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Monetary policy deliberations: committee size and voting rules

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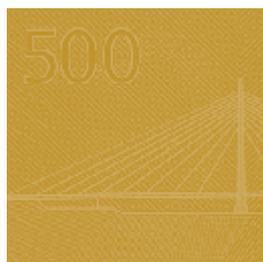
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MONETARY POLICY DELIBERATIONS COMMITTEE SIZE AND VOTING RULES

by Vincent Maurin and
Jean-Pierre Vidal



In 2012 all ECB
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feature a motif
taken from
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Abstract

How large should a monetary policy committee be? Which voting rule should a monetary policy committee adopt? This paper builds on Condorcet's jury theorem to analyse the relationships between committee size and voting rules in a model where policy discussions are subject to a time constraint. It suggests that in large committees majority voting is likely to enhance policy outcomes. Under unanimity (consensus) it is preferable to limit the size of the committee. Finally, supermajority voting rules are social contrivances that contribute to policy performance in a more uncertain environment, when initial policy proposals are less likely to be correct, or when payoffs are asymmetric.

JEL codes: D71, D78, D81, E58

Keywords: Collective decision-making, optimal committee sizing, deliberations, voting rules

Non technical summary

Condorcet's inquiry¹ about the "[...] *degree of confidence the judgement of assemblies deserves, whether large or small, [...], composed by men more or less wise* " is at the heart of institutional design and decision-making theory. This begs two further, more precise questions addressed to institution designers. First, how many people should be involved in the decision-making process? Second, how should the decision-making rule be designed? Finding the right answers to these two questions is pivotal to policy performance.

Monetary policy making by committee has become common practice in today's world, with rare exceptions. The size of monetary policy decision-making bodies varies from 1 in the case of the Reserve Bank of New Zealand, where decisions are taken by the Governor, to 21 voting members in the case of the ECB's Governing Council². Some committees are more consensual in nature and generally decide without explicit voting by agreeing on a policy action supported by all members, others explicitly vote and generally are more enclined to express dissenting views.

There have been limited attempts to analyse the relationships between the size of monetary policy committees, the decision-making rules and policy performance. This paper builds on Condorcet's jury theorem to shed more light on the institutional design of monetary policy decision-making bodies, and explicitly accounts for monetary policy deliberations. Specifically, we believe institutional design should take into account the time constraint faced by real-time policy making. In the long run, after having expounded all possible arguments, policy makers would presumably all agree, provided that they share the same preferences. Yet decisions have to be taken in finite time, with actual policy decisions reflecting both the distribution of views in the decision-making body at the end of the deliberations and the decision-making rule (e.g., majority voting or unanimity/consensus).

Our main findings relate to the institutional design of committees. First, the policy performance of large committees is generally better under majority voting than under unanimity. Second, committees wishing to decide by unanimity should be limited in size. Intuitively, the formation of a consensus

¹See Condorcet (1785), quoted in Moulin and Young (2008).

²At the time of writing this paper, there are 23 voting rights in the Governing Council. The number of voting rights will be limited to 21 when the voting rotation system starts with the adoption of the euro by a 19th Member State.

is time consuming. As a decision-making rule, unanimity would make large committees unable to agree on a policy proposal under a time constraint. At the same time, with simple majority, decisions can easily be taken in real time even when there are dissenting views.

Under majority voting, discussions can be bad for policy performance. When there initially is a fragile majority for the right decision, discussions provide an opportunity for the minority to convince some members to change camp and eventually to gather a majority for the wrong decision. If a committee is very large, there is little time for discussion, which limits this risk. Alternatively, under unanimity time to deliberate is pivotal to policy performance. A limited number of members makes the convergence of views in the committee more likely. With too many members the time constraint kicks in and unanimity makes too large a committee rather impotent. Finally, supermajority voting rules are social contrivances that contribute to policy performance in a more uncertain environment, when initial policy proposals are less likely to be correct, or when payoffs are asymmetric.

1 Introduction

Condorcet's inquiry³ about the "[...] *degree of confidence the judgement of assemblies deserves, whether large or small, [...], composed by men more or less wise* " () applies to many, if not all fields of decision theory. More recently, the quiet revolution in central banking (see Blinder (2007)) sparked a strand of economic literature on monetary policy-making by committees. There is a broad consensus on the pros and cons of monetary policy committees (MPC). They provide a hedge against extreme preferences and allow for the aggregation of information in an uncertain world (see Vandebussche (2006)), but are subject to the limitations of group decision-making. There is less consensus, however, on how to model the decision-making problem of a committee.

Our model does not consider the role of committee members as individuals endowed with possibly different preferences and able to act strategically. Rather, it focuses on the mechanics of decision-making in committees and aims to shed light on a limited number of questions that are particularly relevant for the institutional design of monetary policy making by committee. How large should monetary policy committees be? Should committees decide by voting or should they proceed by consensus (unanimity)?

Our modelling approach avoids the well-known pitfalls of the information aggregation literature, according to which in the absence of information costs or strategic behaviours more members always means better decisions. Specifically, we account for monetary policy deliberations and the time constraint faced by real-time policy making. In the long run, after having expounded all possible arguments, policy makers would presumably all agree, provided that they share the same preferences. Yet decisions have to be taken in finite time, with actual policy decisions reflecting both the distribution of views in the decision-making body at the end of the deliberations and the decision-making rule (e.g., majority voting or unanimity/consensus).

Our main findings relate to the institutional design of committees. First, the policy performance of large committees is generally better under majority voting than under unanimity. Second, committees deciding by unanimity should be limited in size. Intuitively, the formation of a consensus is time consuming. As a decision-making rule, unanimity would make large committees unable to agree on a policy proposal under a time constraint. At

³See Condorcet (1785), quoted in Moulin and Young (2008).

the same time, with simple majority, decisions can easily be taken in real time even when there are dissenting views.

There are interesting trade-offs between committee size and time for policy deliberations. Under majority voting, discussions do not necessarily improve policy outcomes, because if there already is a majority for the right decision at the onset of a meeting, there is a risk that the minority can convince some members to change camp and eventually gather a majority for the wrong decision. If a committee is very large, there is little time for discussion, which limits this risk. Alternatively, under unanimity, there is a need for ample time for deliberations to ensure a satisfactory policy performance. If time is needed for deliberations and for members to express their views, the number of members should be limited, as otherwise the time constraint would kick in and unanimity would make the committee rather impotent. Finally, supermajority voting rules are social contrivances that contribute to policy performance in a more uncertain environment, when initial policy proposals are less likely to be correct, or when payoffs are asymmetric.

The insight into the nature of decision-making processes in committees comes at a very high cost. Simplifying assumptions do not pay tribute to the role of individual committee members and fail to account for the inherent complexity of policy decisions. Only a narrative approach to monetary policy making would be able to capture the richness of real-life policy making. Clearly, our results have to be assessed in light of the assumptions on the utility function of the committee, the structure of uncertainty, and the nature of the discussion process.

The paper is structured as follows. Section 2 briefly reviews the literature on monetary policy-making by committees. Section 3 sets out the basic assumptions of the model, including the discussion process and the voting rules. Section 4 analyses the long-run properties of the discussion process. Section 5 focusses on the optimal size of committees, and suggests that the optimal size depends on the voting rule. Section 6 extends the analysis by looking at the role of uncertainty and asymmetric payoffs. Section 7 concludes and technical proofs are relegated to the Appendix.

2 Overview of the literature

There are different strands of literature on monetary policy-making by committees. First, the federalist structure of some major monetary unions (EMU or United States) has elicited interest in the analysis of differences in preferences. Farvaque et al. (2009) compare various voting rules ranging from majority voting to dictatorship in a monetary union. Heterogeneous economic areas are impacted by union-wide and idiosyncratic shocks and members of the monetary policy committee represent their respective constituent area. In their analyses of the MPC of the Bank of England, for which voting records of individual members are available, Besley et al. (2008), Riboni and Ruge-Murcia (2008), and Hansen and McMahon (2011) corroborate the importance of differences in preferences.

Second, monetary policy making has often been modelled as a signal extraction problem. Without uncertainty there would be no dissenting views on the optimal policy rate, as in such an approach policymakers would agree on the reaction function. In Gerlach-Kristen (2005; 2006), the divergence of views is for example caused by imperfect observation of the output gap. The aggregation of MPC members' opinions increases the precision of output gap estimates, thereby improving policy performance. She mainly focuses on averaging and majority voting and characterises the conditions under which one may outperform the other. In a recent contribution (Gerlach-Kristen (2008)), the MPC includes a chairman that is more skilled than the other members and facilitates the convergence of views in the committee. This modelling approach is compelling when it comes to comparing the efficiency of group decision-making under several voting procedures. However, it fails to provide useful insight into the optimal size of a committee, because adding members is always beneficial, regardless of the degree of precision of their information. There are two further caveats to this approach. First, it is based on the assumption that members know to which extent their information is noisy. In other words, members are aware of their lack of skills and take it into account when deciding. Second, the precise modelling of the aggregation process consubstantial to the voting rule, and in particular whether members vote on their estimation of the relevant variables or directly on the policy instrument, affects the outcome of the decision-making process (see Claussen and Roisland (2010)).

Third, coordination motives between committee members can affect policy outcomes. In a paper not only related to MPCs, Morris and Shin (2002)

account for herding behaviour in committees by adding a desire for coordination to a common utility function. In deriving the members' best responses to the economic outlook, they show that when policymakers' preferences embed such an externality, releasing public information can reduce social welfare. Morimoto (2010) builds on their framework to analyse optimal committee sizing. When people have coordination motives, the herding effect in big committees might be so costly that it eventually cancels out the gain from the aggregation of opinions.

