (1982) to prevent a detrimental concurrence-seeking group dynamics, labelled as groupthink. 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,

[3]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.

[4]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.

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 than 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 central bank behavior 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 behavior of individuals that together form a monetary policy committee. These authors focus on the case in which committee members have common abilities but different preferences, which may lead to different voting behavior, see also von Hagen and Süppel (1994) and Grüner (1999). Our work by and large forms the complement to this approach as we focus on the situation in which committee members have common preferences but different abilities, and thus may vote differently. See in this respect also the work of Gersbach and Hahn (2001a,b). 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 a methodological point as well. A prominent exception is a 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 2.1 below describes the basic model and illustrates the suboptimality of simple majority voting in a monetary policy committee with heterogeneous members. Section 2.2 proposes an alternative institutional set-up, and explores the (rationality of the) voting behavior of members in this alternative regime. Section 2.3 presents the consequences of our alternative structure of the monetary policy committee for the quality of monetary policy, and section 2.4 concludes. Proofs of propositions can be found in the appendix (section 2.5).

2.1 Effects of a suboptimal decision rule

In a monetary policy committee, members are presented with evidence concerning the state of the economy. 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 in fact requires a change in rates. The committee member must also consider the likely effect of her vote on the final 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 be modelled using Bayesian game theory, see for example Osborne (2004) and Hirschleifer and Riley (1992).

Our setup is a modification 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 furthermore follow the literature and assume that committee members have identical prior beliefs regarding the appropriate monetary policy stance.[6] Of course this prior belief may and in general will 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, i.e. in favour of a change in interest rates (signal A) in state a and in favour for unchanged rates (signal B) in state b:

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

We label the q_i as individual decisional skills.[7] In terms of the reasons given by Blinder (2004) for heterogeneity of committee members' voting behavior, our skill differential can

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

[6] This assumption is formalised by symmetric priors: $\forall i : P_i(a) = P_i(b) = 0.5$. For an analysis of heterogenous priors, see Li, Rosen and Suen (2001).

[7] We assume $0.5 < q_i < 1$. This restriction on individual decisional skills implies that forming a committee to take the particular decision is useful. If $q_i = 0.5$, then the decision could be taken by

be interpreted as stemming from differences in the way information is processed. Suppose furthermore that individual committee members can be ordered according to their skills and be clustered into 2 non-overlapping subgroups. That is, the committee is comprised of m more-skilled and n less-skilled members.[8] 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 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 convenes a single time, and decides only on interest rates, via a simultaneous voting procedure. Also, assume m is an even number and n is odd. In order to simplify the analysis, we fix $m = 6$ and analyze the effects of variations in n.[9]

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. Put differently, she strictly prefers the two appropriate policy outcomes over the two bad ones. 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

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tossing a coin as many times as we have members. If $q_i = 1$, then one individual would be sufficient to take a perfectly correct decision. The assumption $0 < q_i < 0.5$ yields analogous results, except that the actual decision should be the opposite to the one chosen by the committee. See also Ladha (1992).

[8] It has been shown (see Grofman et al. (1983)) that the accuracy of the collective decision taken by a committee where individuals have heterogeneous decisional skills can be expressed in terms of the average of their skill levels, $q = \frac{1}{n+m}\sum_{i=1}^{n+m} q_i$, if individual skills q_i are independently drawn from the following (normal) distribution: $q_i \sim N(q, \frac{q(1-q)}{m+n})$.

The important assumption here is that the distribution of individual skills has second and higher moments that are negligible. This results in a clustering of individual skill levels around the mean and makes the approximation relatively accurate.

In our analysis we will use the subgroup averages, denoted by q_M and q_N respectively. Hence, our approximation will by assumption be more accurate than the approximation of Grofman et al. using one average skill level, since clustering of committee members into two non-overlapping sub-groups results in the reduction of skill dispersion within the subgroups (relative to the skill variance in the whole committee), i.e. $\sigma_M^2 < \sigma_i^2$, $\sigma_N^2 < \sigma_i^2$, where $\sigma_i^2 = \frac{1}{n+m}\sum_{i=1}^{n+m}(q_i - q)^2$. Ordering results in the skill bias, i.e. the difference in the average skill levels between the sub-groups: $q_M \geq q_N$.

[9] $m = 6$ is chosen as it corresponds to the size of the 'hub' in real-life examples. More specifically, the Executive Board of the ECB has 6 members.

Bernoulli payoffs for each committee member:[10]

$$u_i\left(X|x\right)=\begin{cases}1 \text{ if } X=B \text{ and } x=b \text{ or if } X=A \text{ and } x=a\\ 0 \text{ if } X=A \text{ and } x=b \text{ or if } X=B \text{ and } x=a\end{cases} \tag{2.1}$$

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.[11] Weighted majority maximizes the gains from aggregating individual heterogeneous expertise. However, in most real-life situations, and in particular in monetary policy committees, votes are not weighted according to decisional skills. Instead, decisions are taken by simple majority. It can be shown[12] 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 2.1, which presents on the vertical axis the probability of an accurate collective decision (interpreted as the quality of monetary policy and represented by the conditional probability that the committee takes a correct decision) under both simple majority[13] (dotted lines) and the optimal rule, i.e. weighted majority[14] (solid lines). The

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

[11] The weight should be calculated as $w_i=\ln\left(\frac{q_i}{1-q_i}\right)$.

[12] 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).

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

[14] That is, $P^{FB}(B|b)=$

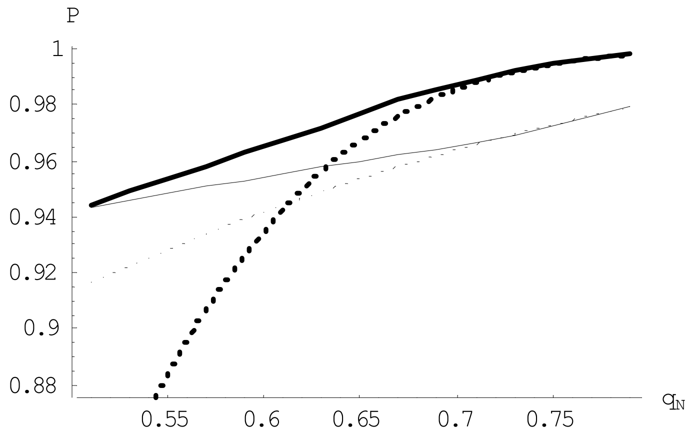

Figure 2.1: Probability of an accurate interest rate decision under weighted and simple majority

horizontal axis measures the skill bias, i.e. the differential between the average skill level of the higher and the lower skilled group. We present 2 cases, depending on the size of the less-skilled group, i.e. $n = 3$ (thin lines) and $n = 13$ (thicker lines).

Comparing the solid lines with the dotted ones, it can be seen that the loss in accuracy of the collective decision can be quite substantial 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.

2.2 Individual voting behavior

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. See Meyer (2004) for evidence that

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$$\sum_{s_M=0}^{m}\left(\binom{m}{s_M} q_M^{s_M}\left(1-q_M\right)^{m-s_M} \sum_{s=\left\lceil \frac{1}{2}\left(n+\frac{w_M}{w_N}(m-s_M)\right)\right\rceil}^{n} \binom{n}{s} q_N^{s}\left(1-q_N\right)^{n-s}\right)$$

$= P^{FB}(A|a)$, 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 2.1 in the appendix). FB refers to the first best decision rule, i.e. weighted majority.

such a pre-committee meeting of a subgroup, in this case the Board of Governors, is relevant for the US. We assume that both the subgroup and the full committee decide using a simple majority voting rule,[15] 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.

As the formal monetary policy decision has to be taken by the full committee, the subgroup has the option to decide 'not to decide'. Given the size of this group, which is even by assumption (6 to be exact), the meeting of the subgroup thus can generate three outcomes. 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.[16] 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) common position for a correct decision (e.g. status quo in state b: $P(CB|b)$), (2) common position for an incorrect decision (e.g. a change in interest rates in state b: $P(CA|b)$), and (3) no common position (i.e. $P(NC|b)$).[17] Formally, the probabilities are given by:

$$P(CB|b) = P(CA|a) = \sum_{\substack{S_M \subset M \\ s_M \geq \frac{m}{2}+1}} \prod_{i \in S_M} q_i \prod_{i \notin S_M} (1-q_i) \tag{2.2}$$

$$P(CA|b) = P(CB|a) = \sum_{\substack{S_M \subset M \\ s_M \geq \frac{m}{2}+1}} \prod_{i \in S_M} (1-q_i) \prod_{i \notin S_M} q_i \tag{2.3}$$

$$P(NC|b) = P(NC|a) = 1 - P(CB|b) - P(CA|b) \tag{2.4}$$

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

[15] The assumption of simple majority voting in the full committee obviously is essential. The same does not apply for the subgroup, we use the simple majority assumption mainly for reasons of simplicity.

[16] Meade and Sheets (forthcoming) present an interesting analysis of voting behaviour within monetary policy committees of actual central banks, including dissenting behaviour.

[17] 'CB' stands for 'consensus for decision B', 'CA' for 'consensus for decision A' and 'NC' for 'no consensus'.

of the three actions as:

$$P(CB|b) = P(CA|a) = \sum_{s_M=\frac{m}{2}+1}^{m} \binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \tag{2.5}$$

$$P(CA|b) = P(CB|a) = \sum_{s_M=\frac{m}{2}+1}^{m} \binom{m}{s_M} q_M^{m-s_M} (1-q_M)^{s_M} \tag{2.6}$$

$$P(NC|b) = P(NC|a) = \binom{m}{\frac{m}{2}} q_M^{\frac{m}{2}} (1-q_M)^{\frac{m}{2}} \tag{2.7}$$

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 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:

$$P(B|b) = P(B \cap CB|b) + P(B \cap CA|b) + P(B \cap NC|b) \tag{2.8}$$

where:

$$P(B \cap CB|b) = P(CB|b) \sum_{\substack{S \subset N \\ s \geq \frac{n+m+1}{2} - m}} \prod_{i \in S} q_i \prod_{i \notin S} (1-q_i) \tag{2.9}$$

$$P(B \cap CA|b) = P(CA|b) \sum_{\substack{S \subset N \\ s \geq \frac{n+m+1}{2}}} \prod_{i \in S} q_i \prod_{i \notin S} (1-q_i) \tag{2.10}$$

$$P(B \cap NC|b) = P(NC|b) \sum_{\substack{S \subset N-M \\ s \geq \frac{n+1}{2}}} \prod_{i \in \mathbb{S}} q_i \prod_{i \notin S} (1-q_i) \tag{2.11}$$

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 each subgroup, q_M and q_N analogously to formulas (2.5)-(2.7).

Equations (2.8)-(2.11) 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, i.e. that they vote informatively.[18] The lemma below indicates that this voting procedure possesses desirable equilibrium properties.

Lemma 2.1 *Informative voting constitutes a Nash equilibrium in the two-tier voting setup, provided that the interest rate decision is taken by simple majority.*

Proof. See appendix. ■

2.3 Quality of collective monetary policy decisions

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 2.1 below.

Proposition 2.1 *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 2.2 illustrates proposition 2.1, using numerical assumptions identical to the ones underlying figure 2.1. The figure again relates the quality of the collective decision (vertical axis) to the average decisional skills of the less-skilled committee members (horizontal axis). 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, and the latter illustrates a committee dominated by the spokes.

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

[18] Austen-Smith and Banks (1996) provide a formal definition of informative voting. In our notation, a voting strategy v_i is informative if $v_i(s_i = A) = A$ and $v_i(s_i = B) = B$.

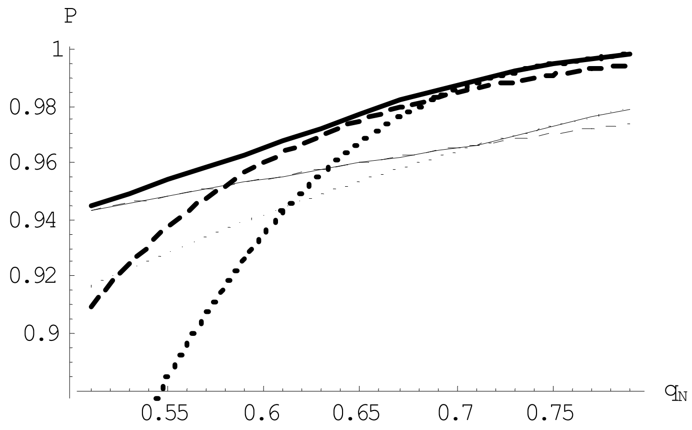

Figure 2.2: Probability of an accurate interest rate decision under weighted majority, simple majority and two-stage voting

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 2.2 *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.*

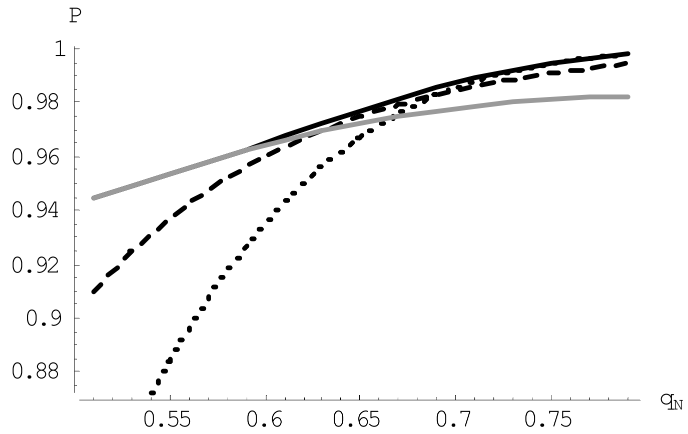

Figure 2.3: Probability of an accurate interest rate decision under four decision-making rules

Proof. See appendix. ■

Again we illustrate the results from proposition 2.2 graphically in figure 2.3: we reproduce the lines from figure 2.2 drawn for the larger committee of 19 individuals and introduce a solid gray line for the two-tier setup with communication stage.

Figure 2.3 illustrates the fact that communication yields the highest accuracy of the collective decision for the lowest average skills of the less-skilled members. As we move from left to right on the horizontal axis (the skill bias decreases) the optimal decision procedure changes from two-tier voting with communication, through two-tier voting without communication, to simple majority voting. 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. This is because the (opportunity) cost of following a common position, i.e. giving up one's own assessment of the economic situation, increases as the skill advantage of the group that forms the common position decreases.

In any case, institutional amendments can overcome the inefficiency in the use of information and restore the efficient bias towards the more-skilled committee members. This, however, does not mean that delegating the decision to the more-skilled committee members is desirable.

Proposition 2.3 *Only when decisional skills of committee members are very unevenly distributed (e.g. if $q_N \sim 0.5$) will delegation of monetary policy decisions to the more-skilled members improve the quality of monetary policy. In all other cases, delegation is most likely to yield worse results than a decision made by the full monetary policy committee, either by simple majority or by two-stage voting.*

Proof. See appendix. ■

Both propositions 2 and 3 have clear implications for monetary policy. They also illustrate a fundamental result in the theory of information, due to Blackwell.[19] Loosely interpreted, Blackwell's theorem states that ignoring information is detrimental. Take proposition 2.3 as an example. Under our assumptions, the less-skilled members bring valuable expertise to the full committee meeting (although it is relatively less valuable than the knowledge of the more-skilled members), so ignoring it will in most cases imply a less informed decision.

Our proposal thus approximates the infeasible optimal decision rule of weighted voting by reinforcing the position of the higher skilled MPC members. Furthermore, 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

[19] Blackwell (1951), (1953). See also Hirschleifer and Riley (1992) and Bielinska-Kwapisz (2003) for recent expositions.

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 2.3: for a skill bias smaller than 0.11 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.

2.4 Discussion

The key idea underlying the analysis presented above is the suggestion of Blinder (2004) that members of monetary policy committees might differ 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. In addition, it has been argued (see Hefeker (2003)) that hub-and-spokes central banks, and corresponding monetary policy committees, reflect 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 oriented towards processing macro-economic information (i.e. regarding the currency area as a whole), with the spokes bringing more micro-economically oriented decision-making methods to the table. This is well-documented for the US. Presidents of the Federal Reserve Banks (the spokes) are selected by the boards of these regional banks, and (6 out of 9) of these board members are appointed by the regions themselves and supposed to represent local (banking, industry, agriculture and commerce) interests in mind, see Mayer (2001) and Chappell et al. (2005) for details.[20] The thrust of this

[20] As Mayer (2001, p. 145) notes, there has been some discussion in the US relating to the fact that the FOMC is seen as: '... a committee that makes the key decisions on ... interest rates with almost half of its members chosen by local boards of directors of whom two-thirds are bankers or bankers' representatives.' Meade and Sheets (forthcoming) analyse and confirm the importance of regional considerations for the

argument is not so much that there is an informational asymmetry, but rather a difference in information processing methods due to different 'mind sets'.[21] Finally, note that our set-up can be also applied to the situation in which one of the members has relatively superior skills, in our terminology, $m = 1$. This can be interpreted as the situation in which the committee has a chairman that dominates in terms of abilities, as some argue is the case under the current FOMC chairman.

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.[22] 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 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

US case.

[21] Chappell et al. (1993, 1995) argue that 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. We find this argument less convincing, as it seems unlikely that (given equal preferences of members) this information is not shared in the meeting.

[22] Ultimately, the existence of a skill bias is an empirical question. Unfortunately, an empirical analysis is impossible to do for the euro area, given the fact that minutes and/or voting records of the policy meetings are not published. For the US, Chappell et al. (2005) find no evidence of difference in 'power' of Governors and voting Federal Reserve Bank presidents. However, it is difficult to relate this to skill differentials, as there is also evidence that such a bias in the US case would not show up in voting records, as dissenting votes are seen as a revolt to the leadership of the chairman (Meyer (2004)).

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, De Nederlandsche Bank (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.

2.5 Appendix. Proofs to propositions

Lemma 2.1 *Informative voting constitutes a Nash equilibrium in the two-tier voting setup, provided that the interest rate decision is taken by simple majority.*

Proof. 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).[23] 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 (see equation 2.1). In the latter cases, the vote of individual i changes the collective outcome (i.e. is pivotal)[24] 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.

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

[24] Formally, a vote v_i is pivotal if $P(A) = 1 \Leftrightarrow v_i = A$ and $P(B) = 1 \Leftrightarrow v_i = B$, where $P(A)$ $(P(B))$ denotes the probability that the committee will take decision A (B).

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.[25] The latter consists of her own signal and the information deduced from the fact that her vote is pivotal.[26] Informative voting constitutes a rational choice if the following conditions are met:[27]

$$P_{i\in N}\left(b|s_i = B, \text{pivotal}\right) \geq 0.5 \tag{2.12}$$

$$P_{i\in N}\left(a|s_i = A, \text{pivotal}\right) \geq 0.5 \tag{2.13}$$

where

$$P_{i\in N}\left(b|s_i = B, \text{pivotal}\right) = \frac{P_i(b)q_iP_{i\in N}(\text{pivotal}|b)}{P_i(b)q_iP_{i\in N}(\text{pivotal}|b)+P_i(a)(1-q_i)P_{i\in N}(\text{pivotal}|a)} \tag{2.14}$$

$$P_{i\in N}\left(a|s_i = A, \text{pivotal}\right) = \frac{P_i(a)q_iP_{i\in N}(\text{pivotal}|a)}{P_i(a)q_iP_{i\in N}(\text{pivotal}|a)+P_i(b)(1-q_i)P_{i\in N}(\text{pivotal}|b)} \tag{2.15}$$

Informative voting constitutes a Nash equilibrium if the conditions (2.12)-(2.13) hold when the probabilities are evaluated under the assumption that all (other) committee members vote informatively. This is shown formally below.