Fourth, the assumption of a continuous set of policy options entails oversimplifying the voting mechanism and makes the analysis of voting procedures boil down to a review of somewhat expedient aggregation mechanisms (median voter, averaging). Monetary policy committee members generally deliberate about very few policy options. Binary decision-making models, as in Condorcet's Jury framework, may offer a more accurate picture of monetary policy-making in practice. Condorcet's Jury theorem contends that, under the assumptions of independence of votes and of competent jurors, the probability that the right option is selected under majority voting increases with the size of the jury. Some attempts were made at extending the scope of Condorcet's Jury Theorem. See for example, List and Goodin (2001) who prove that the result still holds for multiple proposals and Berg (1993) where the independence assumption is relaxed. However, the most fertile developments relying on the implementation of Bayesian equilibrium to the basic Condorcet's setting came in the wake of Austen-Smith and Banks (1996). They defined the essential notions of *sincere voting* (voting for the option maximizing your welfare) as well as *informative voting* (voting in accordance to the information you received) and proved that voting is informative only under majority voting and might never be informative in certain settings. In a related framework, Berk and Bierut (2005) analyse rules of procedures in committees and suggest that policy outcomes can be enhanced by dividing the committee in a higher skilled and a lower skilled group.

Overall, there have been few attempts at analysing decision making when discussions are possible (see Austen-Smith and Feddersen (2006) and Berk and Bierut (2011)). One exception is Spencer (2005) who builds on De Marzo et al. (2003) model of the evolution of opinions in a social network subject to a persuasion bias. The evolution of a member's opinion follows a process determined by the weight he puts on other members' opinions. Spencer's main result is that under certain soft assumptions on the way people listen to each other, committee members reach a consensus. Bhat-

tacharjee and Holly (2009) use an empirical model to build a proxy for such communication relationships in the MPC of the Bank of England during the term of Governor George.

3 The Model

Modelling decision-making by committee is particularly challenging, as it can be approached from radically different angles, as shown by our brief literature review. One can distinguish the holistic approach that envisages a committee as a body from the individualistic approach that would focus on the role of each committee member in the formation of decisions. Strategic behaviours would feature prominently only in the latter approach. Our model belongs to the holistic approach, and focuses on the functioning of the group as a whole.

3.1 The utility function

Our analysis of decision-making by committees builds on Condorcet’s jury theorem, where a committee consisting of m decision makers faces a binary choice. The committee can either support a proposal (P) or reject it (\bar{P}). Without loss of generality, we assume that there are two states of nature (P and \bar{P}) that can be associated with the proposal. Either the proposal is the optimal policy response to the current state or it is not. In the latter case, rejecting the proposal would be the committee’s best policy response.

The members of the committee have identical preferences, and their payoffs depend on whether or not the committee has made the right decision. If the state of nature is P , the right decision is to adopt the proposal. If the state of nature is \bar{P} , the right decision is to reject it.

$$\forall i \in [1; m], u_i(P|P) = u_i(\bar{P}|\bar{P}) = 1 \text{ and } u_i(P|\bar{P}) = u_i(\bar{P}|P) = 0$$

As there is no heterogeneity of preferences over states of nature and policy actions in the committee, we can define social welfare, which the institutional setting of the committee should aim at maximising:

$$U(P|P) = U(\bar{P}|\bar{P}) = 1 \text{ and } U(P|\bar{P}) = U(\bar{P}|P) = 0$$

In our analysis of voting rules, we consider the possibility for the committee to be confronted with a proposal that is not the optimal policy response, and to do so we denote with $\pi \in [0;1]$ the probability that the state of nature is P . As the alternative faced by the committee is to accept or reject a proposal, our approach slightly differs from classical binary choice models. There is a presumption that π should be larger than $\frac{1}{2}$, while there is generally no such restriction on the distribution of states of nature. We assume that proposals are made only if the probability of them being desirable exceeds $\frac{1}{2}$.

The difference between classical binary choice models and ours is otherwise of limited importance. Intuitively, our model captures the decision process of a monetary policy committee in a simplified economy where there is uncertainty about the inflation trend. With probability π underlying inflationary pressures actually threaten price stability (\nearrow), and with probability $1 - \pi$ there are no underlying inflationary pressures (\longrightarrow) posing a risk to the achievement of the central bank objective. In such a situation the policy options a monetary policy committee is confronted with are either raising the interest rate (P) or maintaining it at its current level (\bar{P})⁴. There is a natural mapping⁵ from the states of the economy into the policy options:

$$\begin{pmatrix} \nearrow \\ \longrightarrow \end{pmatrix} \longrightarrow \begin{pmatrix} P \\ \bar{P} \end{pmatrix}$$

When a central bank staff's analysis points to underlying inflationary pressures (\nearrow), the monetary policy committee generally deliberates on the basis of a proposal to tighten the monetary policy stance (P). If they decide against tightening, the policy rate is kept at its current level.

⁴While Gerlach-Kristen (2006) argues that a continuous set of alternatives for policy-makers gives a better account of what is at stake in monetary policy, we believe that MPC members very often have to deal with two main options, one of them being a proposal from the chairman.

Over the voting records published by the Bank of England from 1997 to mid-2010, the average number of opinions voiced out in votes is inferior to 2. One can conclude that the number of options discussed is certainly closer to 2 than 9. From the same data, we find that less than 4% of the meetings bear the trace of a strict loosening/tightening dispute.

⁵Natural mapping means that every member would agree on the optimal policy if he had access to perfect information on the state of nature.

3.2 The meeting

The committee members do not observe the state of nature. Once the proposal is submitted to the committee, members form their opinion on the basis of private information and decide on the proposal following three steps:

1. They receive a private signal on the economic situation;
2. They exchange views on the staff proposal during a meeting;
3. They vote according to the institutional provisions of the committee.

Each member i receives a private signal s_i about the state of nature. The signals are independently drawn from a state dependent distribution:

$$\Pr[s_i = P|P] = \Pr[s_i = \bar{P}|\bar{P}] = \Pr[s_i = R] = q$$

where $\Pr[s_i = R]$ denotes the probability that the member receives a signal that reflects the true state of nature.

The meeting starts with a round-table discussion during which members report their opinion about the economic situation, thereby truthfully revealing their signals. The opinions of committee members are assumed to evolve during the meeting. At each round of discussion, the share of the committee supporting the proposal P is a state variable that describes the distribution of opinions. Assuming that signals are independently distributed⁶ across members we can easily characterise the initial probability distribution of the number of members supporting P . This assumption is not essential to our results. The probability of having k members initially supporting the proposal P out of m is:

$$\Pr(k \text{ for } P) = \begin{cases} \binom{m}{k} q^k (1-q)^{m-k} & \text{if the true state of nature is } P \text{ } (\pi) \\ \binom{m}{k} (1-q)^k q^{m-k} & \text{if the true state of nature is } \bar{P} \text{ } (1-\pi) \end{cases}$$

If the proposal P is the right decision (with probability π), this probability is obtained by drawing k members having received the right signal out of m . Conversely, if the proposal is a policy mistake (with probability

⁶Correlated signals would limit the benefits from information aggregation, make the size effect less powerful and strengthen the case for small committees. The independence assumption is not pivotal to our results from a qualitative standpoint, because it is still good to add members when signals are weakly correlated.

$1 - \pi$), this probability is obtained by drawing k members having received the wrong signal out of m . This is a non-Bayesian framework, because members form their opinions without taking account of the fact that a proposal has been submitted to the committee. One can further observe that the number of members initially supporting the correct decision (whether it is P or \bar{P}) is $\binom{m}{k} q^k (1 - q)^{m-k}$. This results from the state-dependent definition of the signal. We therefore define $\theta_{m,q}(k)$ as the probability of having k members supporting the correct decision:

$$\theta_{m,q}(k) = \pi \binom{m}{k} q^k (1 - q)^{m-k} + (1 - \pi) \binom{m}{k} q^k (1 - q)^{m-k} = \binom{m}{k} q^k (1 - q)^{m-k}$$

Our modelling approach to the distribution of opinions in a committee has been inspired by Kirman's (1993) analysis of the behaviour of ants faced with two identical sources of food. We assume that the evolution of opinions in the committee can be described in a stochastic manner, in line with Kirman's modelling of the behaviour of ants. There is no focus on the opinion of any specific member, and we are only interested in the statistical evolution of opinions in the committee.

Precisely, we describe the discussion process as a Markov Chain recording the number of committee members in favour of the proposal P . $X_0 \sim \mu^0$ is the random variable denoting the number of members initially supporting P . μ^0 is a row vector with $m + 1$ components that represents the initial state of the Markov chain. Its $k + 1$ component represents the probability that the meeting starts with k members supporting the proposal, with k varying from 0 to m . The $k + 1$ component of μ^0 is $\Pr(k \text{ for } P)$.

After the first round of discussion some members may change their view from P to \bar{P} , or conversely from \bar{P} to P - in practice because of convincing arguments expressed by other committee members. The number of members supporting P after the first round of discussion is X_1 . Accordingly, X_n records the number of members in favour of the proposal after n rounds of discussion.

We further assume that the state of the discussion at round $n + 1$ only depends on the previous state X_n and if the discussion goes back to a previously "visited" state, the outcome of the discussion round is the same in terms of probability. In addition, in a discussion round, one member at most can change camp. These assumptions, which we formalise in what follows,

are made for the sake of analytical tractability. Our main results are robust to their relaxation.

Assumption 1 (Markovian process): X_n is a time-homogeneous Markov chain.

Assumption 2 (Discussion round): A discussion round ends up either with the status quo, or with an increase or decrease of X_n by only one member⁷. Formally,

$$\forall n \in \mathbb{N}^+, \forall (k, l) \in \llbracket 1 : m - 1 \rrbracket^2, \Pr(X_{n+1} = k \mid X_n = l) \neq 0 \text{ if and only if } k \in \{l - 1; l; l + 1\}.$$

To fully characterise the Markov chain, we need to define the following transition probabilities, including the probability of the status quo:

$$\forall l \in \llbracket 1 : m - 1 \rrbracket,$$

$$\begin{aligned} \Pr(X_1 = l + 1 \mid X_0 = l), \\ \Pr(X_1 = l - 1 \mid X_0 = l), \end{aligned}$$

$$\forall l \in \llbracket 0 : m \rrbracket,$$

$$\Pr(X_1 = l \mid X_0 = l).$$

Because of herding or coordination motives, it is likely that, in practice, the probability that the balance of opinions in the committee remains the same decreases, when one of the options has less supporters. Our results are robust to various functional specifications of $\Pr(X_{n+1} = l \mid X_n = l)$ as increasing over $l \in \llbracket 0; \frac{m}{2} \rrbracket$ and decreasing over $l \in \llbracket \frac{m}{2}; m \rrbracket$. For the sake of simplicity we assume that the probability of the status quo does not depend on the number of supporters $l \in \llbracket 0; m \rrbracket$. It is equal to a constant $\nu \in [0; 1]$, which can be interpreted as an indicator of the members' reluctance to change their views. In the extreme, still plausible case where the probability of the status quo is equal to 1, the discussion would have no impact on the distribution of opinions. Such extreme cases would rather be relevant to the analysis of decision-making in a partisan committee, but are less relevant to a common value problem like monetary policy making.

⁷It is worth noticing that this assumption is not essential to our results, which are robust to more general specifications of the transition matrix where any leap in the number of members supporting the proposal would be possible in each discussion round. However, the simpler definition we adopt allows for a detailed analysis of the process.

We make a number of additional assumptions on the discussion process that drives the evolution of opinions in the committee. First, unanimity is an absorbing state for the discussion. Once unanimity is reached, the opinions are crystallized. Second, the more members are in favour of an alternative, the more likely they are to convince the "marginal" member to change camp. Third, the number of discussion rounds N is finite. After N rounds of discussion, the committee must decide according to a specific voting rule.

Assumption 3 (Unanimity is an absorbing state): When all members support an alternative, the discussion process ends⁸. Formally,

$$\forall n \in \mathbb{N}^+, \forall l \in [[0 : m]], \Pr(X_{n+1} = l \mid X_n = 0) = \delta_{l,0} \text{ and } \Pr(X_{n+1} = l \mid X_n = m) = \delta_{l,m}.$$

Assumption 4 (Transition probabilities): The probability of the status quo is arbitrarily defined as follows: $\forall l \in [[0; m]], \Pr(X_{n+1} = l, X_n = l) = \nu$, where $\nu \in [0; 1]$. The probabilities of change in the opinions of members are proportional to the share of the two camps in the committee: $\forall l \in [[1 : m - 1]], \Pr(X_1 = l + 1 \mid X_0 = l) \propto \frac{l}{m}$ and $\Pr(X_1 = l - 1 \mid X_0 = l) \propto \frac{m-l}{m}$, where $\frac{l}{m}$ is the share of the committee supporting the proposal before the discussion round takes place⁹.

Assumption 5 (Meeting of finite length) The number of discussion rounds is an increasing function of time devoted to the meeting T and a decreasing function of committee size m . Precisely, $N = T.f(m)$ where f is a decreasing function.

With these assumptions we can define the transition matrix, $M \in M_{m+1, m+1}(\mathbb{R})$, of the time-homogenous Markov process. $M_{k,l}$ is the probability that l mem-

⁸ $\delta_{i,j}$ is the Kronecker indicator function $\delta_{i,j} = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{if } i \neq j \end{cases}$

⁹ Our discussion process can be interpreted as a twisted form of a well known stochastic process: the Ehrenfest urn. Such an urn contains balls of two colors (say black and white). The number of members supporting P would correspond to the number of white balls in the urn. In an Ehrenfest urn, when a white ball is drawn it is replaced by a black one and conversely. The equilibrium distribution then puts a high weight on balanced proportions (half white, half black)

On the contrary, our model increases imbalance between the two types. When having a lot of white balls, a black ball will more likely flip into a white one than a white one into a black one. The equilibrium distribution, therefore, is likely to be polarised: all white or all black.

bers support P after $n + 1$ rounds of discussion when they were k after n rounds. We have:

$$\forall n \in \mathbb{N}^+, \forall (k, l) \in [[0 : m]]^2, M(k, l) = \Pr(X_{n+1} = l \mid X_n = k) = \Pr(X_1 = l \mid X_0 = k).$$

The transition matrix of the discussion process is:

$$M = \begin{pmatrix} M_{0,0} & 0 & \dots & \dots & 0 \\ M_{0,1} & M_{1,1} & M_{2,1} & & \vdots \\ 0 & & \ddots & & 0 \\ \vdots & & & M_{m-2,m-1} & M_{m-1,m-1} & M_{m,m-1} \\ 0 & \dots & \dots & 0 & M_{m,m} \end{pmatrix}$$

$$M = \begin{pmatrix} 1 & 0 & \dots & \dots & 0 \\ (1 - \nu) \cdot \frac{m-1}{m} & \nu & (1 - \nu) \cdot \frac{1}{m} & & \vdots \\ 0 & & \ddots & & 0 \\ \vdots & & (1 - \nu) \cdot \frac{1}{m} & \nu & (1 - \nu) \cdot \frac{m-1}{m} \\ 0 & \dots & \dots & 0 & 1 \end{pmatrix}$$

In each round of discussion n , we can retrieve the probability distribution of the state vector X_n given the distribution of X_0 . If we denote with μ^n and μ^0 the law of X_n and X_0 , then we have: $\mu^n = \mu^0 \cdot M^{(n)}$, where $M^{(n)}$ is the transition matrix to the power n .

3.3 Voting rules

In the course of a meeting, some members change camp, because they are influenced by the views expressed by other members during the deliberations. The outcome of a vote cast after N rounds of discussion is likely to be different from that cast at the onset of a meeting. After $N = T \cdot f(m)$ rounds of discussion have taken place, there are X_N committee members supporting the proposal, and the decision will ultimately depend on the voting provisions of the committee.

3.3.1 Definition of decision-making rules

Three types of voting rules are analysed: majority voting, unanimity and qualified majority voting.

Definition 1 *In a committee with $m \geq 1$ members (voting rights), the majority $\bar{m} \leq m$ is the number of voting rights required for the adoption of a proposal.*

For a proposal to be rejected $m - \bar{m} + 1$ members of the committee must vote against it. The parameters \bar{m} and m allow us to analyse a wide range of voting rules, from simple majority to supermajority and unanimity rules, in committees consisting of both odd or even numbers of members. In a committee with an even number of voting rights acting by simple majority, we make the assumption that half of the committee is a majority ($\bar{m} = m/2$). This assumption reflects the conventional provision that, in the event of a tie, the chairman shall have the casting vote. It prevents the emergence of indeterminate outcomes that, in a model, would have to be solved by tossing a coin. In our modelling approach, however, the chairman of the committee is not identified as a specific member. The Markov chain only provides a statistical description of the distribution of votes and does not tell us anything about the vote of the chairman.

The class of voting rules can be indexed by $r = \bar{m}/m \in [0.5, 1]$. Conversely¹⁰, for any real number $r \in [0.5, 1]$ and any committee of size $m \geq 1$, we can fully characterise the voting rule corresponding to r .

Definition 2 *In the voting rule $r \in [0.5, 1]$, a proposal is adopted if and only if the majority, i.e. $\bar{m} = \lceil rm \rceil$ members vote for it, where $\lceil rm \rceil$ is the nearest integer greater or equal to rm .*

Given a voting rule $r \in [0.5, 1]$, two outcomes - described in terms of probability - are possible:

- P is adopted: $\Pr(P \text{ adopted}) = \sum_{k=\lceil rm \rceil}^m \mu^N(k)$
- P is rejected: $\Pr(P \text{ rejected}) = \sum_{k=0}^{\lceil rm \rceil - 1} \mu^N(k)$

¹⁰It is convenient to index voting rules with a continuous parameter, but only the pair (\bar{m}, m) fully describes a voting rule in practice. For example, in a committee of 5 members there only are 3 possible voting rules: simple majority (3 over 5), qualified majority (4 over 5) and unanimity (5 over 5). They correspond to the following intervals: $[0.5, 0.6[$, $[0.6, 0.8[$ and $[0.8, 1]$.

3.3.2 The social value of policy-making by committee

How can one define the social value of policy-making by committee? The decision-making process influences the quality of policy decisions. We need to define a criterion against which to assess the social merits of alternative voting rules. Given a proposal P , we define the expected social welfare of a policy decision as follows:

$$w = \Pr(P \text{ voted} | P) \cdot \Pr(P) \cdot U(P|P) + \Pr(P \text{ rejected} | \bar{P}) \cdot \Pr(\bar{P}) \cdot U(\bar{P}|\bar{P})$$

When the true state of nature is \bar{P} , the right policy decision is to reject the proposal. This is the outcome of the meeting only if the number of votes cast in support of the proposal falls short of the required majority $[rm]$. With the notations of the previous section:

$$w(m, r, q, T, \pi) = \pi \sum_{k=[rm]}^m \mu^N(k)_{|P} + (1 - \pi) \sum_{k=0}^{[rm]-1} \mu^N(k)_{|\bar{P}}$$

where the subscripts $|P$ and $|\bar{P}$ indicate that the distribution of opinions depends on whether the proposal is the right policy decision $|P$ or a policy mistake $|\bar{P}$. The subscripts are necessary, because the initial distribution of members supporting the proposal depends on the underlying state of nature.