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 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 (remember that $m = 6$ and n is odd throughout), depending on the earlier decision of the more-skilled subgroup (see

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

[26]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.

[27]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).

equations (2.8)-(2.11)): (1) if the more-skilled subgroup has taken the correct position and the votes of the less-skilled members are split $\frac{n+m-1}{2}-m$ for the correct decision and $\frac{n+m-1}{2}$ against, (2) if the more.-skilled members have taken the incorrect decision and the less-skilled members are split: $\frac{n+m-1}{2}$ voting for the correct decision and $\frac{n+m-1}{2}-m$ against, and (3) if the more-skilled subgroup has not taken any common position and the less-skilled members are also split: $\frac{n-1}{2}$ voting for the correct decision and $\frac{n-1}{2}$ voting incorrectly. Hence the probability of being pivotal if all other members vote informatively is given by:

$$\begin{aligned} P_{i\in N}\left(\text{pivotal}|b\right) = P(CB|b)\tbinom{n-1}{\frac{n+m-1}{2}-m}\left(q_N^{\frac{n+m-1}{2}-m}\left(1-q_N\right)^{\frac{n+m-1}{2}}\right) \\ +P(CA|b)\tbinom{n-1}{\frac{n+m-1}{2}}\left(q_N^{\frac{n+m-1}{2}}\left(1-q_N\right)^{\frac{n+m-1}{2}-m}\right) \\ +P(NC|b)\tbinom{n-1}{\frac{n-1}{2}}q_N^{\frac{n-1}{2}}\left(1-q_N\right)^{\frac{n-1}{2}} \end{aligned} \tag{2.16}$$

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:

$$P_{i\in N}\left(\text{pivotal}|b\right) = P_{i\in N}\left(\text{pivotal}|a\right) = P_{i\in N}\left(\text{pivotal}\right)$$

Given this result and our assumption about the priors, we arrive at the following simplification of conditions (2.12)-(2.13):

$$P_{i\in N}\left(b|Bs_i =, \text{pivotal}\right) = P_{i\in N}\left(a|s_i = A, \text{pivotal}\right) = q_{i\in N} \tag{2.17}$$

By assumption $q_{i\in N} \geq 0.5$ 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.[28] This

[28] 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.

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[29] 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 taken by simple majority $\frac{n+7}{2}$):[30]

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	$\frac{n-5}{2}+3=\frac{n-1}{2}$	$\frac{n+5}{2}+3=\boxed{\frac{n+11}{2}}$

[29] 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.

[30] 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).

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 is pivotal for the interest rate decision are:

$$P_{i\in M}\left(\text{pivotal}|a\right)=\binom{m-1}{\frac{m}{2}}\left(1-q_M\right)^{\frac{m}{2}}q_M^{\frac{m}{2}-1}\sum_{s=\frac{n-m+1}{2}}^{\frac{n-1}{2}}\binom{n}{s}q_N^s\left(1-q_N\right)^{n-s}$$
$$+\binom{m-1}{\frac{m}{2}-1}\left(1-q_M\right)^{\frac{m}{2}-1}q_M^{\frac{m}{2}}\sum_{s=\frac{n+1}{2}}^{\frac{n+m-1}{2}}\binom{n}{s}q_N^s\left(1-q_N\right)^{n-s} \tag{2.18}$$

and

$$P_{i\in M}\left(\text{pivotal}|b\right)=\binom{m-1}{\frac{m}{2}}q_M^{\frac{m}{2}}\left(1-q_M\right)^{\frac{m}{2}-1}\sum_{s=\frac{n-m+1}{2}}^{\frac{n-1}{2}}\binom{n}{s}q_N^{n-s}\left(1-q_N\right)^{s}$$
$$+\binom{m-1}{\frac{m}{2}-1}q_M^{\frac{m}{2}-1}\left(1-q_M\right)^{\frac{m}{2}}\sum_{s=\frac{n+1}{2}}^{\frac{n+m-1}{2}}\binom{n}{s}q_N^{n-s}\left(1-q_N\right)^{s} \tag{2.19}$$

Since $\binom{m-1}{\frac{m}{2}}=\binom{m-1}{\frac{m}{2}-1}$, $\sum_{s=\frac{n-m+1}{2}}^{\frac{n-1}{2}}\binom{n}{s}q_N^s\left(1-q_N\right)^{n-s}=\sum_{s=\frac{n+1}{2}}^{\frac{n+m-1}{2}}\binom{n}{s}q_N^{n-s}\left(1-q_N\right)^{s}$, and $\sum_{s=\frac{n+1}{2}}^{\frac{n+m-1}{2}}\binom{n}{s}q_N^s\left(1-q_N\right)^{n-s}=\sum_{s=\frac{n-m+1}{2}}^{\frac{n-1}{2}}\binom{n}{s}q_N^{n-s}\left(1-q_N\right)^{s}$, again we have the result:

$$P_{i\in M}\left(\text{pivotal}|a\right)=P_{i\in M}\left(\text{pivotal}|b\right)=P_{i\in M}\left(\text{pivotal}\right) \tag{2.20}$$

and

$$P_{i\in M}\left(b|s_i=B,\text{pivotal}\right)=P_{i\in M}\left(a|s_i=A,\text{pivotal}\right)=q_{i\in M} \tag{2.21}$$

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. It is therefore also rational for the more-skilled members to stick to the common position formed in their prior meeting (if one is formed) in the full committee vote. Hence, informative voting constitutes a Nash equilibrium in this two-tier voting setup, provided that the interest rate decision is taken by simple majority. ■

Proposition 2.1 *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. The weights applied under the weighted voting rule are given as: $w_i = \ln\left(\frac{q_i}{1-q_i}\right)$. It can be shown that the weight based on the average skill level is a good approximation of the average weight of votes of the members belonging to one of the sub-groups within the committee:

$$\begin{aligned}
E_{i \in M}[w_i] &= E_{i \in M}\left[\ln\left(\tfrac{q_i}{1-q_i}\right)\right] = E_{i \in M}\left[\ln\left(\frac{q_i}{q_M} q_M\right) - \ln\left(\frac{1-q_i}{1-q_M}(1-q_M)\right)\right] \\
&= E_{i \in M}\left[\ln\left(\frac{q_i}{q_M}\right) + \ln(q_M) - \ln\left(\frac{1-q_i}{1-q_M}\right) - \ln(1-q_M)\right] \\
&= E_{i \in M}\left[\ln\left(1 + \frac{q_i}{q_M} - 1\right) + \ln(q_M) - \ln\left(1 + \frac{1-q_i}{1-q_M} - 1\right) - \ln(1-q_M)\right] \\
&\simeq E_{i \in M}\left[\frac{q_i}{q_M} - 1 + \ln(q_M) - \left(\frac{1-q_i}{1-q_M} - 1\right) - \ln(1-q_M)\right] \\
&= \ln\left(\tfrac{q_M}{1-q_M}\right) + E_{i \in M}\left[\frac{q_i}{q_M} - 1 - \left(\frac{1-q_i}{1-q_M} - 1\right)\right] = \ln\left(\tfrac{q_M}{1-q_M}\right)
\end{aligned}$$

Analogously:

$$E_{i \in M}[w_i] = E_{i \in N}\left[\ln\left(\tfrac{q_i}{1-q_i}\right)\right] \simeq \ln\left(\tfrac{q_N}{1-q_N}\right)$$

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

If the skills of committee members are relatively homogeneous, then the weights converge, i.e. $w_N \longrightarrow w_M$ as $q_N \rightarrow q_M$, and they 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 has the most pronounced effects on the voting outcomes when q_N converges to the lower bound of 0.5, i.e. $q_N \sim 0.5$ (see figure 2.1). 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). The probability that the committee takes the correct decision is given by:

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

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

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

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

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

If $m > n-1$, i.e. if the subgroup dominates the committee, then $\frac{n+m+1}{2} > n$ and $\frac{n+m+1}{2} - m \leq$, and the above probability can be simplified to obtain:

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

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 the two-tier set-up is inferior to the first best decision rule:

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

and

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

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

However, the two-tier procedure still yields results superior to simple majority:

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

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

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

■

Proposition 2.2 *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 (common) information about the likely state of the economy for the less-skilled members. Voting behavior of these individuals changes.

Knowing that the more-skilled members have agreed on option B and assuming that other less-skilled individuals will vote informatively, a less-skilled individual will vote informatively if and only if the following conditions are met (see the main text):

$$\begin{aligned} P_{i\in N}(b|s_i = B, CB, \text{pivotal}) &\geq 0.5 \\ P_{i\in N}(a|s_i = A, CB, \text{pivotal}) &\geq 0.5 \end{aligned}$$

where

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

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

The same conditions define the optimal strategy of a less-skilled individual in case the consensual position is A, since the setup is symmetric, i.e. $P_{i\in N}\left(b|s_i=B,CA,\text{pivotal}\right) = P_{i\in N}\left(a|s_i=A,CB,\text{pivotal}\right)$ and $P_{i\in N}\left(a|s_i=A,CA,\text{pivotal}\right) = P_{i\in N}\left(b|s_i=B,CB,\text{pivotal}\right)$.

In the case that no consensual position has been reached by the more-skilled members and no announcement has been made, 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 in case the announcement has been made can be solved to yield the following restrictions on the relationship between average skill levels and sizes of the two subgroups (assuming $q_i \sim q_N$):

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

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

Obviously, these conditions are not necessarily simultaneously satisfied. First, for $q_N \sim 0.5$, only the first condition will be satisfied, since $\lim\limits_{q_N\to 0.5}\left(\frac{q_N}{1-q_N}\right) = 1$. 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 as a function of q_N and x) and it becomes increasingly likely that the first constraint will be violated, while the second inequality becomes easily satisfied.

We thus have shown, that informative voting when both private and common signals are used by the less-skilled committee members is not likely to be Nash equilibrium behavior. Nevertheless, this set-up has another equilibrium, where the less-skilled committee members ignore their private information and follow the more skilled members. Under this strategy a less-skilled individual is never pivotal; following the more-skilled members

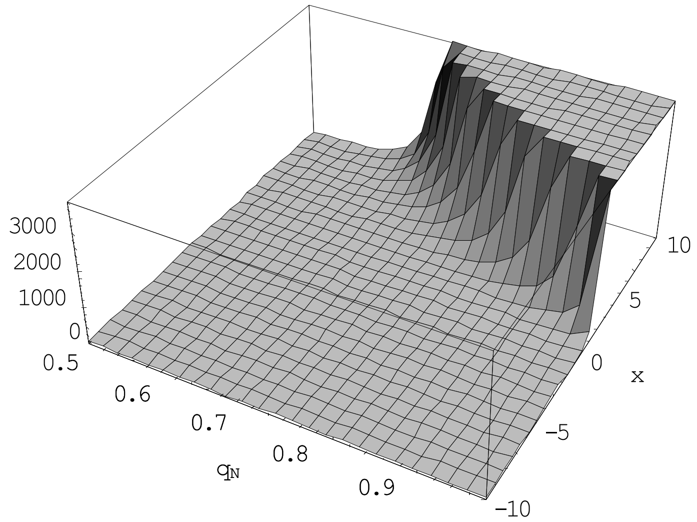

Figure 2.4:

trivially becomes her optimal voting strategy:

$$
\begin{aligned}
P_{i\in N}\left(b|CB,\text{follow}\right) &= \tfrac{P(CB|b)}{P(CB|b)+P(CB|a)} \geq 0.5\\
P_{i\in N}\left(a|CB,\text{follow}\right) &= \tfrac{P(CB|a)}{P(CB|a)+P(CB|b)} \leq 0.5
\end{aligned}
$$

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 the proof to lemma 2.1 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 the proof to lemma 2.1 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 the proof to lemma 2.1 hold in the setup enlarged by communication.

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

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

■

Proposition 2.3 *Only when decisional skills of committee members are very unevenly distributed (e.g. if $q_N \sim 0.5$) will delegation of monetary policy decisions to the more-skilled members improve the quality of monetary policy. In all other cases, delegation is most likely to yield worse results than a decision made by the full monetary policy committee, either by simple majority or by two-stage voting.*

Proof. If the decision is delegated to the more skilled committee members, then its accuracy is given by:

$$P^D(B|b) = \sum_{s_M=\frac{m}{2}+1}^{m} \binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} + 0.5\binom{m}{\frac{m}{2}} (q_M (1-q_M))^{\frac{m}{2}} \tag{2.22}$$

The optimality of delegation relative to simple majority and two-tier voting rules depends on the composition of the committee, specifically: on the average skill levels and the relative sizes of the two subgroups. We analyze the problem in two cases: (1) the more-skilled group dominates the committee (i.e. $m \geq \frac{n+m+1}{2}$, or $m \geq n+1$) and (2) the less-skilled committee members dominate (i.e. $m \leq n-1$).

Case 1: The simple majority and the two-tier voting procedures yield the following accuracy of collective decisions:

$$P^{SM}(B|b)|_{m \geq n+1} = \sum_{s_M=\frac{m-n+1}{2}}^{m} \left(\binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \sum_{s=\frac{n+m+1}{2}-s_M}^{n} \binom{n}{s} q_N^{s} (1-q_N)^{n-s} \right) \tag{2.23}$$

and

$$\begin{aligned}P(B|b)|_{m \geq n+1} = &\sum_{s_M=\frac{m}{2}+1}^{m} \binom{m}{s_M} q_M^{s_M} (1-q_M)^{m-s_M} \\ &+\binom{m}{\frac{m}{2}} (q_M (1-q_M))^{\frac{m}{2}} \sum_{s=\frac{n+1}{2}}^{n} \binom{n}{s} q_N^{s} (1-q_N)^{n-s}\end{aligned} \tag{2.24}$$

The comparison of simple majority with delegation yields the following:

$$P^{SM}(B|b)|_{m\geq n+1} - P^{D}(B|b) =$$
$$\sum_{s_M=\frac{m}{2}+1}^{m}\left(\begin{array}{c}\binom{m}{s_M} q_M^{s_M}\left(1-q_M\right)^{m-s_M} \\ \sum\limits_{s=\frac{n+m+1}{2}-s_M}^{n}\binom{n}{s} q_N^{s}\left(1-q_N\right)^{n-s}\end{array}\right) - \sum_{s_M=\frac{m}{2}+1}^{m}\binom{m}{s_M} q_M^{s_M}\left(1-q_M\right)^{m-s_M}$$
$$+\sum_{s_M=\frac{m}{2}-\frac{n-1}{2}}^{\frac{m}{2}}\left(\begin{array}{c}\binom{m}{s_M} q_M^{s_M}\left(1-q_M\right)^{m-s_M} \\ \sum\limits_{s=\frac{n+m+1}{2}-s_M}^{n}\binom{n}{s} q_N^{s}\left(1-q_N\right)^{n-s}\end{array}\right) - 0.5\binom{m}{\frac{m}{2}} q_M^{\frac{m}{2}}\left(1-q_M\right)^{\frac{m}{2}} \tag{2.25}$$

The expression in the first line is always negative (since $\sum\limits_{s=\frac{n+m+1}{2}-s_M}^{n}\binom{n}{s} q_N^{s}\left(1-q_N\right)^{n-s} < 1$ for $q_N < 1$), while the expression in the second line is always nonnegative (since the last element of the sum alone, $\binom{m}{\frac{m}{2}} q_M^{\frac{m}{2}}\left(1-q_M\right)^{\frac{m}{2}} \sum\limits_{s=\frac{n+m+1}{2}-\frac{m}{2}}^{n}\binom{n}{s} q_N^{s}\left(1-q_N\right)^{n-s}$, is equal to $0.5\binom{m}{\frac{m}{2}} q_M^{\frac{m}{2}}\left(1-q_M\right)^{\frac{m}{2}}$ for $q_N = 0.5$ and larger than $0.5\binom{m}{\frac{m}{2}} q_M^{\frac{m}{2}}\left(1-q_M\right)^{\frac{m}{2}}$ for $q_N > 0.5$). Hence the results are not clear-cut:

$$P^{SM}(B|b)|_{m\geq n+1}\begin{cases} \leq P^{D}(B|b) \text{ if } q_N \to 0.5 \\ \geq P^{D}(B|b) \text{ if } q_N \to q_M > 0.5 \\ \to P^{D}(B|b) \text{ if } q_M \to 1 \end{cases} \tag{2.26}$$

The comparison for the two-tier voting:

$$P(B|b)|_{m\geq n+1} - P^{D}(B|b) =$$
$$\binom{m}{\frac{m}{2}}\left(q_M\left(1-q_M\right)\right)^{\frac{m}{2}} \sum_{s=\frac{n+1}{2}}^{n}\binom{n}{s} q_N^{s}\left(1-q_N\right)^{n-s} - 0.5\binom{m}{\frac{m}{2}}\left(q_M\left(1-q_M\right)\right)^{\frac{m}{2}} \tag{2.27}$$

Hence the following relations hold:

$$P(B|b)|_{m\geq n+1}\begin{cases} \longrightarrow P^{D}(B|b) \text{ if } q_N \to 0.5 \\ > P^{D}(B|b) \text{ if } q_N > 0.5 \\ \to P^{D}(B|b) \text{ if } q_M \to 1 \end{cases} \tag{2.28}$$

Case 2: For the simple majority voting rule we have:

$$P^{SM}(B|b)|_{m\leq n-1} = \sum_{s_M=0}^{m}\left(\binom{m}{s_M} q_M^{s_M}\left(1-q_M\right)^{m-s_M} \sum_{s=\frac{n+m+1}{2}-s_M}^{n}\binom{n}{s} q_N^{s}\left(1-q_N\right)^{n-s}\right) \tag{2.29}$$

and

$$P^{SM}(B|b)|_{m\leq n-1} - P^{D}(B|b) =$$

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

$$+\sum_{s_M=0}^{\frac{m}{2}}\left(\begin{array}{c}\binom{m}{s_M}q_M^{s_M}(1-q_M)^{m-s_M}\\ \sum\limits_{s=\frac{n+m+1}{2}-s_M}^{n}\binom{n}{s}q_N^{s}(1-q_N)^{n-s}\end{array}\right)-0.5\binom{m}{\frac{m}{2}}q_M^{\frac{m}{2}}(1-q_M)^{\frac{m}{2}} \tag{2.30}$$

where the first line is negative and the second - nonnegative. Hence we have similar result as in the first case, except for the case $q_M \sim 1$:

$$P^{SM}(B|b)|_{m\leq n-1}\begin{cases}\leq P^{D}(B|b) \text{ if } q_N \sim 0.5\\ \geq P^{D}(B|b) \text{ if } q_N \sim q_M > 0.5\\ \leq P^{D}(B|b) \text{ if } q_M \sim 1\end{cases} \tag{2.31}$$