4 The discussion process

In this section, we analyse the outcome of a meeting that can last forever ($T = \infty$) and focus on the long run properties of the discussion process. The number of discussion rounds is unbounded ($N = \infty$).

Obviously, the absence of a time constraint does not help much in comparing the efficiency of voting rules, for such rules generally are social contrivances to make decisions in finite time. However, it gives a useful insight into the main effects at work during the discussion process, regardless of the overall decision-making rule.

4.1 The convergence effect

Voting rules are irrelevant in the long run, provided that unanimity is an absorbing state of the discussion process. The following proposition can be

extended to more general settings than that defined in 3.2. Indeed, the proof (see appendix) clearly shows that the restrictions imposed on the transition matrix can be relaxed. The indispensable assumption is that unanimity is an absorbing state of the Markov chain. Discussions ensure that decisions can be taken in the long run, regardless of the stringency of the voting rule. When time is infinite and discussions can last forever, the voting rule has no impact on the quality of the eventual decision, provided that in the long run committee members all agree.

Proposition 1 *The discussion converges towards unanimity for one of the options : either P or \bar{P} . Formally, the probability of ending up in a state different from unanimity goes to 0 when the number of discussion rounds tends to infinity:*

$$\forall l \in \llbracket 0 : m \rrbracket, \quad \lim_{n \rightarrow \infty} M^{(n)}(l, j) = 0 \text{ if } j \notin \{0, m\}$$

such that $\lim_{n \rightarrow \infty} M^{(n)}(l, 0) + M^{(n)}(l, m) = 1$

It is worth mentioning a couple of related results in the literature. Spencer (2005) obtains a broadly similar result in a related framework, where committee members influence each other. At the onset of the deliberations each member has a preferred interest rate. Members update their beliefs by listening to the members they are connected with in a social network described as a Markov chain. The network must be aperiodic and irreducible for a consensus to emerge in the long run. In a completely different, game-theoretical framework, Gerardi & Yariv (2006) observe that when deliberations occur, different voting rules may generate the same set of equilibrium outcomes. They conclude their equivalence result implies that, when jurors can communicate, the problem of a social planner designing a jury system becomes one of equilibrium selection, rather than one of institutional design via the voting rule itself. In our framework, the voting rule is irrelevant in the long-run, because of the convergence towards an absorbing state. It still matters when time is finite and decisions are taken before the distribution of opinions in the committee has converged.

4.2 The size effect

Condorcet's jury theorem contends that, under some conditions, collective decision making is superior to individual decision making. Formally, it says

that, under a majority rule, a group of voters is more likely to make a correct decision than any single individual if the quality of an individual's judgement, measured by the probability of him making the right decision (q), is greater than $\frac{1}{2}$. Furthermore, the probability of making a correct decision is increasing in the size of the group, and tends to 1, when the number of voters tends to infinity.

Condorcet's jury theorem rests on the assumption that votes are uncorrelated. This assumption has been criticised on two grounds (see Ladha (1992)). First, voters share common information. Second, they are not isolated, but can exchange views. Communication between the members of a decision-making body broadly invalidates the independence assumption, because it can turn private knowledge into common knowledge.

The discussion process that operates in our committee of m members accounts for exchanges of information in a statistical way. It introduces a separation between the time when members form their opinion on the basis of independent signals and the time when they vote and decide. Original opinions are independently drawn from the same binomial distribution, but votes are not. This begs the question, whether Condorcet's jury theorem would still apply when voters can exchange views in a committee meeting.

The answer is yes. In section 4.1 we proved that the discussion process converges to unanimity in the long run, yet not always unanimity for the correct decision. In our model, we show that the probability of reaching the right consensus in the long-run increases in the committee size when members are better informed than random observers ($q > \frac{1}{2}$). When the number of discussion rounds tends to infinity, Condorcet's jury theorem still holds in a committee where members exchange views before voting.

For each initial distribution of opinions indexed by the number of members initially supporting the proposal $k \in [0; m]$, $r_m^\infty(k)$ stands for the probability of convergence to unanimity for the correct decision. $\theta_{(m,q)}$ is a probability vector of dimension $m + 1$, whose k^{th} component $\theta_{(m,q)}(k) = \binom{m}{k} \cdot q^k \cdot (1 - q)^{m-k}$ is the probability of having k members supporting the correct decision at the beginning of the discussion process. With these notations the probability for a committee of size m to take the right decision in the long run can be expressed as follows:

$$R^\infty(m, q) = \sum_{k=0}^m \theta_{(m,q)}(k) \cdot r_m^\infty(k)$$

Proposition 2 *The probability of reaching the right consensus when the number of discussion rounds tends to infinity for a committee of size m with quality of information q is given by:*

$$R^\infty(m, q) = \frac{1}{2^{m-1}} \cdot \sum_{k=1}^m \binom{m}{k} \cdot q^k \cdot (1-q)^{m-k} \cdot \sum_{l=0}^{k-1} \binom{m-1}{l}$$

This probability is increasing in the size of the committee if and only if signals are instructive ($q > \frac{1}{2}$).

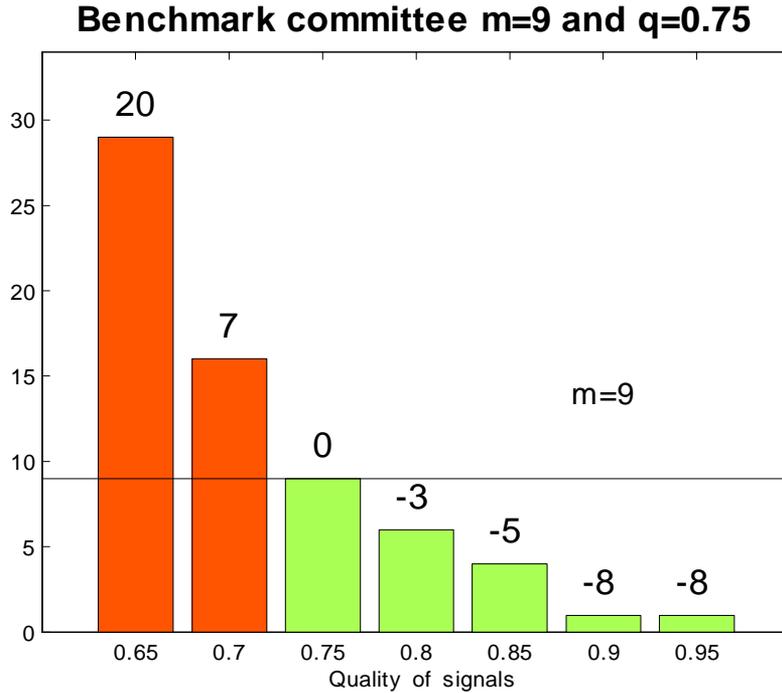


Figure 1: Change in committee size

Empirical evidence on the size of MPCs in the world reported by Berger et al. (2006) shows that on average MPCs consist of 7 to 9 members. The Bank of Japan's Policy Board and the Bank of England's MPC consist of

9 voting members¹¹. Can we account for the differences in committee size observed in the world? As an illustration, chart 1 shows the change in the size of a committee of initially 9 members that would be required to maintain the same level of policy performance when the quality of signals varies. This obviously is an imperfect gauge of optimal committee size, and our numerical exercises hinges upon rather strong assumptions. As an order of magnitude, however, we find that the difference in committee size observed between the ECB (21 voting members, as soon as the voting rotation system is put in place¹²) and the Bank of Japan (9 members) or the Bank of England (9 members) could be explained by a difference of about 10% in the quality of signals received by committee members.

4.3 The social value of discussions

So far, we have established two main results. First, the distribution of opinions converges to unanimity when the number of discussion rounds tends to infinity. If enough time is available for members of a committee to expound their opinions, they will eventually all agree either to accept or to reject the proposal under discussion. Second, larger committees are more likely to agree on the correct decision, under the assumption that committee members receive instructive signals.

Do discussions always bring about decisions that are better than those resulting from an immediate vote? Not always, but the precise answer to this question largely depends on the decision-making rule. If decisions are taken by unanimity and signals are instructive, discussions enhance welfare. If monetary policy committee members, however, are already well informed about the state of the economy, discussions provide an opportunity for less informed members to convince the committee about their views, which under a majority voting rule might eventually lead to a worse outcome than a vote taking place before any discussion. Intuitively, discussions are likely to generate better outcome under more demanding voting rules. We summarise these considerations in a proposition on the welfare impact of discussions on policy outcomes for a broad range of voting rules.

¹¹ See also table 3 in Moutot et al. (2008) for an international comparison of MPCs.

¹² On the rotation of voting rights in the Governing Council of the ECB, see the July 2009 issue of the ECB Monthly Bulletin.

Proposition 3 *Let us assume that committee members receive instructive signals ($q > \frac{1}{2}$).*

1. *Under majority voting, discussion is welfare-reducing*
2. *Under unanimity, discussion is welfare-enhancing*
3. *For voting rules indexed by $r \in]\frac{1}{2}; 1[$ (supermajority rules), there exists a threshold q_r such that discussion is welfare-enhancing for $q \in [\frac{1}{2}; q_r]$, and welfare-reducing for $q \in [q_r; 1]$
 $r \rightarrow q_r$ is an increasing function.*

Under majority voting a committee consisting of very well informed members would gain little in engaging in a discussion, because most members would initially support the correct decision. The better informed members can convince the rest of the committee, but at the onset of the meeting it is very likely that the requirement of the voting rule is already met. On the contrary, there is a risk that the discussion would result in some well informed members being convinced by less informed members in the course of the discussion. This is a low probability event, but still an event that increases the likelihood that the correct decision is not taken. Intuitively, a wrong but persuasive minority can overturn a majority, but when an initial majority in favour of the correct decision recruits supporters, this does not change the outcome of the vote under majority voting.

Under unanimity, the intuition is straightforward. Let us again suppose that the proposal is correct. Unanimity is an absorbing state, and the discussion increases the likelihood of adopting the proposal from a previous round when only $m-1$ members support the proposal. In the case of supermajority voting rules, as signals are state-dependent and not proposal-dependent, the aggregation mechanism works more in the direction of the absorbing state "unanimity for the correct decision" than in that of the state "unanimity for the wrong decision".

Figure 2 illustrates our proposition for a committee consisting of 21 members, for voting rules ranging from simple majority (11 out of 21) to unanimity, and for signals ranging from 0.5 to 1. Under simple majority voting, discussions are harmful, but they improve policy performance under unanimity. If the committee decides according to a supermajority voting rule requiring more than 17 out of 21 members, discussions are beneficial regardless of the quality of signals received by members. However, for less

stringent supermajority voting rules, discussions are harmful when signals are good. For example, if the voting rule requires a supermajority of 14 out of 21 members, discussing reduces policy performance when the quality of signal is above a threshold of around 0.9.

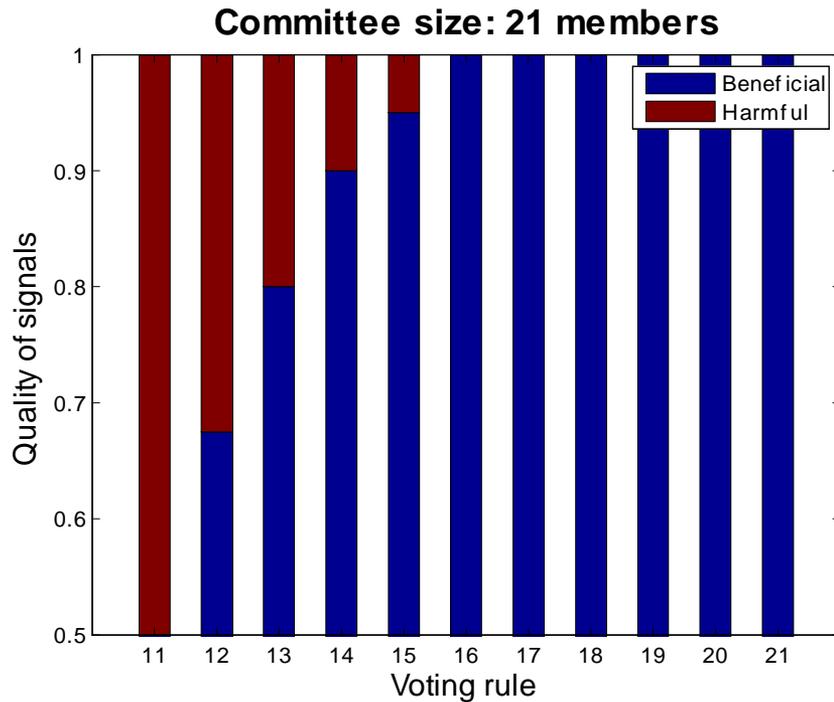


Figure 2: Do discussions enhance policy performance?

One should here bear in mind our results so far are theoretical and, in particular, assume that discussions can last forever. Our numerical examples for a committee of 21 members report the policy performance associated with the long-run distribution of opinions in the committee. But real-time monetary policy decision making is subject to the constraint of time. In finite time, the welfare properties of voting rules depends on the size of the committee that affects the efficiency of the discussion process. When discussions are beneficial, large committees' difficulties to talk will make their decision making process inefficient. On the contrary, and suprisingly, when discussions are bad for policy performance, the bane becomes a boon:

large committees are better off, because of their inability to communicate efficiently.

5 Optimal committee size

One major concern of the decision making literature (and particularly papers dealing with MPCs) is that of the optimal size of committees. The main advantages of large committees are well identified and remarkably homogenous in different strands of literature: the aggregation of informed opinions increases the likelihood of taking right decisions - in binary alternative setups - or reduces the variance of the selected policy instrument - in continuous signal-extraction frameworks. On the contrary, while common sense suggests that very large committees are an aberration in many fields requiring some expertise, this argument has, to the best of our knowledge, not yet been modelled precisely. There is a presumption that large committees incur coordination, communication or even wage costs that would offset the gain from aggregating opinions.

Our model provides a consistent approach to communication costs in decision-making bodies. We posit that members of large committees are less able to exchange views than members of small committees by imposing a constraint on the number of discussion rounds. The dynamic stochastic process we consider reflects this very simple but natural limitation of human nature and is a simple way to flesh out the idea of agreement costs in large committees.

For our numerical exercises, we further specify f to be the inverse function up to a coefficient. One would expect that 6 members can speak twice as less as 3 members during a given period of time. Because our focus is on comparing the relative efficiency of various committees, the choice of this coefficient is not relevant. In our numerical exercises, we assume that each member speaks during 3 minutes in each round of discussion and set $N = \frac{T}{3m}$. The state vector that we will use for the computation of social welfare is $X_N = X_{\frac{T}{3m}}$. We further assume a meeting length of 180 minutes.

5.1 Majority Voting

Majority voting certainly is one of the most common decision-making rule. Under majority voting, we find that an infinitely large committee is the best performing committee size, provided that signals are instructive ($q > \frac{1}{2}$). There are two reasons for this. First, the size effect at work in Condorcet's Jury Theorem plays exactly the same role here. When signals are instructive, there is a marginal social gain from adding members to the committee. Second, and more surprisingly, we know from section 4.3 that discussions can reduce the quality of decisions under majority voting. The limited number of discussion rounds in (infinitely) large committees makes them more efficient than small committees.

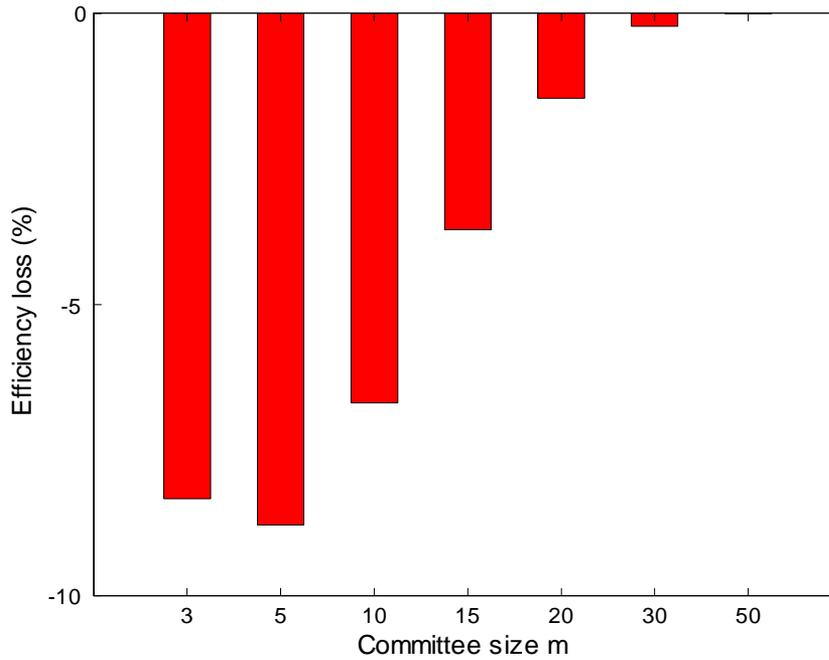


Figure 3: Efficiency loss from discussions under majority voting

Figure 3 shows the performance of a committee deciding by majority as a function of its size¹³. The signal quality is equal to 3/4 and the meeting lasts 3 hours. More specifically, the measure we report is the efficiency loss that can be attributed to the discussions compared to the policy performance of a committee voting immediately. This loss decreases in the size of the committee, and is virtually nil for committee of more than 30 members. In large committees, the vote takes place immediately, because there is no time for discussions, and Condorcet’s Jury Theorem tells us that the probability of taking the right decision tends to 1. In relatively small committees, discussions are bad for policy performance under majority voting.

Under majority voting, it is quite remarkable that communication failures that are more likely to prevail in large committees contribute to their efficiency. Rational committee members aware of this feature of the discussion process in large groups would decide not to discuss and to initiate the voting procedure immediately, thereby avoiding coordination costs.

Obviously, the subtleties of monetary policy deliberations cannot be captured by our statistical approach. Yet the result that majority voting is a social contrivance that allows for efficient decision making is obtained under fairly reasonable assumptions about the deliberation process. One of this assumption is that signals are instructive ($q > \frac{1}{2}$).

5.2 Unanimity

Very few committees are known to use unanimity *stricto sensu* as a decision-making rule. Yet there is an obvious inclination towards consensus, to which exchanges of views are instrumental. Because of reputation or credibility concerns (see Visser and Swank (2007)), MPCs in particular tend to display unanimous agreement.

The intuition behind optimal committee designing under unanimity is rather straightforward. Under majority voting, lengthy discussions were harmful, because they could increase the likelihood of gathering a majority of members supporting the wrong decision. Under unanimity discussions improve social welfare (unless signals are perfect ($q = 1$)) and there is a very clear tradeoff between the two conflicting forces at work in large committees:

¹³The probability π that the proposal is the right option is irrelevant to the majority voting case.

the error reduction gain from the aggregation of opinions and the costs from communication.

Figure 4 shows the efficiency gains from discussions in a committee deciding by unanimity. We measure the efficiency gain (as a percentage) against the policy performance of a committee deciding immediately. When the committee is very small, efficiency gains are already sizeable (more than 20% for a committee of three members), although there is a fairly high probability that all members could unanimously agree on the right decision without any discussion. This probability decreases in the size of the committee. In large committees, the number of discussion rounds is limited and the efficiency gains from discussions gradually vanishes. Decision-making by unanimity does not make much sense in large committees.