In the case of the two-tier voting procedure:

$$P(B|b)|_{m\leq n-1} = \sum_{s_M=0}^{\frac{m}{2}-1}\binom{m}{s_M}q_M^{s_M}(1-q_M)^{m-s_M}\sum_{s=\frac{n+m+1}{2}}^{n}\binom{n}{s}q_N^{s}(1-q_N)^{n-s}$$
$$+\binom{m}{\frac{m}{2}}\left(q_M(1-q_M)\right)^{\frac{m}{2}}\sum_{s=\frac{n+1}{2}}^{n}\binom{n}{s}q_N^{s}(1-q_N)^{n-s}$$
$$+\sum_{s_M=\frac{m}{2}+1}^{m}\binom{m}{s_M}q_M^{s_M}(1-q_M)^{m-s_M}\sum_{s=\frac{n+m+1}{2}-m}^{n}\binom{n}{s}q_N^{s}(1-q_N)^{n-s} \tag{2.32}$$

and

$$P(B|b)|_{m\leq n-1} - P^{D}(B|b) =$$

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

$$+\left(\begin{array}{c}\sum\limits_{s_M=0}^{\frac{m}{2}-1}\binom{m}{s_M}q_M^{s_M}(1-q_M)^{m-s_M}\sum\limits_{s=\frac{n+m+1}{2}}^{n}\binom{n}{s}q_N^{s}(1-q_N)^{n-s}\\ +\binom{m}{\frac{m}{2}}\left(q_M(1-q_M)\right)^{\frac{m}{2}}\sum\limits_{s=\frac{n+1}{2}}^{n}\binom{n}{s}q_N^{s}(1-q_N)^{n-s}\end{array}\right)-0.5\binom{m}{\frac{m}{2}}q_M^{\frac{m}{2}}(1-q_M)^{\frac{m}{2}} \tag{2.33}$$

where the first difference is negative and the second - positive. Hence the following relations hold:

$$P(B|b)|_{m\leq n-1}\begin{cases}\leq P^{D}(B|b) \text{ if } q_N\sim 0.5\\ \geq P^{D}(B|b) \text{ if } q_N\sim q_M>0.5\\ \leq P^{D}(B|b) \text{ if } q_M\sim 1\end{cases} \tag{2.34}$$

Comparing delegation to the first best decision-making rule, it is immediately obvious that both procedures yield the same results iff $q_N\sim 0.5$ (see also the proof to proposition 2.1):

$$\lim_{q_N\to 0.5} P^{FB}(B|b)=\sum_{s_M=\frac{m}{2}+1}^{m}\tbinom{m}{s_M}q_M^{s_M}\left(1-q_M\right)^{m-s_M}+0.5\tbinom{m}{\frac{m}{2}}\left(q_M\left(1-q_M\right)\right)^{\frac{m}{2}} \tag{2.35}$$

However, this is the only case when the two expressions are equal, since $\lim\limits_{q_N\to 0.5} P^{FB}(B|b)$ consists the lower bound on the accuracy of the collective decision taken by the whole committee under the first best decision rule:

$$\begin{aligned}P^{FB}(B|b) &= \sum_{s_M=0}^{m}\left(\tbinom{m}{s_M}q_M^{s_M}\left(1-q_M\right)^{m-s_M}\sum_{s=\frac{n+m+1}{2}-\frac{w_M}{w_N}s_M}^{n}\tbinom{n}{s}q_N^{s}\left(1-q_N\right)^{n-s}\right)\\ \frac{\partial P^{FB}(B|b)}{\partial q_N} &\geq 0\Rightarrow P^{FB}(B|b)>P^{D}(B|b) \text{ if } q_N>0.5\end{aligned} \tag{2.36}$$

The nonnegative value of the derivative $\frac{\partial P^{FB}(B|b)}{\partial q_N}$ results from two interacting effects:

$$\frac{\partial s}{\partial q_N}=\frac{\partial s}{\partial q_N}\left(\frac{n+m+1}{2}-\tfrac{w_M}{w_N}s_M\right)=\frac{w_M s_M}{q_N\left(1-q_N\right)\left(\ln\frac{q_N}{1-q_N}\right)}\geq 0$$

and

$$\frac{\partial s}{\partial q_N}\left(q_N^{s}\left(1-q_N\right)^{n-s}\right)=\frac{s-q_N n}{q_N\left(1-q_N\right)}q_N^{s}\left(1-q_N\right)^{n-s}\begin{cases}\geq 0\Longleftrightarrow s\geq q_N n\\ \leq 0\Longleftrightarrow s\leq q_N n\end{cases}$$

Hence a rise in q_N increases the size of the lower bound of the second sum, s, which makes it more likely that each element of this sum, $q_N^{s}\left(1-q_N\right)^{n-s}$, will increase due to a rise in q_N. The first best thus generally outperforms delegation. ■

Chapter 3

Communication in Monetary Policy Committees

[1]

Most monetary policy decisions are nowadays taken by a group of individuals, organized in the form of a committee. 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 preferences, thereby introducing strategic behavior, see *inter alia* von Hagen and Süppel (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 monetary policy committee (henceforth: 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)). The contribution this paper makes, is that it provides an analysis of the effects of interaction or communication in a MPC. As we argue below, our concept of communication is richer than used in most of the existing literature. We are thereby 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), Meade and Sheets (forthcoming)

[1]This chapter is a version of a paper co-authored by Jan Marc Berk.

and Chappell et al. (2005).

The current paper builds on Berk and Bierut (2005), who study the suboptimality of a simple majority voting rule for a MPC in which members' skills are highly heterogeneous. It is well-known (see e.g. Ben-Yashar and Nitzan (1997)) that in this case the optimal decision rule is weighted majority, as this voting rule maximizes the gains from aggregating individual heterogeneous expertise. Using simple majority in such situations yields inferior results in terms of the accuracy of the collective decision. However, we found that by imposing minimal structure on the heterogeneity of members' skills it was possible to eliminate this suboptimality whilst retaining simple majority rule. This is to be achieved by making certain institutional changes to the functioning of the monetary policy committee. These changes implied allowing for prior meetings of a subgroup of the monetary policy committee. This closely resembles the actual practice in real-life monetary policy committees, in particular of those that are organized along federal lines, such as the FOMC and the ECB Governing Council. Both committees consist of a hub (Board of Governors and the ECB Executive Board, respectively) and spokes (regional federal reserve banks and national central banks of members of the euro area). The current paper adds substance to the communication between members of the monetary policy committee.

The structure of the paper is as follows. We start, in section 3.1, by describing the communication and learning process in a committee. In section 3.2, 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 3.3), 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 committee members' characteristics. Section 3.4 discusses the optimal size and decision time of the committee, under the assumption that collective decision making entails costs. Section 3.5 concludes.

As in the case of simple decision-making rules which do not involve interaction among committee members, the optimal decision-making rule in the case when committee members communicate and learn from one another, but they have heterogeneous skills, also involves weighting. We also show that implementing simpler decision-making rules, which do not require weighting, can be used to approximate the optimal outcome. Depending on the degree of heterogeneity of skills, the optimal decision making rule can be approximated by unweighted averaging of information shared by all committee members or by limiting information sharing to a pre-meeting where only the more-skilled committee members are present. 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.

3.1 Communication and learning

In most of the existing literature on the effects of communication on collective decision-making (see, for example, Coughlan (2000) Gerardi and Yariv (2003)), an exchange of views has the form of members sending simultaneous messages regarding their preferred outcome, which are then aggregated into a single recommendation for the collective decision. The recommendation is binary and depends on the number of messages received for each alternative. This setup merely aggregates existing knowledge, 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 than sending simple yes-or-no messages to a certain 'aggregation device'. 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. As a result, communication improves the quality of the collective decision, made by simple majority voting. Take the FOMC as an example: the meeting is composed of two rounds of discussion: in the first round FOMC members share their insights on the economy (and e.g. report the regional developments that have taken place), in the second, they vote on the proposal for the interest rates (Chappell et al. (2005)).

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. 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. 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).[2] In the following section we formalize this description.

3.2 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 and in general will be modified by the evidence on the state of the economy presented in the meeting. We model the possibility that committee members interpret the evidence differently by assuming that this interpretation represents a private signal each member receives and that is imperfectly correlated with the true state of the economy. The higher the quality of this interpretation, the larger the probability that the member receives the correct signal. This translates directly into a higher probability of making the correct individual decision, i.e. voting for a change in interest rates in state a and voting for unchanged rates in state b:[3]

$$P(v_i = A|a) = P(v_i = B|b) = q_i \tag{3.1}$$

[2] See also Evans and Honkapohja (2001), sections 1.5 and 3.2.

[3] 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 $q_i \leq 0.5$, the decision could be taken by tossing a coin.

and consequently:

$$P(v_i = B|a) = P(v_i = A|b) = 1 - q_i \tag{3.2}$$

We label the q_i's as individual decisional skills. In line with earlier work (Berk and Bierut (2005)) 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. This assumption will simplify the calculations somewhat.

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:

$$\pi_{t+1} = \pi_t - \alpha r_t + e_{t+1} \tag{3.3}$$

where π_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 - interest rate i_t - is related to inflation via the Fisher equation:

$$r_t = i_t - E_t \pi_{t+1} \tag{3.4}$$

Each committee member believes the model (3.3)-(3.4) to be true but has his/her own idea about the strength of the transmission mechanism (α_i) and has his/her own forecast (expectations) of future disturbances to the inflation rate ($E_i e_{t+1}$). Individual MPC members would like to set the following interest rate:

$$i_{i,t} = \frac{1}{\alpha_i} \left(\pi_t + E_i e_{t+1} \right) + \frac{\alpha_i - 1}{\alpha_i} \pi^* \tag{3.5}$$

where π^* 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 $P\left(|E_i e_{t+1} - e_{t+1}| \leq x\right)$, where x is an arbitrarily chosen bound. A larger variance of the individual information about the state of the economy (σ_i^2) implies that the individual forecast ($E_i e_{t+1}$) is more likely to diverge substantially from e_{t+1}. It thus lowers q_i, the accuracy of the individual vote. Formally, if individual forecasts are independent and accurate on average but differ in their uncer-

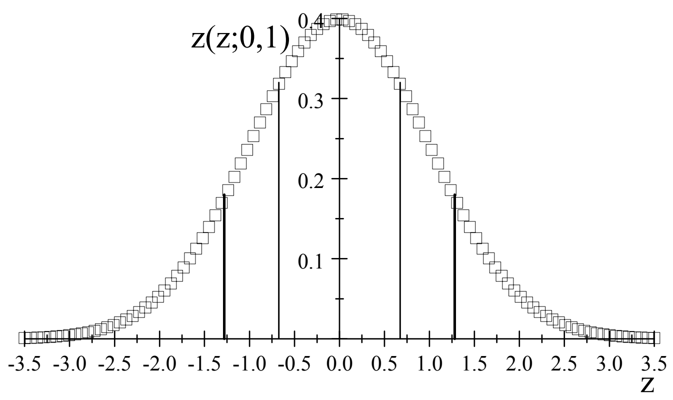

Figure 3.1: Graphical interpretation of individual decisional skills

tainty: $E_i e_{t+1} \sim IIN\left(e_{t+1}, \sigma_i^2\right)$, then:

$$\begin{aligned} q_i\left(x,\sigma_i\right) &= P\left(\left|E_i e_{t+1} - e_{t+1}\right| \leq x\right) \\ &= P\left(-x \leq E_i e_{t+1} - e_{t+1} \leq x\right) \\ &= P\left(-\frac{x}{\sigma_i} \leq \frac{E_i e_{t+1} - e_{t+1}}{\sigma_i} \leq \frac{x}{\sigma_i}\right) \\ &= Z\left(x/\sigma_i\right) - Z\left(-x/\sigma_i\right) \\ &= \frac{1}{\sqrt{2\pi}} \int_{-x/\sigma_i}^{x/\sigma_i} e^{-\frac{z^2}{2}} dz \end{aligned} \tag{3.6}$$

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

$$\frac{\partial q_i\left(x,\sigma_i\right)}{\partial \sigma_i} \leq 0 \tag{3.7}$$

Figure 3.1 illustrates this, for $x = 1$. Individual skills $q_i\left(1,\sigma_i\right)$ are measured by the size of the symmetric area under the standard normal DF $\left(z\left(z;0,1\right)\right)$ 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%: $q_i\left(1,\sigma_i\right) = 0.5$, while the thick lines define the area of 80%: $q_i\left(1,\sigma_i\right) = 0.8$. The thin lines correspond to $\sigma_i = 1.4826$, the thick lines to $\sigma_i = 0.78027$.

Figure 3.2 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. $q_i\left(1,\sigma_i\right)$), as a function of the uncertainty of individual forecast, σ_i.[4] The figure illustrates that the relation between $q_i\left(\sigma_i\right)$ and σ_i is functional, i.e. it

[4] The size of the bound, x, is arbitrary. However, it does define the magnitude of the variances of

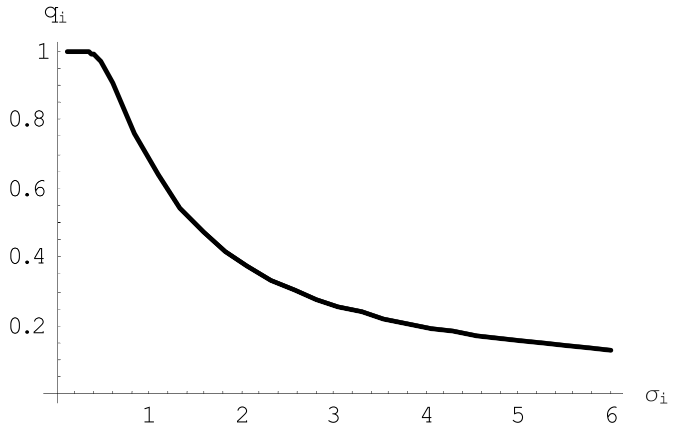

Figure 3.2: Relation between individual decisional skills and the uncertainty of individual forecast of future inflation shocks

is a one-to-one correspondence. Hence $q_i(\sigma_i)$ is invertible and σ_i is uniquely defined as $q_i^{-1}(1)$.

Without communication, a MPC using simple majority rule will adopt the median interest rate, that is:

$$i_{m,t} = Median\left(\frac{1}{\alpha_i}(\pi_t + E_i e_{t+1}) + \frac{1-\alpha_i}{\alpha_i}\pi^*\right) \tag{3.8}$$

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:

$$\widetilde{i}_{m,t} = Median\left(\frac{1}{\widetilde{\alpha}_i}\left(\pi_t + \widetilde{E}_i e_{t+1}\right) + \frac{1-\widetilde{\alpha}_i}{\widetilde{\alpha}_i}\pi^*\right) \tag{3.9}$$

where tilda denotes the elements, which committee members update with the information provided by their colleagues in the meeting. If $\widetilde{\alpha}_i \neq \alpha_i$ and $\widetilde{E}_i e_{t+1} \neq E_{i,t} e_{t+1}$, then interest rate $\widetilde{i}_{m,t} \neq i_{m,t}$. 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 our case, they would communicate $E_i e_{t+1}$ and (possibly) α_i. This means that 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.

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 $q_i(\sigma_i)$.

If we for simplicity abstract from uncertainty related to the transmission mechanism from the central bank's instrument to the inflation rate, the problem of deciding on the appropriate interest rate is similar to trying to obtain the best estimate of the mean of an unknown distribution (e_{t+1}) from the sample of $m + n$ observations. As is well known from statistics, the best estimator of e_{t+1} is the average of all the observations, and larger samples will tend to give more accurate estimates than smaller samples. The results in Gerlach-Kristen (2003b) reflect these considerations. Sharing the information allows committee members to improve the accuracy of their estimates and therefore to be able to take a better decision. Communication in MPCs implies aggregation of individual (independent) assessments of the future risks to inflation. As a consequence, the variance of the aggregated estimate of the future inflation risks should have a lower variance, i.e. higher accuracy, than individual observations.

Communication is the combination of speaking and listening. But not everyone has to speak, some committee members may just listen. Still, someone must speak so that others have something to listen to. Hence, having at least one committee member speaking in the meeting is necessary for learning. 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. The following illustrates the improvement in the decision skills due to learning. 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 (=speaking and listening), and none of the less-skilled members speak. If every more-skilled committee member incorporates the information obtained by listening to his/her colleagues into his/her original estimation of the future inflation disturbance, the updated estimate ($\widetilde{E}_{i \in M} e_{t+1}$) becomes:[5]

[5] One could imagine that the forecasts could be aggregated in the form of a weighted average, i.e. those forecasts that are less uncertain (i.e. have lower σ_i^2) should have a higher weight in the average $\widetilde{E}_i e_{t+1}$. Although this is the first-best approach (see Ben-Yashar and Nitzan (1997)), we abstract here from these issues, as they are very difficult to put into practice for political reasons (see Berk and Bierut (2005) for details).

$$\begin{aligned} \widetilde{E}_{i\in M} e_{t+1} &= \frac{1}{t+1}\left(\sum_{j=1,j\neq i}^{t} E_{j\in M} e_{t+1} + E_{i\in M} e_{t+1}\right) \\ \widetilde{E}_{i\in M} e_{t+1} &\sim N\left(e_{t+1}, \frac{\sigma_M^2}{t+1}\right) \end{aligned} \tag{3.10}$$

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

$$\begin{aligned} \widetilde{E}_{i\in M} e_{t+1} &= \frac{1}{t}\left(\sum_{j=1,j\neq i}^{t-1} E_{j\in M,t} e_{t+1} + E_{i\in M,t} e_{t+1}\right) \\ \widetilde{E}_{i\in M} e_{t+1} &\sim N\left(e_{t+1}, \frac{\sigma_M^2}{t}\right) \end{aligned} \tag{3.11}$$

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

The less-skilled committee members listen to their more-skilled colleagues and update their forecasts of the future inflation shock in the following way:

$$\begin{aligned} \widetilde{E}_{i\in N} e_{t+1} &= \frac{1}{t+1}\left(\sum_{j=1}^{t} E_{j\in M,t} e_{t+1} + E_{i\in N,t} e_{t+1}\right) \\ \widetilde{E}_{i\in N} e_{t+1} &\sim N\left(e_{t+1}, \frac{t\sigma_M^2 + \sigma_N^2}{(t+1)^2}\right) \end{aligned} \tag{3.12}$$

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 larger than initial skills:[6]

$$\frac{(m+1)\,\sigma_M^2}{m\,(t+1)} \leq \sigma_M^2 : q_M\left(\sigma_M\sqrt{\tfrac{m+1}{m(t+1)}}\right) \geq q_M\left(\sigma_M\right) \tag{3.13}$$

$$\frac{t\sigma_M^2 + \sigma_N^2}{(t+1)^2} \leq \sigma_N^2 : q_N\left(\frac{\sqrt{t\sigma_M^2+\sigma_N^2}}{t+1}\right) \geq q_N\left(\sigma_N\right) \tag{3.14}$$

Figure 3.3 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

[6]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: $\frac{t*\frac{\sigma_M^2}{t}+(m-t)\frac{\sigma_M^2}{t+1}}{m} = \frac{m+1}{m(t+1)}\sigma_M^2$. 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 $\frac{1}{m}\sigma_M^2$.

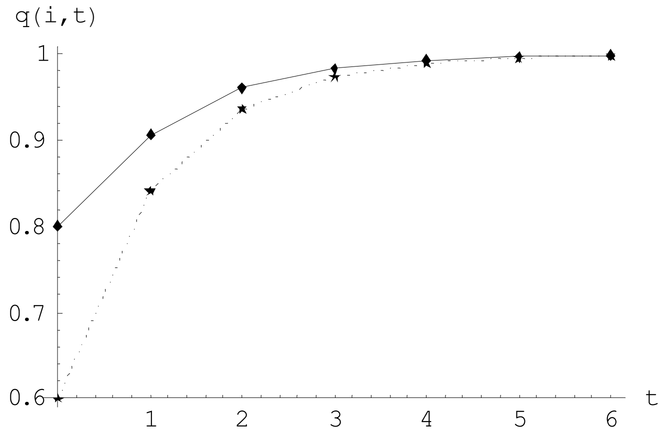

Figure 3.3: Learning curves for committee members

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 fixed at $q_M(\sigma_M) = 0.8$ 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 their listening to colleagues, their initial assessments of the state of the economy differ and remain private.