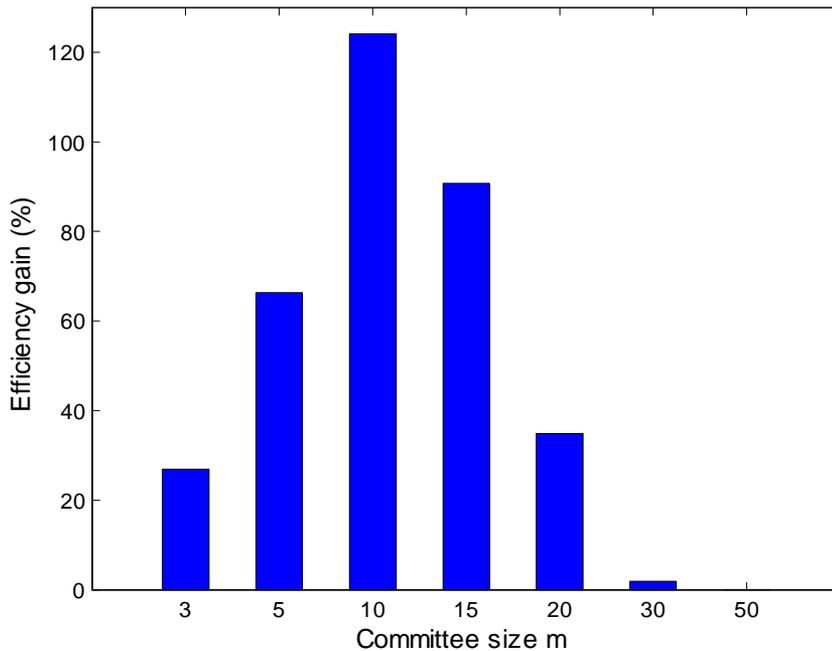


Figure 4: efficiency gain from discussions under unanimity

Committees wishing to decide by unanimity should be limited in size.

How many members should be invited around the table? Our numerical exercises suggest that, under reasonable assumptions on the duration of meetings (meetings should not exceed 8 hours), the optimal committee size is always below 10. Figure 5 shows the optimal committee size as a function of the quality of signals (q) and the quality of proposals (π) for a meeting of 3 hours. The optimal size increases in the quality of signals. Our finding that the optimal size for a committee deciding by unanimity is included in the interval $[5 : 10]$ is robust to changes in the probability π that the initial proposal is for the correct decision.

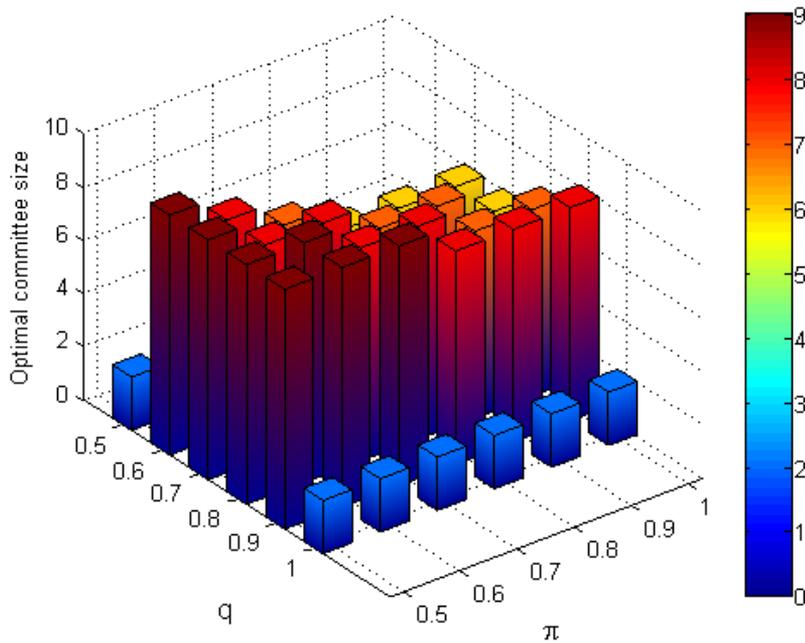


Figure 5: Optimal committee size under unanimity

A committee deciding by unanimity should be small enough to be able to eventually adopt a proposal by the end of a meeting. As a matter of fact, to obtain an optimal committee size of about 20 members, one would

have to significantly relax the time constraint to about between 32 to 40 hours (see figure 5b, where time is expressed in minutes). One should however not conclude from this that decision-making by unanimity/consensus in large committees is inefficient. In practice the initial distribution of opinions in large committees can be influenced by preparatory meetings at technical levels that contribute to convergence of views before policy rate-setting meetings (see Moutot et al. (2008)).

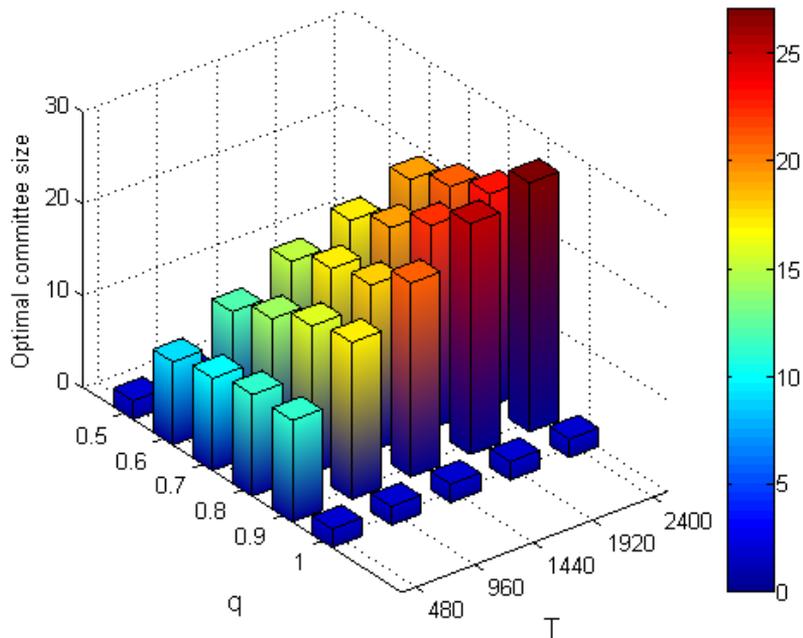


Figure 5b: The importance of time

5.3 Supermajority voting rules 3.3.1

In the absence of time constraints, our finding that committees deciding by majority voting should optimally be of infinite size is attributable to the negative impact of discussions on policy performance. By contrast, discussions are welfare-enhancing in committees deciding by unanimity. Time plays an important role in the quality of decisions taken by unanimity, and committee

size matters for the quality of discussions. There always exists an optimal, finite size for a committee deciding by unanimity, regardless of the quality of signals.

In the case of supermajority voting rules, an optimal, finite committee size exists only for a certain range of signal quality. We display in the (r, q) space, the frontier delineating the parameter region in which the optimal committee size is finite. For a given voting rule r , there is a value of the signal quality q above which the marginal gain from adding a member is always positive and the optimal committee size becomes infinite. Discontinuity effects make the frontiers quite imprecise; in particular, several values of r correspond to the same voting rule, as explained in section 3.3.1.

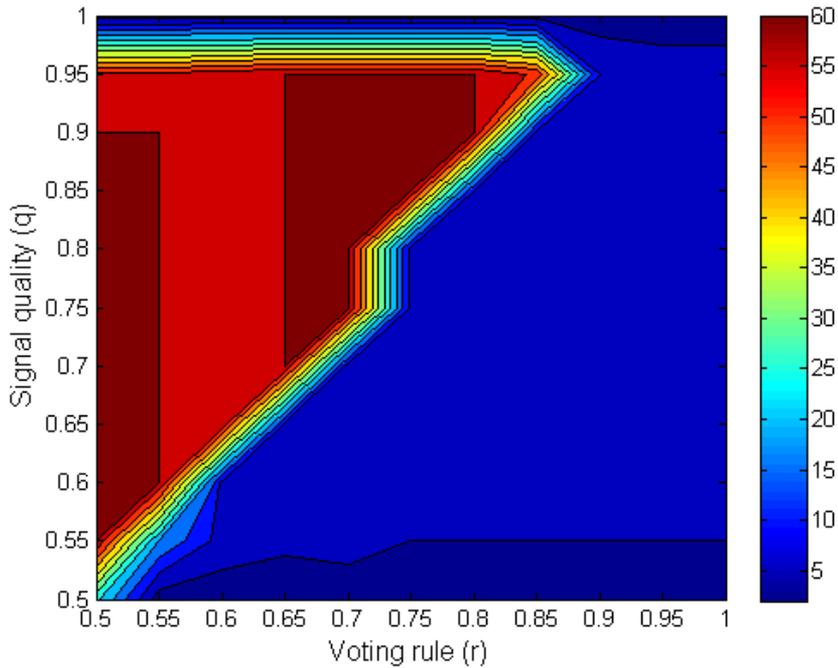


Figure 6: optimal committee size ($T = 180$; $\pi = 1$)

Overall, our analysis stresses the existence of a relationship between voting rules and the optimal size of a committee. Majority voting can work

well even in very large committees, under the rather demanding assumption that it is possible to find a sufficiently large number of individuals with access to relevant information. Unanimity is more efficient if implemented in small committees, with a fairly robust upper bound of about 10 members for meetings of reasonable duration. Finally, when analysing intermediate voting rules, we show that the existence of an optimal, finite committee size depends on the quality of signals. More stringent voting rules allows for defining an optimal committee size, while very large committee are more likely to perform better when decision rules are less stringent (e.g., simple majority)¹⁴.

6 Further considerations on voting rules

6.1 The performance gap between majority voting and unanimity

In our model, the time constraint works against the information aggregation gain that result from adding members to the committee. The time constraint alone does not discriminate between voting rules, because once discussion time is over, the distribution of opinions in the committee does not depend on the voting rule.

Given a committee size, only the requirement imposed by the voting rule will determine the outcome of the decision-making process. In this respect, the more efficient rule is the less demanding one: majority voting. When a proposition is right and members are informed, there is no gain in adopting it unanimously rather than by simple majority voting¹⁵.

It should, however, be noted that extension of the duration of the meeting reduces the efficiency gap in favour of majority voting to the point that it

¹⁴Our results are in line with those of Morimoto (2010). Introducing an explicit coordination motivation in the welfare function of members, he finds that the optimality of finite size committees depends on the precision of information available to the members of the committee, under median and averaging voting rule.

¹⁵This result is not very robust. It depends on the incentive structure, i.e., the payoffs of committee members. Visser & Swank (2007) show that, when concerned with their reputation, committee members present a bias towards adopting proposals unanimously. Furthermore, MPCs may seek unanimity as a way to strengthen markets' confidence in their expertise and for other communication purposes.

disappears in theoretical infinite discussions. The long-run convergence of the distribution of opinions eliminates differences between voting rules. A simple example is here in order. Let's consider a committee of 4 members. The transition matrix of the discussion process is

$$M = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ \frac{3}{4} & 0 & \frac{1}{4} & 0 & 0 \\ 0 & \frac{1}{2} & 0 & \frac{1}{2} & 0 \\ 0 & 0 & \frac{1}{4} & 0 & \frac{3}{4} \\ 0 & 0 & 0 & 0 & 1 \end{pmatrix}$$

Let us further assume, for the sake of exposition, that the proposal P is right and that initially 3 members support the proposal and one is against it. In the absence of discussion, the right decision would be taken under majority voting, but would be rejected under unanimity. Now, suppose that members engage in one round of discussion. With probability $\frac{1}{4}$, P has 2 supporters and with probability $\frac{3}{4}$ all members support the proposal. After this discussion round, the proposal is still adopted under majority voting with probability 1. The probability of adoption of the proposal under unanimity has increased from 0 to $\frac{3}{4}$ in one discussion round. The efficiency gap between majority voting and unanimity is further reduced throughout the discussion process.

The influence of the quality of signals on the difference between majority and unanimity is obvious. If members receive very good signals about the economy, they are more likely to agree immediately and unanimously on the right option. The efficiency gap between the two voting rules is decreasing in the quality of signals.

6.2 The role of uncertainty

The probability π that the true state of the world is P captures the degree of uncertainty of the economic environment. In a more uncertainty environment, the policy proposal emanating from staff analysis is less likely to be correct.

As a first step, recall from section 3.3.2 that the welfare derived from a decision voted by simple majority does not depend on π . Indeed, members

receive a state-dependent signal such that their initial opinions are not biased towards the proposal. In particular, our statistical, non-Bayesian approach implies that members do not extract information from the fact that the proposal is a proposal ($\pi > \frac{1}{2}$).

π matters when analysing other voting rules, because they are asymmetrical. *Ceteris paribus*, the status quo is more likely to prevail under unanimity than under majority voting. This feature of unanimity is largely reflected in institutional design. When major decisions are to be taken, such as an amendment to the constitution, supermajority rules are generally applied. Another example is reported in Gerardi and Yariv (2006), who note that while in the US murder defendants can most always be convicted solely by unanimous juries, non-unanimous decision rules are utilized in many state courts. Unanimity works as a way to enshrine an inclination against mistakes into the decision-making process, and is more likely to be utilized as a decision rule when mistakes are costly.

Let's consider a committee of m members receiving a signal of quality $q > \frac{1}{2}$. We denote with $\theta_{(m,q)}^n(k)$ the probability that k members support the right option after n rounds of discussion. With a supermajority voting rule \bar{m} , we can write social welfare as a function of the parameters:

$$w(m, \bar{m}, q, T) = w_{\bar{m}} = \pi \sum_{k=\bar{m}}^m \theta_{(m,q)}^N(k) + (1 - \pi) \sum_{k=m-\bar{m}+1}^m \theta_{(m,q)}^N(k)$$

Let us now compute the marginal social welfare gain of a more stringent voting rule:

$$w_{\bar{m}+1} - w_{\bar{m}} = (1 - \pi) \cdot \theta_{(m,q)}^N(m - \bar{m}) - \pi \cdot \theta_{(m,q)}^N(\bar{m}) \quad (1)$$

$$w_{\bar{m}+1} - w_{\bar{m}} \geq 0 \iff \frac{\theta_{(m,q)}^N(m - \bar{m})}{\theta_{(m,q)}^N(\bar{m})} \geq \frac{\pi}{1 - \pi}$$

Equation (1) shows the influence of π on the efficiency gap between the two voting rules. A decrease in π reduces the difference between $w_{\bar{m}}$ and $w_{\bar{m}+1}$.

6.3 Asymmetric payoffs

In terms of institutional design of committees, unanimity can be interpreted as a social contrivance to hedge against harmful proposals that could emerge in a very uncertain environment, where the probability of formulating correct policy proposal is low ($\pi \rightarrow \frac{1}{2}$). This interpretation is even more relevant when payoffs are asymmetric. In this section we assume asymmetric payoffs, with the cost of adopting a wrong proposal exceeding that of rejecting a right one:

$$\begin{aligned} U(P|P) &= U(\bar{P}|\bar{P}) = 1 \\ U(P|\bar{P}) &= \beta \quad U(\bar{P}|P) = \alpha \quad (\alpha, \beta) \in]-1; 1]^2, \beta < \alpha \end{aligned}$$

The social welfare associated with a voting rules \bar{m} is:

$$\begin{aligned} w(m, \bar{m}, q, T) &= w_{\bar{m}} = \\ &\pi \left[\sum_{k=\bar{m}}^m \theta_{(m,q)}^N(k) + \alpha \sum_{k=0}^{\bar{m}-1} \theta_{(m,q)}^N(k) \right] + \\ (1 - \pi) &\left[\sum_{k=m-\bar{m}+1}^m \theta_{(m,q)}^N(k) + \beta \sum_{k=0}^{m-\bar{m}} \theta_{(m,q)}^N(k) \right] \end{aligned}$$

We have:

$$w_{\bar{m}+1} - w_{\bar{m}} = (1 - \pi) \cdot (1 + \beta) \cdot \theta_{(m,q)}^N(m - \bar{m}) - \pi \cdot (1 - \alpha) \cdot \theta_{(m,q)}^N(\bar{m})$$

and

$$w_{\bar{m}+1} - w_{\bar{m}} \geq 0 \quad \iff \quad \frac{\theta_{(m,q)}^N(m - \bar{m})}{\theta_{(m,q)}^N(\bar{m})} \geq \frac{\pi(1 - \alpha)}{(1 - \pi)(1 - \beta)}$$

One can see, that the assumption $\beta < \alpha$ relaxes the constraint we found in section 6.2 for $\bar{m} + 1$ to outperform \bar{m} . Indeed, as $\frac{1 - \alpha}{1 - \beta} < 1$, it is possible that $\frac{\pi(1 - \alpha)}{(1 - \pi)(1 - \beta)}$ is smaller than 1, so that the requirement can be met more easily.

One can also check the equivalence between voting rules when there is no time constraint. Indeed, when $N \rightarrow \infty$, $\theta_{(m,q)}^N(m - \bar{m})$ and $\theta_{(m,q)}^N(\bar{m})$ converge towards 0. The voting rules do not matter when committees can discuss forever.

7 Conclusion

Our modelling framework assumes that committee members have identical preferences and focusses on the mechanics of policy deliberations by fleshing out the concept of agreement costs. It suggests that both committee size and voting rule matter for policy performance in a rather intertwined way. The lessons one can draw for institutional design largely depends on the constraints (typically the voting rule, the committee size or even the length of the meeting) the institutional designer is confronted with. Overall, our main findings suggest that in large committees majority voting is likely to enhance policy outcomes. Under unanimity (consensus), however, it is preferable to limit the size of the committee.

The optimal size of a committee is sensitive to the voting rule and the quality of signals received by members. Under unanimity, and reasonable assumptions on the duration of policy meetings, our numerical exercises suggest an upper bound of about 10 members. When comparing voting rules, unanimity is less efficient than majority voting, but the ranking of voting rules is affected by the payoffs structure. Supermajority rules, including unanimity, can perform better than simple majority when the social loss from adopting a bad proposal is greater than that from rejecting a good one. Finally, supermajority voting rules are social contrivances that contribute to policy performance in a more uncertain environment, when initial policy proposals are less likely to be correct.

Appendix

Proof of Proposition 1

Proposition 1 is a well-known result of absorbing Markov chains. The transition matrix of the Markov chain can be rewritten in *canonical form* by renumbering the states so that the two absorbing states (0 and m) come last:

$$M = \begin{pmatrix} Q & F \\ 0 & I_2 \end{pmatrix}$$

Here Q is an $m - 1 \times m - 1$ sub-matrix, the elements of which are the probabilities of moving from a non-absorbing state to a non-absorbing state, F is an $m - 1 \times 2$ non-zero matrix, and I_2 is the 2×2 identity matrix. In canonical form, the $2 \times m - 1$ submatrix of $M^{(n)}$ (M to the power n) formed by the 2 last lines and the $m - 1$ first columns of $M^{(n)}$ is the zero matrix, for every n .

Let us consider the matrix Q . $\forall n \in \mathbb{N}, \forall (i, j) \in \llbracket 1; m - 1 \rrbracket$, $Q^{(n)}(i, j)$ is the probability of being in state j in round n conditional on state i being occupied in round 0. For the Markov chain to converge towards one of the two absorbing states, these probabilities must converge to 0 when n tends to infinity: $\lim_{n \rightarrow \infty} Q^{(n)} = 0$.