Figure 3.3 also illustrates two learning effects, documented by experimental evidence (Lombardelli et al. (2002)): (1) the catching-up effect, i.e. the fact that the less-skilled committee members update their knowledge 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.[7]

3.3 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 conditional 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. We allow for the possibility of a subgroup of the full MPC to meet prior to the vote on interest rates. As mentioned in the introduction, this is likely to occur in hub-and-spokes monetary policy committees like the FOMC in the US and the ECB Governing Council in the euro area. Berk and Bierut (2005) argue furthermore that the division between more-skilled and less-skilled committee members coincides with the division between the hub (US Federal Reserve Board and the ECB Executive Board) and the spokes (regional Federal Reserve Banks and National Central Banks). 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 cases we consider.

[7] Learning shows as an increase in the average accuracy of individual decision-makers with the number of (monetary policy) games played (see Chart 3 in (Lombardelli et al. (2002))). 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).

Case	Meeting	More-skilled members	Less-skilled members
1	Prior meeting	–	–
	MPC meeting	no talk	no talk
2	Prior meeting	–	–
	MPC meeting	talk and learn	talk and learn
3	Prior meeting	no talk	–
	MPC meeting	announcement	no talk
4	Prior meeting	talk and learn	–
	MPC meeting	announcement	no talk
5	Prior meeting	no talk	–
	MPC meeting	no talk	no talk
6	Prior meeting	talk and learn	–
	MPC meeting	no talk	no talk

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 in the whole space of combinations of average decisional skills of more- and less- skilled individuals (i.e. $q_M(\sigma_M) \times q_N(\sigma_N)$) 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 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 4 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, 4 and 6 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 by 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 between each other. That is, all members present at the prior meeting participate in the discussion by talking and listening to each other. After having arrived at the common position, they may before the vote in the full MPC announce this common position (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. The collective (updated) forecast is a simple (unweighted) average of individual forecasts of all committee members:

$$\begin{aligned} \widetilde{E}_C e_{t+1} &= \frac{1}{m+n}\sum_{i=1}^{m+n} E_{i\in(M\cup N)} e_{t+1} \\ \widetilde{E}_C e_{t+1} &\sim N\left(e_{t+1}, \frac{m\sigma_M^2 + n\sigma_N^2}{(m+n)^2}\right) \end{aligned} \tag{3.15}$$

   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 of the more-skilled committee members, 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:

$$\widetilde{E}_C^w e_{t+1} = \frac{\sum_{i=1}^{m+n} w_i E_{i\in(M\cup N)} e_{t+1}}{\sum_{i=1}^{m+n} w_i} \tag{3.16}$$

$$\widetilde{E}_C^w e_{t+1} \sim N\left(e_{t+1}, \left(\frac{1}{nw_N + mw_M}\right)^2 \left(nw_N^2\sigma_N^2 + mw_M^2\sigma_M^2\right)\right) \tag{3.17}$$

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 3.1 below.

Figures 3.4 and 3.5 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 (σ_N). Recall from figure 3.2, that the uncertainty is inversely related to the individual decisional skills. The range of σ_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). 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 dashed 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 dotted 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 3.4 illustrates a trade-off involved in communication and learning: adopting

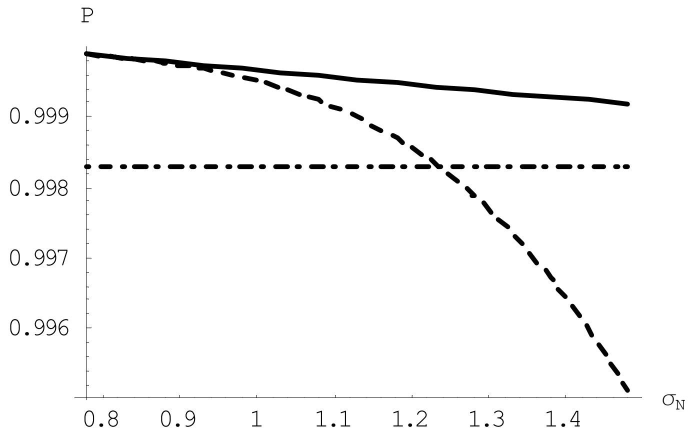

Figure 3.4: Probability of an accurate interest rate decision taken by a small committee with and without learning

the views expressed by others means to some extent giving up your own view.[8] (Only) as long as the latter is qualitatively less than the former, the collective outcome improves. Figure 3.4 shows that allowing for learning across all members (dashed 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 board-dominated committee, allowing for communication beyond the hub implies that the less-skilled sub-group influence the final outcome. In case the knowledge differential is large, the latter 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 3.5 illustrates the 'monotonically increasing' benefits of communication for the accuracy of collective decisions. By this we mean that the more members involved in communication and learning, the higher the collective accuracy. 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-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 results prove to be quite general.

[8]See also Swank and Wrasai (2002).

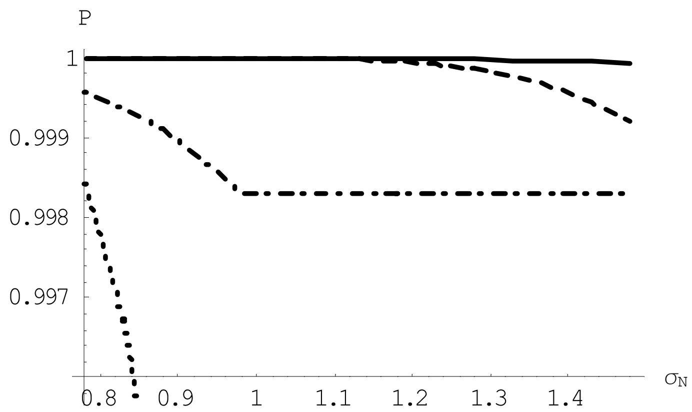

Figure 3.5: Probability of an accurate interest rate decision taken by a large committee with and without learning

Proposition 3.1 *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 3.2 *Assume that individual decisional skills are heterogeneous, i.e.* $q_N(x, \sigma_N) \sim 0.5$ *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 3.3 *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. ■

As in the case of simple decision-making rules which do not involve interaction among committee members, the optimal decision-making rule (or procedure) in the case when committee members communicate and learn from one another also involves weighting.

The weights are positively related to the level of individual intrinsic skills. However, as is the case with weighted voting, this optimal procedure does not have to be applied in reality. Our analysis shows that implementing simpler decision-making rules, which do not require weighting, approximates the optimal outcome for a particular set of parameters.

3.4 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. One can think of direct costs, in terms of additional (travel) expenses, or of more indirect costs, such as changing appointments (with the press, for example) made earlier. We will return to the latter shortly. The improvement of the collective outcome, i.e. of the vote on monetary policy, thus does not come without a cost. Neither should we expect that individuals participate in decision-making bodies for purely altruistic motives. Their participation usually involves paying salaries. Therefore the total cost is related to the size of the committee 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 conditional probability that the committee takes the correct decision. The costs involved in making this decision will be captured by the following function:

$$C(m+n,t) = \alpha\,(m+n) + \exp(\beta t) - 1 \tag{3.18}$$

This form implies that the marginal cost of adding an extra committee member equals α and is constant (see also Gradstein et al. (1990) or Nitzan and Paroush (1985)) and equal for both more- and less-skilled committee members. The functional form is chosen for its simplicity, whilst capturing the essentials. We for have experimented with alternatives that allow more-skilled members to be more expensive.[9] The results turned out to be

[9] Using the following cost function: $C(m+n,t) = \alpha\,(q_M m + q_N n) + \exp(\beta t) - 1$. It it is however unlikely that paying a higher-skilled member a higher salary is politically feasible, using arguments similar to the ones put forward against weighted voting in monetary policy committees.

qualitatively similar to those reported below. Time costs are assumed to be nonlinear, with the parameter β governing the costs of learning; this assumption can be motivated by a real-life relevance.[10] 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-then-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 equals 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 thus 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

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

communication[11] and the optimal average level of skills of the less-skilled subgroup.

		No learning			Limited learning		
α	β	Optimum	Accuracy	Cost	Optimum	Accuracy	Cost
0.001	0.001	$(0.8; 0.8)$ 17	0.997	0.017	$(0.8; NA)$ $(6, 0)$	0.998	0.012
0.001	0.01	$(0.8; 0.8)$ 17	0.997	0.017	$(NA; 0.8)$ $(0, 15)$	0.996	0.015
0.01	0.001	$(0.8; 0.8)$ 7	0.967	0.070	$(0.8; NA)$ $(4, 0)$	0.990	0.044
0.01	0.01	$(0.8; 0.8)$ 7	0.967	0.070	$(0.8; NA)$ $(4, 0)$	0.990	0.081
0.1	0.001	$(0.8; 0.8)$ 3	0.896	0.300	$(0.8; NA)$ $(2, 0)$	0.930	0.202
0.1	0.01	$(0.8; 0.8)$ 3	0.896	0.300	$(0.8; NA)$ $(2, 0)$	0.930	0.220

[11] 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).

		Unlimited learning		
α	β	Optimum	Accuracy	Cost
0.001	0.001	(0.8; 0.8) 5	0.996	0.010
0.001	0.01	(0.8; 0.8) 3	0.974	0.033
0.01	0.001	(0.8; 0.8) 5	0.996	0.045
0.01	0.01	(0.8; 0.8) 3	0.974	0.054
0.1	0.001	(0.8; 0.8) 3	0.974	0.330
0.1	0.01	(0.8; 0.8) 3	0.974	0.330

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 tables is that in the optimum, there is never a difference in the level of skills of members. Even if we would make the participation of more-skilled members slightly more expensive (see footnote 9), it always pays off to have as much 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.

3.5 Discussion

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 (forthcoming) 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 you own view. (Only) as long as the latter is qualitatively less than the former, the collective outcome improves. Another implication for committee design is that there seems to be 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.

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 US Federal Reserve and the ECB, 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.

3.6 Appendix. Proofs to propositions

Proposition 3.1 *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 updated collective estimate of inflation disturbance is computed as a weighted average:

$$\widetilde{E}_C^w e_{t+1} = \frac{\sum_{i=1}^{m+n} w_i E_{i\in(M\cup N),t} e_{t+1}}{\sum_{i=1}^{m+n} w_i} \tag{3.19}$$

The variance of the estimate $\widetilde{E}_C^w e_{t+1}$ is then given by:

$$Var\left(\widetilde{E}_C^w e_{t+1}\right) = \left(\frac{1}{nw_N + mw_M}\right)^2 \left(nw_N^2\sigma_N^2 + mw_M^2\sigma_M^2\right) \tag{3.20}$$

where σ_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, σ_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 $nw_N + mw_M = m + n$,[12] we can compute the weights w_N and w_M that minimize the variance $Var\left(E^w_{C,t}e_{t+1}\right)$. They are given as:

$$w_M = \frac{(m+n)\,\sigma_N^2}{n\sigma_M^2 + m\sigma_N^2} \tag{3.21}$$

$$w_N = \frac{(m+n)\,\sigma_M^2}{n\sigma_M^2 + m\sigma_N^2} \tag{3.22}$$

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 3.2 *Assume that individual decisional skills are heterogeneous, i.e.* $q_N(x, \sigma_N) \sim 0.5$ *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:

$$P_C^W(B|b) = q_C^W\left(x, \frac{\sigma_M\sigma_N}{\sqrt{n\sigma_M^2 + m\sigma_N^2}}\right) \tag{3.23}$$

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

$$P_C(B|b) = q_C\left(x, \frac{\sqrt{m\sigma_M^2 + n\sigma_N^2}}{m+n}\right) \tag{3.24}$$

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

$$P_{LC}(B|b) = Max\left\{P_{LC}^{NA}(B|b), P_{LC}^{A}(B|b)\right\} \tag{3.25}$$

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:

$$\begin{aligned} P_{LC}^{NA}(B|b) &= q_M\left(x, \frac{\sigma_M}{\sqrt{m}}\right) \sum_{s=\frac{n+m+1}{2}-m}^{n} \binom{n}{s} \left(q_N(x, \sigma_N)\right)^s \left(1 - q_N(x, \sigma_N)\right)^{n-s} \\ &+ \left(1 - q_M\left(x, \frac{\sigma_M}{\sqrt{m}}\right)\right) \sum_{s=\frac{n+m+1}{2}}^{n} \binom{n}{s} \left(q_N(x, \sigma_N)\right)^s \left(1 - q_N(x, \sigma_N)\right)^{n-s} \end{aligned} \tag{3.26}$$

[12] This assumption allows for a natural comparison with the case of no weighting, i.e. the case where $w_N = w_M = 1$.

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

$$P_{LC}^{A}(B|b) = q_M\left(x, \frac{\sigma_M}{\sqrt{m}}\right) \tag{3.27}$$

If $q_N(x, \sigma_N) \sim 0.5$, we have

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

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

$$\begin{gathered}
P_{LC}^{A}(B|b) \geq P_{LC}^{NA}(B|b) \Leftrightarrow \\
q_M\left(x, \frac{\sigma_M}{\sqrt{m}}\right) \geq q_M\left(x, \frac{\sigma_M}{\sqrt{m}}\right) \sum_{s=\frac{n+m+1}{2}-m}^{n} \binom{n}{s} 0.5^n \\
+ \left(1 - q_M\left(x, \frac{\sigma_M}{\sqrt{m}}\right)\right) \sum_{s=\frac{n+m+1}{2}}^{n} \binom{n}{s} 0.5^n \Leftrightarrow \\
q_M\left(x, \frac{\sigma_M}{\sqrt{m}}\right) \left(1 - \sum_{s=\frac{n+m+1}{2}-m}^{n} \binom{n}{s} 0.5^n\right) \geq \left(1 - q_M\left(x, \frac{\sigma_M}{\sqrt{m}}\right)\right) \sum_{s=\frac{n+m+1}{2}}^{n} \binom{n}{s} 0.5^n \\
\Leftrightarrow \frac{q_M\left(x, \frac{\sigma_M}{\sqrt{m}}\right)}{1 - q_M\left(x, \frac{\sigma_M}{\sqrt{m}}\right)} \geq \frac{\sum_{s=\frac{n+m+1}{2}}^{n} \binom{n}{s} 0.5^n}{1 - \sum_{s=\frac{n+m+1}{2}-m}^{n} \binom{n}{s} 0.5^n}
\end{gathered}$$

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

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

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: $\frac{\sigma_M \sigma_N}{\sqrt{n\sigma_M^2 + m\sigma_N^2}}$, $\frac{\sqrt{m\sigma_M^2 + n\sigma_N^2}}{m+n}$ and $\frac{\sigma_M}{\sqrt{m}}$:

$$\begin{aligned}
\frac{\sigma_N \sigma_M}{\sqrt{n\sigma_M^2 + m\sigma_N^2}} - \frac{\sqrt{m\sigma_M^2 + n\sigma_N^2}}{m+n} &= \frac{(m+n)\sigma_N\sigma_M - \sqrt{m\sigma_M^2 + n\sigma_N^2}\sqrt{n\sigma_M^2 + m\sigma_N^2}}{(m+n)\sqrt{n\sigma_M^2 + m\sigma_N^2}} \\
&= \frac{(m+n)\sigma_N\sigma_M - \sqrt{\sigma_N^2\sigma_M^2(m^2+n^2) + mn\left(\sigma_N^4 + \sigma_M^4\right)}}{(m+n)\sqrt{n\sigma_M^2 + m\sigma_N^2}} \leq 0
\end{aligned}$$

Thus

$$P_C^W(B|b) \geq P_C(B|b)$$

Since

$$\frac{\sigma_M \sigma_N}{\sqrt{n\sigma_M^2 + m\sigma_N^2}} - \frac{\sigma_M}{\sqrt{m}} = \sigma_M \frac{\sqrt{m\sigma_N^2} - \sqrt{n\sigma_M^2 + m\sigma_N^2}}{\sqrt{m}\sqrt{n\sigma_M^2 + m\sigma_N^2}} \leq 0$$

Thus

$$P_C^W(B|b) \geq P_{LC}(B|b)$$

The comparison between the two sub-optimal decision making rules is less straightforward and depends on the degree of skill asymmetry:

$$\frac{\sqrt{m\sigma_M^2 + n\sigma_N^2}}{m+n} - \frac{\sigma_M}{\sqrt{m}} = \frac{\sqrt{m\left(m\sigma_M^2 + n\sigma_N^2\right)} - (m+n)\,\sigma_M}{\sqrt{m}\,(m+n)}$$

$$\sigma_M^2 \sim \sigma_N^2 : \sigma_M \frac{\sqrt{m\,(m+n)} - (m+n)}{\sqrt{m}\,(m+n)} \leq 0$$

$$\sigma_M^2 \sim 0 : \frac{\sigma_N \sqrt{mn}}{\sqrt{m}\,(m+n)} \geq 0$$

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

$$P_{LC}(B|b) \leq P_C(B|b) \leq P_C^W(B|b)$$

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 equivalent to the position of the more-skilled committee members:

$$P_C(B|b) \leq P_{LC}(B|b) \leq P_C^W(B|b)$$

■

Proposition 3.3 *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:

$$P(B|b) = Max\left\{P_{SM}(B|b), P^{NA}(B|b), P^A(B|b)\right\} \tag{3.28}$$

where

$$P_{SM}(B|b) = \sum_{s_M=0}^{m} \left(\begin{array}{c} \binom{m}{s_M} \left(q_M\left(x,\sigma_M\right)\right)^{s_M} \left(1-q_M\left(x,\sigma_M\right)\right)^{m-s_M} \\ \sum\limits_{s=\frac{n+m+1}{2}-s_M}^{n} \binom{n}{s} \left(q_N\left(x,\sigma_N\right)\right)^{s} \left(1-q_N\left(x,\sigma_N\right)\right)^{n-s_N} \end{array} \right) \tag{3.29}$$

$$\begin{aligned} P^{NA}(B|b) = & \left(\begin{array}{c} \sum_{s_M=\frac{m}{2}+1}^{m} \binom{m}{s_M} \left(q_M\left(x,\sigma_M\right)\right)^{s_M} \left(1-q_M\left(x,\sigma_M\right)\right)^{m-s_M} \\ \sum\limits_{s=\frac{n+m+1}{2}-m}^{n} \binom{n}{s} \left(q_N\left(x,\sigma_N\right)\right)^{s} \left(1-q_N\left(x,\sigma_N\right)\right)^{n-s_N} \end{array} \right) \\ & + \left(\begin{array}{c} \binom{m}{\frac{m}{2}} \left(q_M\left(x,\sigma_M\right)\right)^{\frac{m}{2}} \left(1-q_M\left(x,\sigma_M\right)\right)^{\frac{m}{2}} \\ \sum\limits_{s=\frac{n+1}{2}}^{n} \binom{n}{s} \left(q_N\left(x,\sigma_N\right)\right)^{s} \left(1-q_N\left(x,\sigma_N\right)\right)^{n-s_N} \end{array} \right) \\ & + \left(\begin{array}{c} \sum_{s_M=0}^{\frac{m}{2}-1} \binom{m}{s_M} \left(q_M\left(x,\sigma_M\right)\right)^{s_M} \left(1-q_M\left(x,\sigma_M\right)\right)^{m-s_M} \\ \sum\limits_{s=\frac{n+m+1}{2}}^{n} \binom{n}{s} \left(q_N\left(x,\sigma_N\right)\right)^{s} \left(1-q_N\left(x,\sigma_N\right)\right)^{n-s_N} \end{array} \right) \end{aligned} \tag{3.30}$$

and

$$\begin{aligned} P^{A}(B|b) = & \sum_{s_M=\frac{m}{2}+1}^{m} \binom{m}{s_M} \left(q_M\left(x,\sigma_M\right)\right)^{s_M} \left(1-q_M\left(x,\sigma_M\right)\right)^{m-s_M} + \\ & \binom{m}{\frac{m}{2}} \left(q_M\left(x,\sigma_M\right)\right)^{\frac{m}{2}} \left(1-q_M\left(x,\sigma_M\right)\right)^{\frac{m}{2}} \sum_{s=\frac{n+1}{2}}^{n} \binom{n}{s} \left(q_N\left(x,\sigma_N\right)\right)^{s} \left(1-q_N\left(x,\sigma_N\right)\right)^{n-s_N} \end{aligned} \tag{3.31}$$

In the case of highly asymmetric skills, i.e. $q_N\left(x,\sigma_N\right) \sim 0.5$ and $q_M\left(x,\sigma_M\right) \sim 1$, $P(B|b) = P^A(B|b)$ (see Berk and Bierut (2005)), and:

$$\begin{aligned} \lim_{\substack{q_N(x,\sigma_N)\to 0.5 \\ q_M(x,\sigma_M)\to 1}} P(B|b) &= 1 \\ \lim_{\substack{q_N(x,\sigma_N)\to 0.5 \\ q_M(x,\sigma_M)\to 1}} P_C(B|b) &= q_C\left(x, \frac{1.4826\sqrt{n}}{m+n}\right) \end{aligned}$$

The figure below presents the difference $\lim\limits_{\substack{q_N(x,\sigma_N)\to 0.5 \\ q_M(x,\sigma_M)\to 1}} P(B|b) - \lim\limits_{\substack{q_N(x,\sigma_N)\to 0.5 \\ q_M(x,\sigma_M)\to 1}} P_C(B|b)$ for m between 2 and 20, and n between 1 and 29. It shows clearly that in smaller committees $\lim\limits_{\substack{q_N(x,\sigma_N)\to 0.5 \\ q_M(x,\sigma_M)\to 1}} P(B|b) > \lim\limits_{\substack{q_N(x,\sigma_N)\to 0.5 \\ q_M(x,\sigma_M)\to 1}} P_C(B|b)$. ■

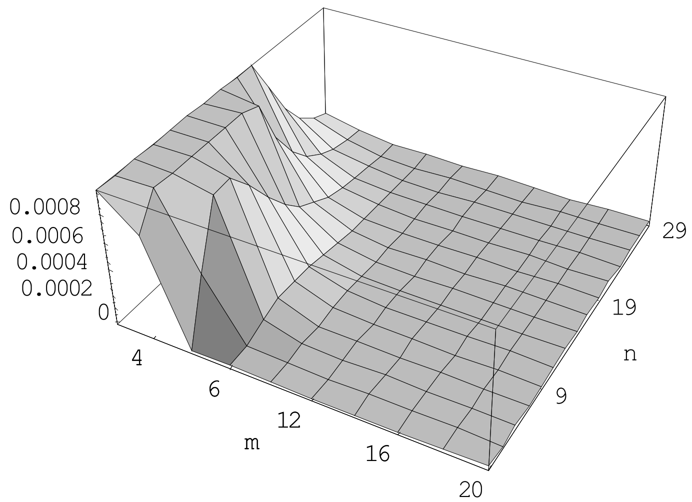

Figure 3.6:

Chapter 4

Central bank's operations in the reserve market

We address an issue in central bank policy making which has largely been taken for granted in the literature so far[1] - the *frequency* of open market operations (OMOs). However, in reality the frequency of central banks' operations in the reserve market is far from uniform. Our objective therefore is to assess the effects of different frequencies in terms of achieving the central bank's operating target, i.e. controlling short-term interest rates.

We therefore narrow our interest to the link between the frequency of open market operations and the volatility of overnight interest rates. Hence we will focus on controlling interest rates through an appropriate management of liquidity in the reserve market.[2] Let us note that the overnight liquidity can be managed by establishing standing facilities as well. However, open market operations are carried out on the initiative of the central bank, whereas standing facilities are activated on demand by market participants. As a result, central banks tend to steer liquidity mainly through open market operations and to utilize standing facilities only as "safety valves" for end-of-day imbalances. The central bank can furthermore introduce required reserves, an obligation for financial institutions

[1] With an exception of Hardy (1997), who examines the consequences of an informational advantage on the side of reserve market participants versus the central bank.

[2] Overnight interest rates can be steered through a (tight) corridor between the rates on standing facilities. Creating an interest rate corridor might be a very efficient way of steering overnight interest rates. This approach, however, may practically eliminate the market for short-term liquidity (see also Davies (1998)).

to hold a certain level of liquidity over a specified period of time, which act as a 'buffer' to stabilize overnight interest rates in the face of unexpected liquidity shocks (e.g. due to autonomous factors, i.e. net foreign assets, net lending to the government, cash in circulation, etc.). Averaging provisions, which allow for an averaged fulfillment of reserve requirements, foster the stabilization function of required reserves by providing extra flexibility in the face of fluctuations in market interest rates.

Table 4.1 summarizes actual operating frameworks applied in four monetary areas: the euro area, United States, Japan and United Kingdom.[3] All central banks except the Bank of Japan[4] use the interest rate as the main operating target.

As table 4.1 shows, the applied frequency of open market operations varies considerably among the countries. These differences, however, do not necessarily translate into diverging accuracy of controlling short-term interest rates, which we measure with the level of the overnight interest rate volatility. Table 4.2 presents the average volatility, defined as the average of squared deviations from the target rate, of the overnight market rates in the euro area and the United Sates, Eonia and the federal funds (FF) rate. Average levels of the overnight volatility in the two monetary areas do not always differ in a statistical sense, even though the Federal Reserve intervenes daily whereas the European Central Bank only weekly.

We therefore conclude that more frequent interventions in the reserve market do not automatically translate into more stable interest rates. This suggests that other instruments at the disposal of the central bank must play an important role. We proceed by investigating the three-way relation between the frequency of open market operations, the volatility of overnight interest rates and the design of other central bank's instruments.

In the following two sections we introduce our setup: a general specification of the central bank's liquidity management problem and a specific model for the 2-day reserve maintenance period. In section 4.3 we present the results: the optimal liquidity provision through open market operations and the resulting volatility of overnight interest rates. We conclude by interpreting the results and providing empirical support for our findings in section 4.4.

[3] For a comprehensive discussion, see Borio et al. (2001) or Borio (1997).

[4] Faced with a liquidity trap, deflation and a shrinking economy, the Bank of Japan changed its operating target in March 2001 from the overnight call rate to the amount outstanding of financial institutions' current accounts (henceforth, reserves).

	Euro area	UK	USA	Japan[5]
Lending facility	Applied	Applied[6]	Applied but not important	Applied but not important
Deposit facility	Applied	-	-	-
Outright OMOs	Applied[7]	Applied	Applied	Applied
Reverse OMOs	Applied	Applied	Applied	Applied
Frequency	*Weekly*	*More than once a day*	*Daily*	*More than once a day*
Required reserves	Applied	-[8]	Applied but not important	Applied
Averaging provisions	*Applied*	-	*Applied*	*Applied*

Table 4.1: Selected central bank operating frameworks

	Eonia	FF rate	F-statistic
1999	0.037	0.028	1.394
2000	0.033	0.015	8.141
2001	0.059	0.040	0.771
2002	0.021	0.003	11.058

Table 4.2: Average overnight volatility in the euro zone and the US

Our work comes closest to the contribution of Bartolini et al. (2002), who present a positive analysis of the effects of the Fed's 'intervention style', that is unlimited and limited-size open market operations, on the volatility of the FF rate. Contrary to the study of Bartolini et al. (2002), the analysis presented below is fully normative.

4.1 Analytical setup

We assume that the central bank's operational framework is designed to deliver the desired level (i) of the overnight interest rate (i_t), therefore the objective of the central bank is to minimize the following loss function:

$$L = E\left[\sum_{t=1}^{T}(i_t - i)^2\right] \tag{4.1}$$

where E denotes the expectations operator and T is the length of the maintenance period. The model of the reserve market consists of two equations[9]:

- the supply equation, derived from the central bank's balance sheet identity.:

  $$r_t = m_t + s_t - a_t \tag{4.2}$$

  where r_t denotes reserves held by the banking sector, m_t - open market operations[10], s_t - net standing facilities (i.e. the difference between the lending facility and the deposit facility) and a_t - net autonomous factors (outside the control of the central bank).[11]

Autonomous factors constitute an exogenous stochastic element in the supply of liquidity. We assume that in each sub-period t their expected value $E[a_t]$ is equal to the

[9] The model builds on the work developed in the European Monetary Institute in the preparatory phase for the Stage Three of the Economic and Monetary Union.

[10] The regular main refinancing operations in case of the ECB. We will ignore ad hoc operations (structural and fine-tuning) and the longer term refinancing operations, which (by construction) are carried out only once per maintenance period.

[11] Data on the ECB's balance sheet indicate that reserves held by the banking sector have, on average, constituted around 54,7% and net autonomous factors - 45,0% of liabilities. On the assets' side, 73,6% of liquidity was provided via main refinancing operations and 26,1% via longer term operations. The deposit and lending facilities accounted for around 0,3% of assets and liabilities, respectively. (Source: European Central Bank (2002))

central bank's forecast, which we denote as a_t^f.[12] The size of open market operations is determined by the central bank, based on publicly available information. Consequently the size of open market operations is deterministic. The recourse to standing facilities of the central bank is assumed to represent errors made by commercial banks in the management of reserve funds. Assuming that these errors are non-systematic, the expected size of the net facilities is zero: $E[s_t] = 0$.

- the demand equation, derived form an inventory theoretical model of reserve management (see the appendix (section 4.5)):

$$r_t = -\alpha_t r_{t-1} - \beta_t r_{t+1}^e + \gamma_t R - \delta_t i_t + \varepsilon_t \tag{4.3}$$

  where r_{t+1}^e denotes the expected reserves to be held in the sub-period $t+1$, R is the level of required reserves, i_t is the overnight rate and ε_t is the (white noise) disturbance in the demand for reserves (which may correspond to the demand for reserves necessary to settle transactions with other banks, etc.).

The demand equation (4.3) has two important characteristics. First of all, we assume that banks manage their reserve holdings based on the cost of obtaining the funds (i_t) on the one hand and the compulsory level of reserves imposed by the central bank (R) on the other hand. Furthermore, the specification emphasizes the intertemporal character of funds' management: commercial banks are supposed to analyze their reserve position in the context of several sub-periods within the reserve maintenance period (sub-periods $t-1$, t and $t+1$). To be more specific, if all model parameters are non-negative, the weighted average of reserves that commercial banks are willing to hold over three consecutive sub-periods ($r_t + \alpha_t r_{t-1} + \beta_t r_{t+1}^e$) is assumed to be positively related to the level of required reserves[13] and negatively related to the overnight interest rate. The imposed parameter assumptions result in the behavior of reserves driven by interest rate expectations as described in the literature: in order to minimize the cost of holding reserves, commercial banks try to front- or back-load reserves if they expect interest rates to increase or decrease later on in the maintenance period.[14]

[12] This assumption seems justifiable, since the annual averages of ECB's forecasts were approximately equal to the averages of actual autonomous factors (for 2001 and 2002).

[13] This characteristic seems to be in line with the averaging provision.

[14] See e.g. Swank (1995), Bindseil (2000) and Borio et al. (2001). In our model $\frac{\partial r_t}{\partial i_{t+1}^e} = \frac{\partial r_t}{\partial r_{t+1}^e}\frac{\partial r_{t+1}^e}{\partial i_{t+1}^e} = -\beta_t(-\delta_{t+1}) > 0$ if $\beta, \delta > 0$.

t	1	2
$\alpha_\mathbf{t}$	0.38	0.69
$\beta_\mathbf{t}$	0.78	0.18
$\gamma_\mathbf{t}$	2.15	1.69
$\delta_\mathbf{t}$	0.22	0.05

Table 4.3: Calibrated model coefficients

We estimated equation (4.3) for the euro area.[15] This exercise provided us with the following indicative values for the model parameters, as presented in table 4.3.[16] These results corroborate our assumption of non-negativity for all model parameters. Moreover, the estimated values will be useful for evaluating the results of our analysis. It is therefore important to take note of the following relations: $0 < \alpha_t < 1$, $0 < \beta_t < 1$, and $\gamma_t > 1$.

In the remainder of the paper we will investigate in detail the simplest case for a 2-day reserve maintenance period ($T = 2$). This case is of interest, as it combines analytical tractability with policy-relevant features. Our framework differs considerably from the existing literature, which focuses on the reserve market in *either* the euro area[17] or the US[18]. Our approach can be applied to both monetary areas as it captures an (intertemporal) dependency between liquidity and interest rates and does not represent interest rates as weighted averages of the rates on standing facilities.[19]

[15] Ideally, we should have estimates for the United States as well. However, for the US, the data regarding the sub-periods within a single maintenance period are not available.

[16] The results were obtained by splitting the reserve maintenance period into two 2-week sub-periods. For further details, see appendix 2 (section 4.6).

[17] See e.g. Ayuso and Repullo (2003), Bartolini et al. (2001), Bindseil (2000), Quirós and Mendizábal (2001) and Välimäki (2002).

[18] See e.g. Bartolini et al. (2002) and Furfine (1998).

[19] Averaging is justified in the case of the euro area but problematic in the case of the United States.

4.2 Interest rates over a 2-day reserve maintenance period

We solve for interest rates on both days of the maintenance period using equation (4.3) written for $t = 1, 2$:

$$r_1 = -\alpha_1 r_0 - \beta_1 r_2^e + \gamma_1 R - \delta_1 i_1 + \varepsilon_1 \tag{4.4}$$

$$r_2 = -\alpha_2 r_1 - \beta_2 r_3^e + \gamma_2 R - \delta_2 i_2 + \varepsilon_2 \tag{4.5}$$

The first equality implies

$$i_1 = \frac{1}{\delta_1}(\gamma_1 R - \beta_1 r_2^e - r_1 - \alpha_1 r_0 + \varepsilon_1) \tag{4.6}$$

and the second

$$i_2 = \frac{1}{\delta_2}(\gamma_2 R - r_2 - \alpha_2 r_1 - \beta_2 r_3^e + \varepsilon_2) \tag{4.7}$$

Equations (4.6) and (4.7) reveal that a central bank will be able to steer interest rates through liquidity provision if and only if the following conditions hold: $\delta_1 \neq 0$ and $\delta_2 \neq 0$. Otherwise market interest rates are uncontrollable.

Using the supply equation (4.2) we can write the above expressions in terms of open market operations, autonomous factors and standing facilities:

$$i_1 = \frac{1}{\delta_1}(\gamma_1 R - \beta_1(m_2 - a_2^f) - (m_1 - a_1 + s_1) - \alpha_1 r_0 + \varepsilon_1) \tag{4.8}$$

$$i_2 = \frac{1}{\delta_2}(\gamma_2 R - (m_2 - a_2 + s_2) - \alpha_2(m_1 - a_1 + s_1) - \beta_2 r_3^e + \varepsilon_2) \tag{4.9}$$

where we have made use of the assumptions regarding the non-stochastic character of open market operations and the zero expected value of net standing facilities made in the previous section.

Overnight interest rates are lower if there is more liquidity available in the market due to open market operations, net liquidity-providing autonomous factors (negative a_t's) and net standing facilities. Lower required reserves also reduce market interest rates.

In subsequent sections we will calculate the size of open market operations necessary to keep interest rates given by expressions (4.8) and (4.9) as close as possible to the target rate i. We will do this first under the assumption that the central bank intervenes in the reserve market twice - that will be our frequent (multiple) intervention benchmark. Secondly, we will explore the consequences of intervening less frequently, i.e. only once, within the maintenance period.

4.3 Multiple vs single open market operations

The central bank that wants to use open market operations to minimize the volatility of interest rates around the operating target, has to solve the following stochastic optimization problem:

$$\begin{aligned} Min_{m_1,m_2}\, L &= E[(i_1 - i)^2 + (i_2 - i)^2] \\ &\quad \text{subject to conditions (4.8), (4.9) and } r_0 = r_3^e = 0 \end{aligned} \tag{4.10}$$

The last constraint is added to improve the transparency of the analysis and is justified if we restrict our attention to the relationship between interest rates and reserves held within a single maintenance period.[20]

The sequence of events is as follows: before the beginning of the maintenance period the central bank calculates its forecasts of autonomous factors for both days and makes them public. The level of required reserves as well as the target interest rate are also known to market participants. The central bank has to decide on its operations before it observes the realization the autonomous factors and the reserves' demand disturbance on the first day of the maintenance period.

If the operational framework of the central bank presumes open market operations only on one day of the maintenance period, it implies that the size of one of the open market operations m_t in expressions (4.8) and (4.9) should by assumption be set to zero. Carrying out open market operations towards the end of the reserve maintenance period raises issues related to the availability and usefulness of information on liquidity conditions at the beginning of the maintenance period. If midway through the maintenance period data on the actual level of autonomous factors, the recourse to standing facilities and the actual shock to the demand for reserves on the first day of the reserve maintenance period (i.e. a_1, s_1 and ε_1) is available, the subsequent optimal provision of the central bank's liquidity should take these factors into account.

If required reserves are imposed, with the averaging provision in place, then it is natural that the optimal liquidity provision open market operations should ensure a smooth fulfillment of the reserve requirements. In the case of a 2-day reserve maintenance pe-

[20] r_0 is the level of reserves held in the preceding maintenance period and r_3^e is the expected level of reserves on the first day of the following maintenance period.

riod, that implies the following condition[21] $\frac{(m_1-a_1^f)+(m_2-a_2^f)}{2} = R$ or the set of conditions: $\frac{\partial(m_1+m_2)}{\partial R} = 2$, $\frac{\partial(m_1+m_2)}{\partial a_1^f} = \frac{\partial(m_1+m_2)}{\partial a_2^f} = 1$, $\frac{\partial(m_1+m_2)}{\partial i} = 0$.

Under the multiple operations' strategy, the optimal provision of liquidity reads as follows:

$$m_1^* = a_1^f + \frac{\beta_1\gamma_2 - \gamma_1}{\beta_1\alpha_2 - 1}R + \frac{\delta_1 - \delta_2\beta_1}{\beta_1\alpha_2 - 1}i \tag{4.11}$$

$$m_2^* = a_2^f + \frac{\alpha_2\gamma_1 - \gamma_2}{\beta_1\alpha_2 - 1}R + \frac{\delta_2 - \alpha_2\delta_1}{\beta_1\alpha_2 - 1}i \tag{4.12}$$

If the frequency of open market operations is limited, then the optimal provision of liquidity is given as:

$$m_1^{**} = a_1^f + \frac{\delta_2^2\beta_1+\alpha_2\delta_1^2}{\delta_2^2+\alpha_2^2\delta_1^2}a_2^f + \frac{\delta_2^2\gamma_1+\alpha_2\delta_1^2\gamma_2}{\delta_2^2+\alpha_2^2\delta_1^2}R - \delta_1\delta_2\frac{\delta_2+\alpha_2\delta_1}{\delta_2^2+\alpha_2^2\delta_1^2}i \tag{4.13}$$

if open market operations are carried out on the first day of the reserve maintenance period and

$$m_2^{**} = a_2^f + \frac{\beta_1\delta_2^2+\delta_1^2\alpha_2}{\beta_1^2\delta_2^2+\delta_1^2}a_1^f + \frac{\delta_1^2\gamma_2+\beta_1\delta_2^2\gamma_1}{\beta_1^2\delta_2^2+\delta_1^2}R - \delta_1\delta_2\frac{\beta_1\delta_2+\delta_1}{\beta_1^2\delta_2^2+\delta_1^2}i \tag{4.14}$$

or

$$\widehat{m}_2^{**} = a_2^f + \frac{\alpha_2\delta_1^2+\beta_1\delta_2^2}{\beta_1^2\delta_2^2+\delta_1^2}(a_1 - s_1) + \frac{\beta_1\delta_2^2}{\beta_1^2\delta_2^2+\delta_1^2}\varepsilon_1 + \frac{\delta_1^2\gamma_2+\beta_1\delta_2^2\gamma_1}{\beta_1^2\delta_2^2+\delta_1^2}R - \delta_1\delta_2\frac{\beta_1\delta_2+\delta_1}{\beta_1^2\delta_2^2+\delta_1^2}i \tag{4.15}$$

if the operations are carried out at the end of the reserve maintenance period. Equation (4.14) describes the provision of funds if data on liquidity conditions is available with considerable lags. If data is produced timely, the optimal size of day-2 operations should be calculated according to formula (4.15). Relative to m_2^{**}, $\widehat{m}_2^{**}$ is determined based on the actual level of outstanding autonomous factors after day-1 $(a_1 - s_1)$ instead of the absolute forecast a_1^f. Moreover, $\widehat{m}_2^{**}$ is adjusted in response to the realization of the shock in the demand for liquidity ε_1.

[21] Derived from $\frac{E[r_1]+E[r_2]}{2} = R$, where r_1 and r_2 are given by equation (4.2).

Our calibrated coefficient values indicate the following derivatives in the euro area:[22]

	$m_1^* + m_2^*$	m_1^{**}	m_2^{**} or $\widehat{m}_2^{**}$
a_1^f [23]	1	1	$\frac{\alpha_2\rho^2+\beta_1}{\beta_1^2+\rho^2} \begin{cases} \to 0.69 \text{ if } \rho \to \infty \\ = 0.71 \text{ if } \rho = 4.4 \end{cases}$
a_2^f	1	$\frac{\beta_1+\alpha_2\rho^2}{1+\alpha_2^2\rho^2} \begin{cases} \to 1.45 \text{ if } \rho \to \infty \\ = 1.38 \text{ if } \rho = 4.4 \end{cases}$	1
R	2.25	$\frac{\gamma_1+\alpha_2\gamma_2\rho^2}{1+\alpha_2^2\rho^2} \begin{cases} \to 2.45 \text{ if } \rho \to \infty \\ = 2.42 \text{ if } \rho = 4.4 \end{cases}$	$\frac{\rho^2\gamma_2+\beta_1\gamma_1}{\beta_1^2+\rho^2} \begin{cases} \to 1.69 \text{ if } \rho \to \infty \\ = 1.72 \text{ if } \rho = 4.4 \end{cases}$
i	0 if $\delta_t = 0$ -0.17 if $\delta_t \neq 0$	0 if $\delta_t = 0$ -0.09 if $\delta_t \neq 0$	0 if $\delta_t = 0$ -0.06 if $\delta_t \neq 0$

The calibrated coefficients of the optimal provision of liquidity through multiple open market operations correspond very well to the numbers implied by the smooth fulfillment of averaged required reserves. If the central bank would limit the frequency of the liquidity provision through OMOs, then the smooth fulfillment conditions would hold, if commercial banks would adjust their behavior, so that α_2 and β_1 would come closer to unity and γ_1 would be roughly equal and would approach two.

Let us now consider the behavior of market interest rates. If the central bank employs multiple open market operations, then it is able to keep market interest rates on average be equal to the target rate.[24] Not surprisingly, if we reduce the frequency of interventions,[25] then overnight interest rates may not be equal the target rate, even on average. In formal terms: Under multiple open market operations, the market interest rates are given as follows:

$$i_1(m_1^*, m_2^*) = i + \frac{1}{\delta_1}(a_1 - a_1^f - s_1 + \varepsilon_1) \tag{4.16}$$

$$i_2(m_1^*, m_2^*) = i + \frac{1}{\delta_2}(a_2 - a_2^f - s_2 + \alpha_2\left(a_1 - a_1^f - s_1\right) + \varepsilon_2) \tag{4.17}$$

As a result

$$E\left[i_1(m_1^*, m_2^*) - i\right] = E\left[i_2(m_1^*, m_2^*) - i\right] = 0 \tag{4.18}$$

[22] ρ denotes the ratio of interest rates elasticities: $\rho = \delta_1/\delta_2$. If $\delta_2 \to 0$ then $\rho \to \infty$. $\rho = 4.4$ corresponds to the parameters presented in table 4.3.

[23] Or $(a_1 - s_1)$ in case of $\widehat{m}_2^{**}$.

[24] So that the Tinbergen principle of one instrument-one goal (one intervention-stabilizing interest rate in one sub-period) is satisfied.

[25] Thereby removing one of the instruments, but leaving two objectives.

If the central bank implements the open market operations only on the first day of the reserve maintenance period, interest rates in the reserve market are given by:

$$\begin{aligned} i_1(m_1^{**}) &= \tfrac{\delta_2^2+\alpha_2\delta_1\delta_2}{\delta_2^2+\alpha_2^2\delta_1^2} i + \tfrac{\alpha_2\delta_1(\beta_1\alpha_2-1)}{\delta_2^2+\alpha_2^2\delta_1^2} a_2^f + \tfrac{\alpha_2\delta_1(\gamma_1\alpha_2-\gamma_2)}{\delta_2^2+\alpha_2^2\delta_1^2} R \\ &\quad + \tfrac{1}{\delta_1}\left(a_1 - a_1^f - s_1 + \varepsilon_1\right) \qquad (4.19) \\ i_2(m_1^{**}) &= \tfrac{\delta_2\delta_1\alpha_2+\alpha_2^2\delta_1^2}{\delta_2^2+\alpha_2^2\delta_1^2} i - \tfrac{\delta_2(\beta_1\alpha_2-1)}{\delta_2^2+\alpha_2^2\delta_1^2} a_2^f - \tfrac{\delta_2(\gamma_1\alpha_2-\gamma_2)}{\delta_2^2+\alpha_2^2\delta_1^2} R \\ &\quad + \tfrac{1}{\delta_2}\left(a_2 - a_2^f - s_2 + \alpha_2\left(a_1 - a_1^f - s_1\right) + \varepsilon_2\right) \qquad (4.20) \end{aligned}$$

Therefore:

$$E\left[i_1(m_1^{**}) - i\right] = \tfrac{\alpha_2\delta_1}{\delta_2^2+\alpha_2^2\delta_1^2}\left((\delta_2-\alpha_2\delta_1)\, i + (\beta_1\alpha_2-1)\, a_2^f + (\gamma_1\alpha_2-\gamma_2)\, R\right) \qquad (4.21)$$

$$E\left[i_2(m_1^{**}) - i\right] = -\tfrac{\delta_2}{\delta_2^2+\alpha_2^2\delta_1^2}\left((\delta_2-\alpha_2\delta_1)\, i + (\beta_1\alpha_2-1)\, a_2^f + (\gamma_1\alpha_2-\gamma_2)\, R\right) \qquad (4.22)$$

Contrary to the case of multiple open market operations, the average control errors $E\left[i_t(m_1^{**}) - i\right]$ are non-zero and depend on the relations between parameters of the model. The reasoning is analogous for the open market operations carried out only on the second day of the reserve maintenance period. The informational issues will have impact on the interest rate on the second day of the reserve maintenance period only. The interest rate $i_1(m_2^{**})$ depends on the information available at time $t = 0$ and is given by:

$$\begin{aligned} i_1(m_2^{**}) &= i_1(\widehat{m}_2^{**}) = \tfrac{\beta_1^2\delta_2^2+\beta_1\delta_2\delta_1}{\beta_1^2\delta_2^2+\delta_1^2} i + \tfrac{\delta_1(\gamma_1-\beta_1\gamma_2)}{\beta_1^2\delta_2^2+\delta_1^2} R - \tfrac{\delta_1(\beta_1\alpha_2-1)}{\beta_1^2\delta_2^2+\delta_1^2} a_1^f \\ &\quad + \tfrac{1}{\delta_1}\left(a_1 - a_1^f - s_1 + \varepsilon_1\right) \qquad (4.23) \end{aligned}$$

$i_2(m_2^{**})$ depends on the information available through $t = 1$ and will settle at:

$$\begin{aligned} i_2(m_2^{**}) &= \tfrac{\beta_1\delta_2\delta_1+\delta_1^2}{\beta_1^2\delta_2^2+\delta_1^2} i + \tfrac{\beta_1\delta_2(\beta_1\gamma_2-\gamma_1)}{\beta_1^2\delta_2^2+\delta_1^2} R + \tfrac{\beta_1\delta_2(\beta_1\alpha_2-1)}{\beta_1^2\delta_2^2+\delta_1^2} a_1^f \\ &\quad + \tfrac{1}{\delta_2}\left(a_2 - a_2^f - s_2 + \alpha_2\left(a_1 - a_1^f - s_1\right) + \varepsilon_2\right) \qquad (4.24) \end{aligned}$$

or

$$\begin{aligned} i_2(\widehat{m}_2^{**}) &= \tfrac{\beta_1\delta_2\delta_1+\delta_1^2}{\beta_1^2\delta_2^2+\delta_1^2} i + \tfrac{\beta_1\delta_2(\beta_1\gamma_2-\gamma_1)}{\beta_1^2\delta_2^2+\delta_1^2} R + \tfrac{\beta_1\delta_2(\beta_1\alpha_2-1)}{\beta_1^2\delta_2^2+\delta_1^2}\left(a_1 - s_1\right) \\ &\quad - \tfrac{\beta_1\delta_2}{\beta_1^2\delta_2^2+\delta_1^2}\varepsilon_1 + \tfrac{1}{\delta_2}\left(a_2 - a_2^f - s_2 + \varepsilon_2\right) \qquad (4.25) \end{aligned}$$

We have assumed that $E\left[a_t\right] = a_t^f$ for $t = 1, 2$, where a_t^f is the central bank's forecast, $E\left[s_t\right] = 0$ and ε_t is a white-noise disturbance. As a result the magnitude of the control errors does not depend on the data availability and is given by:

$$E\left[i_1(m_2^{**}) - i\right] = E\left[i_1(\widehat{m}_2^{**}) - i\right]$$
$$= \tfrac{\delta_1}{\beta_1^2\delta_2^2+\delta_1^2}\Big(\left(\beta_1\delta_2 - \delta_1\right) i + \left(1 - \beta_1\alpha_2\right) a_1^f + \left(\gamma_1 - \beta_1\gamma_2\right) R\Big) \tag{4.26}$$
$$E\left[i_2(m_2^{**}) - i\right] = E\left[i_2(\widehat{m}_2^{**}) - i\right]$$
$$= -\tfrac{\beta_1\delta_2}{\beta_1^2\delta_2^2+\delta_1^2}\Big(\left(\beta_1\delta_2 - \delta_1\right) i + \left(1 - \beta_1\alpha_2\right) a_1^f + \left(\gamma_1 - \beta_1\gamma_2\right) R\Big) \tag{4.27}$$

which can deviate from zero.

However, the size of required reserves is also determined by the central bank, and here the importance of this instrument is clearly shown:

Proposition 4.1 *The control errors, i.e. average deviations of market interest rates from the target due to infrequent open market operations, can be reduced if required reserves are set according to the formulas:*

$$R(m_1^{**}) = \frac{\left(\delta_2 - \alpha_2\delta_1\right) i + \left(\beta_1\alpha_2 - 1\right) a_2^f}{\gamma_1\alpha_2 - \gamma_2} \tag{3.19}$$

for the operations carried out at the beginning of the reserve maintenance period, and

$$R(m_2^{**}) = \frac{\left(\beta_1\delta_2 - \delta_1\right) i + \left(1 - \beta_1\alpha_2\right) a_1^f}{\gamma_1 - \beta_1\gamma_2} \tag{3.20}$$

for the operations carried out at the end of the maintenance period.

Proof. See formulas (4.21) and (4.22): $E\left[i_1(m_1^{**}) - i\right] = E\left[i_2(m_1^{**}) - i\right] = 0$ if $\delta_2 - \alpha_2\delta_1 = \beta_1\alpha_2 - 1 = \gamma_1\alpha_2 - \gamma_2 = 0$ or $R = R(m_1^{**})$. Similarly (formulas (4.26) and (4.27)): $E\left[i_1(m_2^{**}) - i\right] = E\left[i_2(m_2^{**}) - i\right] = 0$ if $\beta_1\delta_2 - \delta_1 = 1 - \beta_1\alpha_2 = \gamma_1 - \beta_1\gamma_2 = 0$ or $R = R(m_2^{**})$. ■

Furthermore, an effective use of required reserves, i.e. setting the requirements at the appropriate level (given by formulas (3.19) and (3.20)), affects the overnight volatility, and allows central bank to limit the frequency of interventions in the reserve market without a significant increase in the volatility of interest rates:

Proposition 4.2 *1. If the control errors are eliminated, then the volatility of overnight interest rates does not increase with the reduction in the frequency of open market operations. It is therefore possible to limit the frequency of central bank's interventions in the reserve market without a significant increase in the volatility of interest rates.*

2. *The availability of real-time data on the liquidity conditions throughout the maintenance period is likely to represent an additional factor dampening the excess volatility of overnight interest rates associated with a reduction in the frequency of open market operations.*

Proof. The volatility of overnight interest rates under the multiple operations' strategy $L(m_1^*, m_2^*)$ is given by:

$$\begin{aligned} L(m_1^*, m_2^*) &= E[(i_1(m_1^*, m_2^*) - i)^2 + (i_1(m_1^*, m_2^*) - i)^2] \\ &= \tfrac{\delta_2^2+\delta_1^2\left(\alpha_2^2+1\right)}{\delta_1^2\delta_2^2}\sigma_a^2 + \tfrac{\delta_2^2+\alpha_2^2\delta_1^2}{\delta_1^2\delta_2^2}\sigma_{s_1}^2 + \tfrac{1}{\delta_2^2}\sigma_{s_2}^2 + \tfrac{\delta_2^2+\delta_1^2}{\delta_1^2\delta_2^2}\sigma_\varepsilon^2 \end{aligned} \tag{3.21}$$

The corresponding loss in the case when open market operations are carried out solely on the first day of the reserve maintenance period is given as:

$$L(m_1^{**}) = L(m_1^*, m_2^*) + \tfrac{1}{\delta_2^2+\alpha_2^2\delta_1^2}\left((\delta_2 - \alpha_2\delta_1)\, i + (\beta_1\alpha_2 - 1)\, a_2^f + (\gamma_1\alpha_2 - \gamma_2)\, R\right)^2 \tag{3.22}$$

whereas the loss incurred when the operations take place on the second day of the reserve maintenance period is given as:

$$L(m_2^{**}) = L(m_1^*, m_2^*) + \tfrac{1}{\beta_1^2\delta_2^2+\delta_1^2}\left((\beta_1\delta_2 - \delta_1)\, i + (1 - \beta_1\alpha_2)\, a_1^f + (\gamma_1 - \beta_1\gamma_2)\, R\right)^2 \tag{3.23}$$

Therefore, if $R = R(m_1^{**})$ $(R = R(m_2^{**}))$, then $L(m_1^{**}) = L(m_1^*, m_2^*)$ $(L(m_2^{**}) = L(m_1^*, m_2^*))$.

The use of real-time information affects the ex-ante expected volatility loss: $L(\widehat{m}_2^{**})$ is given by:

$$L(\widehat{m}_2^{**}) = L(m_2^{**}) + \frac{\beta_1^2\delta_2^2}{\left(\beta_1^2\delta_2^2+\delta_1^2\right)^2}\sigma_\varepsilon^2 + \left(\left(\frac{\beta_1\delta_2(\beta_1\alpha_2-1)}{\beta_1^2\delta_2^2+\delta_1^2}\right)^2 - \frac{\alpha_2^2}{\delta_2^2}\right)\left(\sigma_a^2 + \sigma_{s_1}^2\right) \tag{3.24}$$

Since $\left(\left(\frac{\beta_1\delta_2(\beta_1\alpha_2-1)}{\beta_1^2\delta_2^2+\delta_1^2}\right)^2 - \frac{\alpha_2^2}{\delta_2^2}\right) - \frac{\beta_1^2\delta_2^2}{\left(\beta_1^2\delta_2^2+\delta_1^2\right)^2} = -\alpha_2\frac{2\beta_1^3\delta_2^4+2\alpha_2\beta_1^2\delta_2^2\delta_1^2+\alpha_2\delta_1^4}{\left(\beta_1^2\delta_2^2+\delta_1^2\right)^2\delta_2^2} \leq 0$, then (unless σ_ε^2 is much larger than $\left(\sigma_a^2 + \sigma_{s_1}^2\right)$), $L(\widehat{m}_2^{**}) < L(m_2^{**})$. ■

The second part of proposition 1 leads to an immediate result:

Proposition 4.3 *If* $\delta_2/\delta_1 \to 0$, *then foregoing open market operations at the beginning of the reserve maintenance period is likely to yield lower excess overnight volatility than foregoing operations at the end of the maintenance period.*

	Eonia	t-statistic	FF rate	t-statistic
1999	0.026	2.189	-0.006	-0.568
2000	0.109	11.786	0.018	2.444
2001	0.090	6.375	-0.014	-1.113
2002	0.068	8.588	-0.002	-0.475

Table 4.4: Average interest rate control errors in the euro zone and the US

Proof. The difference between the losses in terms of excess overnight volatility due to limited frequency of open market operations is given as:

$$\begin{aligned} L(m_1^{**}) - L(m_2^{**}) &= \tfrac{1}{\delta_2^2+\alpha_2^2\delta_1^2}\Big(\left(\delta_2 - \alpha_2\delta_1\right)i + \left(\beta_1\alpha_2 - 1\right)a_2^f + \left(\gamma_1\alpha_2 - \gamma_2\right)R\Big)^2 \\ &\quad - \tfrac{1}{\beta_1^2\delta_2^2+\delta_1^2}\Big(\left(\beta_1\delta_2 - \delta_1\right)i + \left(1 - \beta_1\alpha_2\right)a_1^f + \left(\gamma_1 - \beta_1\gamma_2\right)R\Big)^2 \end{aligned}$$

If $\delta_2/\delta_1 \rightarrow 0$, then $\frac{1}{\delta_2^2+\alpha_2^2\delta_1^2} \geq \frac{1}{\beta_1^2\delta_2^2+\delta_1^2}$ and, for control errors of comparable magnitude, $L(m_1^{**}) \geq L(m_2^{**}) \geq L(\widehat{m}_2^{**})$. ■

4.4 Discussion

The model predicts that average control errors in the US should be smaller than in the euro area since the Federal Reserve intervenes every day. These conclusions are supported by the empirical evidence, reported in table 4.4. Annual average deviations of the federal funds rate from the target are hardly ever significantly different from zero. The average control errors in the management of the overnight interest rate in the euro area are always significantly different from zero, although their magnitude is very small.

Nevertheless, it is the overnight volatility, which we are mostly concerned about. Our results suggest that comparable levels of overnight interest rates volatility in the euro area and in the United States are due an appropriate use of required reserves. Table 4.5 presents average levels of required reserves in comparison to average levels of net autonomous factors in Europe and in the United States over the years 1999-2002.

Comparing this table with the overnight volatility numbers (reported in table 4.2), we can conclude that there seems to exist a unique ratio of average required reserves and the average of forecasted autonomous factors yielding the best results in terms of reducing the excess overnight volatility: R/a_t^f close to 1.25. The results of our analysis indeed confirm

	Euro area (EUR bln)			USA (USD bln)		
	R	a_t^f	R/a_t^f	R	$E[a_t]$[26]	$R/E[a_t]$
1999	101.69	84.34[27]	1.206	41.63	536.75	0.008
2000	111.64	113.26	0.986	38.95	571.62	0.007
2001	123.73	94.86	1.304	38.45	601.49	0.006
2002	129.88	54.30	2.392	38.76	654.36	0.006

Table 4.5: Required reserves and autonomous factors in the euro area and the US

that such a ratio should exist. Moreover, the empirical ratio corresponds surprisingly well to average of the model-implied ratios:[28] $\frac{1}{2}\left(\frac{\partial R(m_1^{**})}{\partial a_2^f}+\frac{\partial R(m_2^{**})}{\partial a_1^f}\right)=1.3957.$

Although we have to acknowledge that our findings are based on certain simplifications vis-a-vis actual practises (e.g. an implicit treatment of averaging provisions) we were still able to address interesting policy-related issues regarding the factors affecting the overnight volatility. We have identified the crucial factor reducing the overnight volatility in the euro area and bringing it in line with the overnight volatility in the United States: the appropriate level of required reserves implemented by the European Central Bank.

4.5 Appendix 1. Inventory model of the demand for reserves

In this section we seek to provide very simple micro-foundations for the error correction mechanism given by equation (4.3). Let us assume, that a representative commercial bank wants to minimize the discounted cost of holding reserves over the reserve maintenance period of length T, given as the sum of the following components:

1. opportunity cost

$$\sum_{t=1}^{T}\delta^t i_t r_t$$

where δ is the discount factor, i_t is the overnight interest rate and r_t is the level of reserves

[28] Calibrated using the values reported in table 4.3.

2. cost of having excess reserves on the last day of the maintenance period

$$(i_T - i_d)\,\delta^T \left(\left(\frac{1}{T} \sum_{t=1}^{T} r_t - R \right) + x \right) \Pr(\frac{1}{T} \sum_{t=1}^{T} r_t + x > R)$$

3. cost of being short of reserve requirements on day T

$$i_f \delta^T \left(x + \left(\frac{1}{T} \sum_{t=1}^{T} r_t - R \right) \right) \Pr(\frac{1}{T} \sum_{t=1}^{T} r_t + x < R)$$

where x is the liquidity shock on the last day of the maintenance period.

If we assume that this shock is uniformly distributed over $[-M, M]$ (where negative (positive) values correspond to an unexpected outflow (inflow) of liquidity), the bank is facing the following costs:

$$\begin{aligned} TC = \sum_{t=1}^{T} \delta^t i_t r_t + (i_T - i_d)\,\delta^T \left(\left(\frac{1}{T} \sum_{t=1}^{T} r_t - R \right) + x \right) \Pr(\frac{1}{T} \sum_{t=1}^{T} r_t + x > R) \\ + i_f \delta^T \left(x + \left(\frac{1}{T} \sum_{t=1}^{T} r_t - R \right) \right) \Pr(\frac{1}{T} \sum_{t=1}^{T} r_t + x < R) \end{aligned}$$

The expected costs of holding reserves are then given as:

$$\begin{aligned} E_x\left[TC\right] = \sum_{t=1}^{T} \delta^t i_t r_t + \frac{1}{4}(i_T - i_d)\,\delta^T \frac{M^2T^2 - 3\left(\sum_{t=1}^{T} r_t\right)^2 + 6\left(\sum_{t=1}^{T} r_t\right)RT - 3R^2T^2 + 2\left(\sum_{t=1}^{T} r_t\right)MT - 2RT^2M}{MT^2} \\ -\frac{1}{4} i_f \delta^T \frac{M^2T^2 - 3\left(\sum_{t=1}^{T} r_t\right)^2 + 6\left(\sum_{t=1}^{T} r_t\right)RT - 3R^2T^2 - 2\left(\sum_{t=1}^{T} r_t\right)MT + 2RT^2M}{MT^2} \end{aligned}$$

The First Order Condition with respect to time-t reserve holdings is given as:

$$\begin{aligned} \frac{\partial f}{\partial r_t} = \delta^t i_t - \frac{1}{4} i_f \delta^T \frac{-6\left(\sum_{t=1}^{T} r_t\right) + 6RT - 2MT}{MT^2} \\ + \frac{1}{4}(i_T - i_d)\,\delta^T \frac{-6\left(\sum_{t=1}^{T} r_t\right) + 6RT + 2MT}{MT^2} = 0 \end{aligned}$$

which results in the following expression:

$$\frac{1}{T}\left(\sum_{t=1}^{T} r_t \right) = -\frac{2}{3} \frac{MT}{\delta^{T-t}(i_f + i_d - i_T)} i_t + R - \frac{1}{3} M \frac{i_T + i_f - i_d}{i_f + i_d - i_T}$$

Therefore

$$r_t + r_{t-1} + r_{t+1} = -\frac{2}{3} \frac{MT^2}{\delta^{T-t}(i_f + i_d - i_T)} i_t + TR - \frac{1}{3} MT \frac{i_T + i_f - i_d}{i_f + i_d - i_T} - \sum_{s \neq \{t, t-1, t+1\}, s=1}^{T} r_s$$

It follows that the relationship between day-t reserves and other variables in the model is:

$$\frac{\partial r_t}{\partial r_{t-1}} < 0, \frac{\partial r_t}{\partial r_{t+1}} < 0, \frac{\partial r_t}{\partial R} > 0, \frac{\partial r_t}{\partial i_t} < 0$$

4.6 Appendix 2. Regression results

The regressions were carried out on weekly data on the ECB's operations for 1999-2001. The reserve maintenance period was divided into two 2-week sub-periods. The series used were: the average current accounts during the first two weeks (r_t^1), the average current accounts during the last two weeks (r_t^2), the required reserves (R) and average Eonia rate during the first and the last two weeks of the reserve maintenance period (i_t^1 and i_t^2, respectively).

Series	Mean	StDev	ADF test statistic	Unit Root
$r_{\mathbf{t}}^{\mathbf{1}}$	11.89604	0.989459	-1.354202	Yes
$r_{\mathbf{t}}^{\mathbf{2}}$	11.79642	1.249543	-1.149758	Yes
R	11.74642	1.090253	-1.290094	Yes
$i_{\mathbf{t}}^{\mathbf{1}}$	3.676041	0.777347	-2.353858	Yes
$i_{\mathbf{t}}^{\mathbf{2}}$	3.632088	0.825898	-2.477763	Yes

The VAR estimations[29] yield the following coefficients for first sub-period of the maintenance period (standard errors in () and t-statistics in []):

α_1	β_1	γ_1	δ_1
0.381094	0.775794	2.153058	0.223444
(0.17963)	(0.12214)	NA	(0.15687)
[2.12150]	[6.35149]	NA	[1.42440]

For the second sub-period of the maintenance period the estimated VAR coefficients were:

[29]The stationary variables used were the excess reserves (i.e. $r_t - R$) and first differences of interst rates.

α_2	β_2	γ_2	δ_2
0.688416	0.177981	1.688416	0.048781
(0.09902)	(0.11218)	NA	(0.10721)
[6.95210]	[1.58658]	NA	[0.45500]

Both coefficients on interest rate in the first and second sub-periods of the reserve maintenance period in the euro zone are barely statistically significant, although they are of the correct sign.

Chapter 5

Summary and conclusions

5.1 Summary

In the first part of this thesis we have taken a closer look at the effects of collective decision making on the behavior of monetary policy makers. In the case when decisions are taken by a group, instead of a single person, matters such as decision rules and deliberation protocols gain importance and can be modified to make the most efficient use of differences in policy makers' views on the economy, their information and skills. In chapter 2 we have investigated possible improvements of the structure of the monetary policy committee, which would give appropriate attention to these inherent differences.

It is well-known from the jury literature that, if committee members have heterogeneous expertise, then the optimal (first-best) decision rule should weight their votes according to their skills. However, in most real-life situations, and in particular in monetary policy committees, votes are not weighted according to expertise. Instead, decisions are taken by simple majority. Hence, a sub-optimal decision rule is applied and, as a result, the accuracy of collective decision deteriorates in comparison to the first-best outcome. Depending on the heterogeneity in committee members' expertise and the committee size, the loss in accuracy can reach up to 35.5%. In other words, due to procedural shortcomings, the probability that the MPC takes the correct decision is lowered by up to 35.5%.

We have shown that an appropriate structuring of the committee eliminates the inefficient use of heterogeneous expertise of committee members, while retaining the simple majority voting rule. We proposed to divide the committee into two sub-groups according to expertise, allow the more-skilled group to meet prior to the actual policy meeting and to produce a common 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 Janis (1982) to prevent a detrimental concurrence-seeking group dynamics, labelled as groupthink, from occurring.

Creating a subgroup of more-skilled members improves the accuracy of collective decisions. This structure works particularly well in a relatively small committee and completely eliminates the inefficiency stemming from the use of simple majority voting rule. In larger committees, the inefficiency is reduced but not eliminated, in particular when expertise of committee members is highly heterogeneous. However, by requiring higher-skilled committee members to communicate their common position before the vote on interest rates, the quality of monetary policy could again be enhanced to approximate the first-best result. This is because the announcement provides an additional, highly accurate, common signal to the less-skilled committee members; their rational choice is to follow this signal instead of their own, far less accurate, information.

In chapter 3 we have taken another step in assessing the impact of collective decision making on the quality of monetary policy. We formulated a model capturing interaction and exchange of information among committee members. Both effects are considered to be important characteristics of real-life monetary policy committees (Goodfriend (1999)).

We have assumed that monetary policy committee members share a common view on the model of the economy but have their own, independently formulated, views on future shocks to the inflation rate. Hence, they all have different beliefs regarding the appropriate monetary policy stance, even if they share a common inflation objective. If the decision making procedure foresees only simultaneous voting, a committee would adopt the median interest rate. If committee members can share and pool their views, their expertise is likely to improve. We label this process as 'learning'. We have shown that learning improves the accuracy of collective decisions, even though it introduces a positive correlation between the votes of committee members. At its maximum, the improvement comes out at 50%.

If all committee members participate in information sharing and learning, they should form a common estimate of economic shocks. Optimally, such estimate should involve weighting of the information that has been shared according to the level of individual expertise (as in the case of simple decision-making rules which do not involve interaction). However, this optimal procedure need not be applied in reality. Our analysis shows that implementing simpler decision-making rules which do not require weighting, such as simple averaging of individual estimates or limiting information exchange to the more-skilled committee members, can again approximate the optimal outcome.

Lastly, we have compared the net benefits of different decision making procedures discussed in both chapters, having imposed the costs on committee participation and on meeting duration. Allowing for communication among committee members makes the optimal committee size bounded, even if the costs are minimal (without communication we would have the Condorcet's result: the optimal committee size would be infinite). 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). As the membership and time costs increase, communication and learning become more and more crucial for the accuracy of collective decisions: decision-making procedures involving learning yield higher collective accuracy than any procedure that excludes learning. In some cases they involve lower costs as well.

In the second part of the thesis, we have turned to analyzing institutional aspects of central bank's implementation of monetary policy. We have adopted the 'new view' on monetary policy implementation (Bindseil (2005)), assuming that a short-term interest rate represents the appropriate operational target, and standing facilities, open market operations and required reserves are the instruments useful in steering short-term interest rates. This approach has achieved a considerable degree of consensus over the last ten to fifteen years. Nevertheless, it still allows for a considerable room for discretion as regards the exact instrument mix: the level and characteristics of reserve requirements, the type and frequency of open market operations and the width of the interest rate corridor set by standing facilities.

In chapter 4 we have shown, based on real-life examples of the euro area and the United States, that a central bank can achieve comparable levels of interest rate stabilization using quite diverse operating frameworks. An important conclusion is that more frequent central bank operations in the overnight reserve market do not automatically translate into more stable interest rates. Other instruments play an important role as well. This conclusion has led us to formulate a model of the overnight reserve market, where the central bank carries out open market operations with the objective of minimizing the deviations of overnight interest rates from the target rate. Commercial banks are subject to reserve requirements, and therefore their objective is to minimize the opportunity cost of holding reserves throughout the reserve maintenance period and the penalty costs of being long or short of reserves at the end of the maintenance period.

The model predicts that, regardless of the design of required reserves and standing facilities, the average deviation of the overnight interest rate from the target rate is higher if the frequency of open market operations is lower. This result is supported by the empirical evidence. The Federal Reserve carries open market operations daily while the European Central Bank operates weekly: annual average deviations of the Federal Funds rate from the target are hardly ever significantly different from zero, while average deviations for the Eonia rate always significantly differ from zero.

Further, we show that the overnight volatility may be negatively related to the frequency of open market operations, meaning that reducing the frequency is likely to produce increased overnight volatility. However, the model generates a relationship for calculating an appropriate level of required reserves necessary to eliminate such excess volatility. These results are also supported by the data: the average annual overnight volatility in the euro area is not necessarily statistically different from the volatility in the United States. Moreover, the average ratio of autonomous factors and required reserves in the euro area, calculated for the years 1999-2002, is 1.25; calibrated model-implied ratio amounts to 1.4. The similarity is striking. We conclude that this result explains the statistical insignificance of the difference between overnight volatility levels in the two monetary areas.

5.2 Applications and suggestions for further research

The results of the chapters 2 and 3 of the thesis can be applied to explaining the experimental findings discussed in the introduction to this volume. Blinder and Morgan (forthcoming) found that majority decisions quickly evolved into unanimous decisions. This result comes about for the same reason as the herding of the less-skilled committee members, described in chapter 2: a majority position constitutes a highly accurate common signal to other committee members, which they rationally cannot ignore. Lombardelli et al. (2002) found that groups gave more weight to the better and less weight to the worse committee members. This empirical finding is consistent with the theoretical literature, which shows that such behavior consists the most efficient decision making procedure in a committee composed of individuals with diverse levels of expertise. Both experiments resulted in the conclusion that "a committee performs better than a sum of its parts": the accuracy of group decisions has exceeded both the average of individual scores and the median score that would be obtained under pure simultaneous and independent voting. Chapter 3 gives a theoretical rationale for this result. It is due to the fact that committee members exchange information, and therefore improve their performance. Their higher expertise naturally translates into higher quality of collective decisions.

The theoretical results from chapters 2 and 3 provide a rationale for a number of findings from the empirical literature, which has studied the behavior of members of the Federal Open Market Committee (FOMC) of the Federal Reserve and the Monetary Policy Committee (MPC) of the Bank of England. Gerlach-Kristen (2003a), for example, provides evidence that the less experienced MPC members tend to vote with the majority position (on average they dissent for the first time at their ninth meeting.). This is a direct application of the results from chapter 2. Meade (2002) has found that the likelihood of voiced dissents has been comparable between the FOMC and the MPC: 14% in the first and 16.6% in the latter. However, the percentage of formal dissents (i.e. dissenting votes) in the FOMC was only 7.8%. The study covers the period 1992-1996 and Meade concludes that this result is due to a strong influence of chairman Greenspan.[1] Our analysis in chapter 2 not only provides the rationale for such behavior but also shows that it can improve policy outcomes.

Meade and Sheets (forthcoming) and Gerlach-Kristen (2003a), among others, have found that the members of the center are less likely to dissent. Gerlach-Kristen (2003a) explains: "... Working at the Bank may provide them [the insiders] with more information and opportunities for discussion about the economy and each others' views, which might lead them to vote as a block more frequently and dissent from the majority more rarely..."

[1] For more details on the FOMC decisions in the Greenspan years, see Chappell et al. (2005), chapter 8.

(p. 100). This result illustrates our conclusions from chapter 3, where we show that sharing information results in a more accurate estimate of the economic shocks, which will rationally be followed by the sub-committee members in their voting.

Still, the studies cited above limit the analysis to the effects of group dynamics on individually desired interest rates, and hence provide a partial illustration to the conclusions drawn in chapters 2 and 3. However, there is a recent and so far unique study by Romer and Romer (2003) that provides a link between characteristics of individual decision makers and the quality of monetary policy, measured in terms of macroeconomic performance. The authors have concluded that macroeconomic policy outcomes are significantly influenced by professional experience of the chairman of the FOMC. Inarguably, more research following Romer and Romer (2003) is called for, in particular an extension to analyzing the effects of the professional experience of all committee members on their individual voting behavior as well as macroeconomic outcomes. Such research would allow for direct testing of the theoretical results regarding the effects of committee members' expertise and committee structure on individual voting behavior and collective decisions, as presented in this volume.

Chapter 4 of this thesis already contains an empirical application of the results. Their relevance is re-emphasized by the recent proposal to modify the operating framework applied by the Bank of England (see Bank of England (2004a, 2004b)). The current framework consists of standing facilities and operations in the reserve market carried out up to four times a day, and does not include required reserves. Under the new arrangement the frequency of open market operations will be reduced to once a week and commercial banks will hold (voluntarily chosen) required reserves with the maintenance period of roughly one month. The overall change nicely fits with the conclusions presented in the thesis.

Further research could explore incentives of individual commercial banks to bid for liquidity provided by central banks' open market operations. A very recent study by Scalia et al. (2005) is a first step in this direction. The authors employ a data set of individual bids in the Eurosystem's weekly repo auctions in order to test a number of theoretical predictions, including those from reserve management models like the one presented in chapter 4 of this thesis. Undoubtedly more research in this direction is desirable.

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Samenvatting (Summary in Dutch)

In het eerste deel van dit proefschrift nemen wij de gevolgen van collectieve besluitvorming op het gedrag van monetaire-beleidsmakers onder de loep. Als besluiten groepsgewijs worden genomen in plaats van door een enkele persoon, gaan zaken als de besluitvormingsprocedure en overlegprotocollen een rol spelen. Ze kunnen worden aangepast om de verschillen tussen de beleidsmakers in visie op de economie, in kennis en vaardigheden zo efficiënt mogelijk te benutten. In hoofdstuk 2 onderzoeken wij mogelijke verbeteringen van de structuur van het monetaire beleidscomité ('*monetary policy committee*' - MPC), waardoor deze inherente verschillen meer recht wordt gedaan.

De te volgen optimale procedure bij heterogeniteit van expertise binnen een comité is volgens de juryliteratuur om de stem van ieder comitélid afzonderlijk naar individuele expertise te wegen. In de praktijk, en in het bijzonder in MPC's, worden stemmen doorgaans echter niet gewogen naar expertise, maar worden besluiten op basis van een eenvoudige meerderheid van stemmen genomen. In dergelijke gevallen worden dus suboptimale besluitvormingsprocedures gevolgd en is, dientengevolge, de accuratesse van het aldus genomen collectieve besluit lager in vergelijking met de optimale uitkomst. Afhankelijk van de mate van heterogeniteit van de comitéleden qua expertise en van de omvang van het comité kan het verlies aan accuratesse oplopen tot 35,5%. Met andere woorden, door procedurele onvolkomenheden kan de waarschijnlijkheid dat het MPC de juiste beslissing neemt afnemen met 35,5%.

Wij hebben aangetoond dat een juiste structurering van het comité inefficiënt gebruik van de heterogene expertise van de comitéleden uitsluit, óók als besluiten genomen blijven worden op basis van een eenvoudige meerderheid van stemmen. Wij deelden het comité daartoe op in twee subgroepen, te weten één groep met minder en één met meer expertise, en lieten de laatstgenoemde groep voor de eigenlijke beleidsvergadering bijeenkomen om een gezamenlijk standpunt ten aanzien van het te voeren monetaire beleid te bepalen. Vervolgens kwamen de twee groepen bij elkaar om een stem uit te brengen over het renteniveau. Door deze methode wordt niet alleen efficiënt gebruik gemaakt van de beschikbare informatie, maar worden ook enkele aanbevelingen van Janis (1982) opgevolgd waardoor een schadelijke op consensus gerichte groepsdynamiek, '*groupthink*' geheten, wordt vermeden.

De vorming van een subgroep van comitéleden met meer expertise komt de juistheid van collectieve besluiten ten goede. Deze opzet werkt voornamelijk goed in een betrekkelijk klein comité, waar de inefficiëntie die optreedt bij besluitvorming volgens een eenvoudige meerderheid van stemmen word geëlimineerd. In grotere comités is bij deze opzet, zij het in gereduceerde vorm, nog wél sprake van inefficiëntie, vooral als de expertise van de comitéleden uiterst heterogeen is. Echter, door te bepalen dat de comitéleden met meer expertise hun gemeenschappelijke standpunt bekendmaken vóór de stemming over het renteniveau, zou het monetaire beleid ook in dat geval aan kwaliteit winnen en het optimale resultaat benaderen. Dit komt doordat de bekendmaking een aanvullend, zeer accuraat gemeenschappelijk signaal afgeeft aan de comitéleden met mindere expertise, die daardoor de rationele keuze zullen maken zich naar dit signaal te voegen in plaats van af te gaan op hun eigen, veel minder accurate informatie.

In hoofdstuk 3 gaan wij een stap verder in de beoordeling van de gevolgen van collectieve besluitvorming voor de kwaliteit van het monetaire beleid. Hiertoe hebben wij een model geformuleerd dat de effecten van de interactie alsook de uitwisseling van informatie tussen de comitéleden beschrijft. Beide effecten worden als belangrijke kenmerken gezien van overleg binnen MPC's zoals dit in de praktijk geschiedt.

Wij hebben aangenomen dat MPC-leden weliswaar een visie op het economische model delen, maar dat dit niet geldt voor de onafhankelijk geformuleerde visie op toekomstige inflatieschokken. Als de besluitvormingsprocedure alleen voorziet in simultane stemming, zou het comité uitkomen op het mediaanrenteniveau. Als de comitéleden hun visies kunnen delen en bundelen, zal dat hun expertise ten goede komen. Wij bestempelen dit proces als 'leren'. Wij hebben aangetoond dat leren de accuratesse van collectieve besluiten verhoogt, ook al leidt dit tot een positieve correlatie tussen de stemmen van de comitéleden. De verbetering kan maximaal 50% bedragen.

Als alle comitéleden meedoen aan het delen van informatie en leren, moeten zij een gemeenschappelijke raming van economische schokken opstellen. In de optimale situatie zou een dergelijke raming mede gebaseerd dienen te zijn op een weging van de informatie naar verschillende expertiseniveaus (zoals in het geval van een eenvoudige besluitvormingsprocedure die niet voorziet in interactie). Deze optimale procedure hoeft evenwel in de praktijk niet te worden toegepast. In onze analyse laten wij zien dat met een vereenvoudigde besluitvormingsprocedure zonder weging, waarbij bij voorbeeld de individuele ramingen worden gemiddeld of de informatie-uitwisseling tot de comitéleden met meer expertise beperkt blijft, eveneens de optimale uitkomst wordt benaderd.

Ten slotte vergelijken wij de netto voordelen van de in beide hoofdstukken belichte besluitvormingsprocedures, waarbij wij de kosten van comitédeelname en de duur van een vergadering hebben meegewogen. Als gevolg van communicatie tussen comitéleden wordt de optimale comitéomvang beperkt, zelfs als de kosten minimaal zijn (géén communicatie zou het Condorcet-resultaat opleveren: de optimale omvang van een comité zou oneindig zijn). Dit komt doordat informatie-uitwisseling leidt tot verbetering van de individuele vaardigheden, wat op haar beurt weer ten goede komt aan de collectieve accuratesse. Zonder communicatie en de mogelijkheid om te leren kan de collectieve accuratesse alleen worden verhoogd door toevoeging van extra comitéleden (wat weer extra kosten oplevert). Naarmate de kosten verbonden aan het aantal leden en de met de bijeenkomsten gemoeide tijd oplopen, worden communicatie en leerproces steeds belangrijker voor de accuratesse van de collectieve besluiten: besluitvormingsprocedures die voorzien in leren leveren een hogere collectieve accuratesse op dan elke ander procedure zonder leeraspect. In sommige gevallen leveren zij bovendien ook nog kostenbesparingen op.

In het tweede deel van dit proefschrift richten wij ons op de analyse van de institutionele aspecten van de invoering van monetair beleid door centrale banken. Wij doen dat vanuit de 'nieuwe visie' op de implementatie van monetair beleid (Bindseil (2005)), die ervanuit gaat dat een korte rente de juiste operationele doelstelling is en dat de permanente faciliteiten, open-markttransacties en de verplichte reserves, nuttige instrumenten zijn bij het sturen van de korte rente. Terwijl hierover in de afgelopen 10 á 15 jaar een aanzienlijke mate van consensus is gegroeid, biedt deze benadering niettemin nog altijd aanzienlijke ruimte voor eigen beleid ten aanzien van de mix van de te gebruiken instrumenten: het niveau en de kenmerken van de reserveverplichtingen, het type en de frequentie van de open-markttransacties en de door de permanente faciliteiten bepaalde bandbreedte.

In hoofdstuk 4 tonen wij op basis van praktijkvoorbeelden uit het eurogebied en de Verenigde Staten aan dat centrale banken vergelijkbare niveaus van rentestabilisatie kunnen bewerkstellingen bij gebruikmaking van sterk uiteenlopende operationele raamwerken. Een belangrijke conclusie daaruit is dat een hogere frequentie van door centrale banken uitgevoerde open-markttransacties niet automatisch tot stabielere rentetarieven leidt. Andere instrumenten spelen daarbij namelijk ook een belangrijke rol. Deze vaststelling was voor ons aanleiding om een model voor de daggeldmarkt op te stellen waarbij de centrale bank open-markttransacties verricht met als doel om afwijkingen van de daggeldrente van het beoogde niveau tot een minimum te beperken. De commerciële banken moeten voldoen aan reserveverplichtingen en hebben daarom als doelstelling de alternatieve kosten ('*opportunity costs*') van het aanhouden van de desbetreffende reserves gedurende de kasreserve aanhoudingsperiode alsook de boete voor onder- of overschrijding van de reserves aan het eind van die periode tot een minimum te beperken.

Het model voorspelt dat, ongeacht de vormgeving van de verplichte reserves en de permanente faciliteiten, de daggeldrente bij een lagere frequentie van de open-markttransacties gemiddeld meer afwijkt van het beoogde niveau. Deze uitkomst wordt bevestigd door de data. De *Federal Reserve* verricht dagelijks open-markttransacties en de ECB wekelijks. De *Federal Funds* rente wijkt op jaarbasis gemiddeld zelden significant af van nul, terwijl de gemiddelde afwijking van de *Eonia*-rente altijd aanzienlijk afwijkt van nul.

Verder kunnen wij aantonen dat de volatiliteit van de daggeldrente negatief gerelateerd is aan de frequentie van open-markttransacties. Dit zou betekenen dat de volatiliteit van de daggeldrente zou toenemen bij een lagere frequentie van open-markttransacties. Het model genereert echter een verhouding voor de berekening van de verplichte reserves die benodigd zijn om een dergelijke bovenmatige volatiliteit uit te sluiten. Deze resultaten worden ook bevestigd door de data. De gemiddelde twaalfmaands volatiliteit van de daggeldrente in het eurogebied verschilt statistisch niet noodzakelijkerwijs van die in de Verenigde Staten. De gemiddelde verhouding tussen autonome factoren en de reserveverplichtingen in het eurogebied in de periode 1999-2002 bedraagt 1.25 (1.4 volgens het gekalibreerde model). Deze overeenkomst is verrassend. Wij komen tot de conclusie dat deze uitkomst verklaart waarom het verschil in volatiliteit van de daggeldrente tussen de twee monetaire regio's statistisch insignificant is.

Streszczenie (Summary in Polish)

W pierwszej części pracy (rozdziały 2 i 3) przeanalizowano wpływ zbiorowego charakteru podejmowania decyzji na zachowanie podmiotów decydujących o polityce pieniężnej. W sytuacjach kiedy decyzje są podejmowane przez grupę, a nie przez pojedynczą osobę, elementy procesu decyzyjnego takie jak reguły decyzyjne i protokoły dyskusji nabierają znaczenia i mogą być modyfikowane tak, aby różnice w poglądach, zasobach informacyjnych czy poziomie ekspertyzy poszczególnych decydentów zostały jak najefektywniej wykorzystane. W rozdziale drugim przedstawiono możliwe ulepszenia w strukturze rady polityki pieniężnej; takie, które kładłyby należyty nacisk na wymienione różnice pomiędzy decydentami.

W literaturze teoretycznej udowodniono, że, jeśli członkowie rady różnią się poziomem ekspertyzy, to optymalna reguła decyzyjna powinna uwzględniać ważenie głosów według ekspertyzy. Jednakże w praktyce - w szczególności w radach podejmujących decyzje o polityce pieniężnej - głosy członków nie są ważone. Decyzje są podejmowane zwykłą większością głosów. Takie rozwiązanie prowadzi do nieefektywnego wykorzystania wiedzy decydentów i do obniżenia trafności decyzji grupowych w porównaniu do sytuacji optymalnej. W zależności od stopnia różnorodności ekspertyzy członków i wielkości rady, obniżenie trafności decyzji grupowych może dojść do 35.5%. Zatem, w wyniku proceduralnych niedociągnięć, prawdopodobieństwo podjęcia przez radę prawidłowej decyzji może spaść nawet o 35.5%.

W rozdziale 2 pokazano, że nadanie radzie odpowiedniej struktury może wyeliminować nieefektywne wykorzystanie niejednolitej ekspertyzy jej członków, przy jednoczesnym zachowaniu zwykłej większości głosów jako reguły decyzyjnej. Zaproponowano podzielenie rady na dwie podgrupy według poziomu ekspertyzy, pozwolenie bardziej doświadczonej

grupie zebrać się przed posiedzeniem rady i uzgodnić (w drodze głosowania) wspólną pozycję dotyczącą odpowiedniej stopy procentowej. Następnie obie podgrupy powinny razem zagłosować nad stopą procentową. Oprócz bardziej efektywnego wykorzystania dostępnej wiedzy, przedstawione rozwiązanie posiada dodatkowe zalety, gdyż łączy ono niektóre charakterystyki przeciwdziałające wystąpieniu zjawiska '*groupthink*', czyli przesadnego (a zatem szkodliwego) dążenia do jednomyślności (Janis (1982)).

Utworzenie podgrupy złożonej z bardziej doświadczonych decydentów zwiększa trafność grupowych decyzji. Taka dwupoziomowa struktura sprawdza się najlepiej w relatywnie niewielkiej radzie, gdzie nieefektywność wynikająca ze stosowania zwykłej większości głosów zostaje całkowicie wyeliminowana. W większych radach nieefektywność jest zredukowana ale niekoniecznie wyeliminowana, zwłaszcza jeśli poziom ekspertyzy członków jest bardzo różnorodny. W takiej sytuacji zobowiązanie bardziej doświadczonej grupy do ujawnienia ich wspólnej pozycji przed głosowaniem w radzie podnosi trafność grupowych decyzji do tego stopnia, że staje się ona zbliżona do optymalnego rezultatu. Jest to wynikiem racjonalnej zmiany w zachowaniu mniej doświadczonych członków rady: ujawnienie wspólnej decyzji przez doświadczoną grupę decydentów stanowi bardzo wiarygodny sygnał dotyczący odpowiedniej stopy procentowej. Mniej doświadczeni członkowie rady racjonalnie wybiorą głosowanie w zgodzie z usłyszanym oświadczeniem niż w zgodzie z własną, mniej wiarygodną, informacją.

W rozdziale 3 postawiono kolejny krok w kierunku oceny wpływu zbiorowego podejmowania decyzji na jakość polityki pieniężnej: sformułowano model obejmujący interakcje i wymianę informacji pomiędzy członkami rady. Oba efekty są uważane za ważne elementy procesu podejmowania decyzji w istniejących radach polityki pieniężnej.

W analizie przyjęto jako założenie, że członkowie rady polityki pieniężnej zgadzają się co do modelu gospodarki ale mają własne, indywidualnie sformułowane, poglądy dotyczące przyszłych szoków inflacyjnych. W rezultacie mają oni odmienne poglądy dotyczące odpowiedniego nastawienia polityki pieniężnej, nawet jeśli mają wspólny cel inflacyjny. Jeśli procedura podejmowania decyzji przewiduje równoczesne głosowanie, rada przyjmie tę stopę procentową, która jest medianą wszystkich zgłaszanych propozycji. Jeśli członkowie podzielą się swoją wiedzą, ich indywidualny poziom ekspertyzy powinien wzrosnąć. W rozdziale trzecim nazwano ten proces 'uczeniem się'. Pokazano, że uczenie się zwiększa trafność grupowych decyzji, pomimo tego, iż wprowadza ono pozytywną korelację pomiędzy głosami decydentów. W punkcie maksymalnym, poprawa trafności decyzji wynosi nawet 50%.

Jeśli wszyscy członkowie rady biorą czynny udział w wymianie poglądów i uczą się od siebie nawzajem to powinni dojść do wspólnej wizji dotyczącej przyszłych szoków inflacyjnych. W sytuacji optymalnej, taka wspólna wizja powinna być sformułowana jako ważona średnia indywidualnych szacunków (tak jak w przypadku prostych reguł decyzyjnych nie uwzględniających wymiany informacji). Jednakże i w tym przypadku praktyka nie musi podążać za teorią. W rozdziale trzecim pokazano, iż zastosowanie prostszych reguł decyzyjnych - nie wymagających ważenia - takich jak obliczenie zwykłej średniej z indywidualnych szacunków lub ograniczenie wymiany informacji do bardziej doświadczonych członków rady, wystarcza do osiągnięcia wyników zbliżonych do optimum.

W ostatniej części rozdziału 3 dokonano porównania korzyści i kosztów różnych procedur podejmowania decyzji, przedstawionych w obu rozdziałach, poprzez ustanowienie kosztów związanych z uczestnictwem w posiedzeniach rady i kosztów związanych z czasem spędzonym na podejmowaniu decyzji. Jeśli procedura podejmowania decyzji przewiduje wymianę poglądów pomiędzy członkami rady to optymalna wielkość rady jest ograniczona, nawet w sytuacji kiedy parametry kosztów są minimalne (przypomnijmy, że bez komunikacji optymalna wielkość rady zmierzałaby do nieskończoności). Rezultat ten wynika z korzystnego wpływu komunikacji na indiwidualny poziom ekspertyzy członków rady, a zatem i na trafność grupowych decyzji. Bez komunikacji umożliwiającej uczenie się pomiędzy decydentami, trafność grupowych decyzji może być podniesiona tylko poprzez zwiększenie liczebności rady (co pociąga za sobą dodatkowe koszty). W miarę wzrostu kosztów uczestnictwa w posiedzeniach rady i kosztów czasu, znaczenie wymiany informacji i uczenia się dla trafności decyzji rady rośnie: procedury decyzyjne obejmujące uczenie się dają znacznie wyższą jakość grupowych decyzji niż procedury wykluczające uczenie się. W niektórych przypadkach obserwuje się również redukcję kosztów.

W drugiej części pracy (rozdział 4) przeprowadzono analizę instytucjonalnych aspektów wdrażania polityki pieniężnej przez banki centralne. Przyjęto przy tym 'nową wizję' wdrażania polityki pieniężnej (Bindseil (2005)), zakładając, że odpowiednim celem operacyjnym polityki pieniężnej jest kontrola krótkoterminowej stopy procentowej, przy wykorzystaniu instrumentów rynkowych: operacji depozytowo-kredytowych, operacji otwartego rynku i rezerwy obowiązkowej. Takie podejście stało się standardem w praktyce ostatnich 10-15 lat. Niemniej pozostawia ono bankom centralnym duże pole manewru w zakresie szczegółowych rozwiązań: poziomu i charakteru rezerwy obowiązkowej, rodzaju i częstotliwości operacji otwartego rynku, oraz szerokości korytarza stóp procentowych wyznaczonego przez operacje depozytowo-kredytowe.

W rozdziale 4 pokazano, na podstawie realnych przykładów strefy Euro i USA, że banki centralne są w stanie osiągnąć porównywalny poziom stabilizacji krótkoterminowych stóp procentowych przy zastosowaniu zasadniczo odmiennych ram operacyjnych. Z porównania tego należy wyciągnąć jeden ważny wniosek: większa częstotliwość operacji otwartego rynku niekoniecznie oznacza zwiększoną stabilność krótkoterminowych stóp procentowych. Inne instrumenty polityki pieniężnej odgrywają nie mniej znaczącą rolę. Ta obserwacja pozwoliła na zbudowanie modelu rynku funduszy typu *overnight*, na którym bank centralny przeprowadza operacje otwartego rynku w celu minimalizowania odchyleń stopy procentowej typu *overnight* od wartości pożądanej przez bank centralny (tj. od celu operacyjnego banku centralnego). Banki komercyjne są zobowiązane do utrzymywanie rezerwy obowiązkowej, w związku z czym ich celem jest minimalizowanie kosztów utraconego oprocentowania związanych z utrzymywaniem środków na rachunkach w banku centralnym oraz kosztów związanych z brakiem lub nadmiarem rezerw w ostatnim dniu okresu utrzymywania rezerw obowiązkowych.

Model przewiduje, że niezależnie od charakteru rezerwy obowiązkowej i operacji depozytowo-kredytowych, średnie odchylenie stopy procentowej typu *overnight* od wartości wyznaczonej przez bank centralny jest większe jeśli częstotliwość operacji otwartego rynku jest mniejsza. Wyniki te dają się potwierdzić empirycznie. Rezerwa Federalna przeprowadza operacje otwartego rynku codziennie podczas gdy Europejski Bank Centralny – tylko raz na tydzień: roczna średnia odchyleń stopy *Federal Funds* od wartości wyznaczanej przez Rezerwę Federalną prawie nigdy nie jest statystycznie różna od zera, podczas gdy średnia odchyleń stopy *Eonia* jest zawsze statystycznie różna od zera.

Według modelu, zmienność stopy procentowej typu *overnight* jest, ceteris paribus, odwrotnie skorelowana z częstotliwością operacji otwartego rynku, tzn. że zmniejszenie częstotliwości przeprowadzanych operacji może doprowadzić do wystąpienia nadmiernej zmienności stopy procentowej. Jednakże model pozwala na wyprowadzanie formuły do obliczenia takiego poziomu rezerwy obowiązkowej, który eliminowałby nadmierną zmienność stóp procentowych. Wnioski te również znajdują potwierdzenie w praktyce: średnia roczna zmienność stopy procentowej typu *overnight* w strefie Euro nie zawsze różni się statystycznie od średniej rocznej obliczonej dla USA. Średnia ze stosunku rezerwy obowiązkowej i czynników autonomicznych w strefie Euro, obliczona dla lat 1999-2002, wynosi 1.25, podczas gdy skalibrowany stosunek wynikający z modelu wynosi 1.4. Podobieństwo wartości sugeruje, iż brak statystycznie istotnej różnicy w zmienności stóp procentowych typu *overnight* pomiędzy USA i strefą Euro wynika z zastosowania odpowiedniego poziomu rezerwy obowiązkowej w strefie Euro.

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