$\forall (i, j) \in \llbracket 1; m - 1 \rrbracket$, $Q^{(n)}(i, j)$ is less than the probability that an absorbing state has not been reached in n rounds. Let n_i be the minimum number of rounds required to reach an absorbing state from state i

$$n_i = \min \{k \geq 1, \exists l > m - 1, M^{(k)}(i, l) > 0\},$$

Let p_i be the probability that, starting from i , the process will not reach an absorbing state in n_i rounds. This probability is smaller than 1:

$$p_i = \Pr \{X_{n_i} \notin \{0; m\}\} < 1,$$

Let n_{\max} be the largest of the n_i and p the largest of the p_i :

$$n_{\max} = \max_{i=1..m-1} n_i \text{ and } p = \max_{i=1..m-1} p_i$$

Then, the probability of not reaching an absorbing state starting from any non absorbing state in n_{\max} rounds is bounded by p . The probability of not reaching an absorbing state in $n_{\max} \cdot k$ rounds is bounded by p^k . As $\lim_{k \rightarrow \infty} p^k = 0$, $\forall (i, j) \in \llbracket 1; m-1 \rrbracket$, $Q^{(n)}(i, j) \rightarrow 0$.
QED

Proof of Proposition 2

While this result may apply to more general models of the transition between states of discussion, its general proof would be dramatically more involved, if feasible. We prove the proposition for transition matrices satisfying criterion 3.2 which encompasses a broad range of decision making processes:

$$M = \begin{pmatrix} 1 & 0 & \dots & \dots & 0 \\ (1-\nu) \cdot \frac{m-1}{m} & \nu & (1-\nu) \cdot \frac{1}{m} & & \vdots \\ 0 & & \ddots & & 0 \\ \vdots & & (1-\nu) \cdot \frac{1}{m} & \nu & (1-\nu) \cdot \frac{m-1}{m} \\ 0 & \dots & \dots & 0 & 1 \end{pmatrix}$$

The probability π that the proposal P is the right decision does not affect the result. First, because the signal has a state dependent distribution and not a proposal dependent distribution. Secondly because proposition 1 shows that the discussion process converges to unanimity when the number of discussion rounds tends to infinity, so that the relative imbalance¹⁶ introduced by super-majority voting rules is not relevant in the long run.

Proposition 1 states that the discussion process converges to unanimity, regardless of the initial distribution of opinions in the committee.

Let $r_m^\infty(k)$ denote the probability that a discussion starting with k members supporting the correct option converges to unanimity for the correct option. The probability of converging to unanimity for the correct decision in a committee of size m and with a signal of quality q is given by:

¹⁶Imbalance means that for voting rules other than majority voting, the requirement for statu quo to prevail is ceteris paribus less demanding than for the proposal to be accepted.

$$R^\infty(m, q) = \sum_{k=0}^m \theta_{(m,q)}(k) \cdot r_m^\infty(k)$$

The Markov process has two absorbing states (unanimity for or against the proposal); hence: $r_m^\infty(m) = 1$ and $r_m^\infty(0) = 0$. To derive the expressions of $r_m^\infty(k)$ for $k \in \llbracket 1; m-1 \rrbracket$ ¹⁷, we establish a recursive relationship between the terms of the series r_m^∞ . Starting from state $k-1$ (resp., $k+1$), the process reaches state k at the next round with probability $(1-\nu) \frac{m-k}{m}$ (resp., $(1-\nu) \frac{j}{m}$). The probability of staying in state k is ν . This implies the following recursive relationship for the probability of reaching unanimity in the long run:

$$\begin{aligned} \forall k &\in \llbracket 1; m-1 \rrbracket, \\ r_m^\infty(k) &= (1-\nu) \cdot \frac{m-k}{m} \cdot r_m^\infty(k-1) + (1-\nu) \cdot \frac{j}{m} \cdot r_m^\infty(k+1) + \nu \cdot r_m^\infty(k) \end{aligned}$$

We exclude the case $\nu = 1$ to obtain:

$$\forall k \in \llbracket 1; m-1 \rrbracket, \forall \nu \in [0; 1[, \quad r_m^\infty(k) = \frac{m-k}{m} \cdot r_m^\infty(k-1) + \frac{k}{m} \cdot r_m^\infty(k+1)$$

By re-ordering the terms and iterating the relationship backward, one obtains:

$$\begin{aligned} \forall k &\in \llbracket 1; m-1 \rrbracket, \quad r_m^\infty(k+1) - r_m^\infty(k) = \frac{m-k}{k} \cdot (r_m^\infty(k) - r_m^\infty(k-1)) \\ &= \prod_{l=1}^k \frac{m-l}{l} \cdot r_m^\infty(1) = \binom{m-1}{k} \cdot r_m^\infty(1) \end{aligned}$$

Hence,

¹⁷The indice k indicates the state $X_0 = k$, while, in the previous proof, we needed to re-arrange the index notation.

$$\forall k \in [[1; m]], r_m^\infty(k) = r_m^\infty(1) \cdot \sum_{l=0}^{k-1} \binom{m-1}{l}$$

Since $r_m^\infty(m) = 1$ and $\sum_{k=0}^{m-1} \binom{m-1}{k} = 2^{m-1}$, we find that $r_m^\infty(1) = \frac{1}{2^{m-1}}$.

The probability of reaching unanimity for the proposal in the long run when starting with $k \geq 1$ members in favour of the proposal is given by:

$$\forall k \in [[1; m]], r_m^\infty(k) = \frac{1}{2^{m-1}} \cdot \sum_{l=0}^{k-1} \binom{m-1}{l} \quad (2)$$

By induction, we obtain: $\forall k \in [[0; m]], r_m(k) = 1 - r_m(m-k)$. For committees consisting of an even number of members, we have: $r_m(\frac{m}{2}) = \frac{1}{2}$, i.e., starting from a tie there is equiprobability to converge to unanimity for or against the proposal in the long run.

The overall probability of reaching unanimity for the proposal is:

$$R^\infty(m, q) = \sum_{k=0}^m \binom{m}{k} \cdot q^k \cdot (1-q)^{m-k} \cdot r_m^\infty(k)$$

Let us first observe that $R^\infty(m, q)$ as a function of $q \in [0, 1]$ is symmetric around $\frac{1}{2}$:

$$\begin{aligned} R^\infty(m, 1-q) &= \sum_{k=0}^m \binom{m}{k} \cdot (1-q)^k \cdot q^{m-k} \cdot r_m^\infty(k) \\ &= \sum_{k=0}^m \binom{m}{k} \cdot (1-q)^k \cdot q^{m-k} \cdot (1 - r_m^\infty(m-k)) \\ &= \sum_{k=0}^m \binom{m}{k} \cdot (1-q)^k \cdot q^{m-k} - \sum_{k'=0}^m \binom{m}{m-k'} \cdot (1-q)^{m-k'} \cdot q^{k'} \cdot r_m^\infty(k') \\ &= 1 - R^\infty(m, q) \end{aligned}$$

In the proof of the proposition we will make use of the two following expressions (based on Pascal's triangle)

1. $r_{m+1}(k+1) = \frac{1}{2}(r_m(k+1) + r_m(k))$ with convention $r_m(m+1) = 1$;
2. $\theta_{(m+1,q)}(k+1) = (1-q)\theta_{(m,q)}(k+1) + q\theta_{(m,q)}(k)$
with convention $\theta_{(m,q)}(m+1) = 0$.

To prove proposition 4.2 we need to show that :

$$R^\infty(m+1, q) - R^\infty(m, q) \text{ is } \left\{ \begin{array}{l} \text{positive for } q > \frac{1}{2} \\ \text{negative for } q < \frac{1}{2} \end{array} \right\} \text{ for all } m.$$

The symmetry of the function $R^\infty(., q)$ with respect to $q = \frac{1}{2}$ implies

$$R^\infty(m+1, 1-q) - R^\infty(m, 1-q) = R^\infty(m, q) - R^\infty(m+1, q)$$

It is sufficient to prove that

$$\forall m \in \llbracket 1; m \rrbracket, \forall q > \frac{1}{2}, R^\infty(m+1, q) - R^\infty(m, q) > 0$$

Starting from the probability of reaching unanimity for the proposal in a committee of size $m+1$, and bearing in mind that $r_{m+1}^\infty(0) = 0$, we have:

$$\begin{aligned} R^\infty(m+1, q) &= \sum_{k=0}^{m+1} \theta_{(m+1,q)}(k) \cdot r_{m+1}^\infty(k) = \sum_{\mathbf{k}=1}^{m+1} \theta_{(m+1,q)}(k) \cdot r_{m+1}^\infty(k) \\ &= \sum_{k=0}^m \theta_{(m+1,q)}(k+1) \cdot r_{m+1}^\infty(k+1) \end{aligned}$$

We make use of the two recursive relationships 1 and 2 to write

$$\begin{aligned} &R^\infty(m+1, q) \\ &= \frac{1}{2} \sum_{k=0}^m [(1-q)\theta_{(m,q)}(k+1) + q\theta_{(m,q)}(k)] \cdot [r_m(k+1) + r_m(k)] \\ &= \frac{1}{2} q \underbrace{\sum_{k=0}^m \theta_{(m,q)}(k) \cdot r_m(k)}_{R^\infty(m,q)} + \frac{1}{2} (1-q) \underbrace{\sum_{k=0}^m \theta_{(m,q)}(k+1) \cdot r_m(k+1)}_{R^\infty(m,q)} \\ &\quad + \frac{1}{2} \sum_{k=0}^m (1-q)\theta_{(m,q)}(k+1) \cdot r_m(k) + \frac{1}{2} \sum_{k=0}^m q\theta_{(m,q)}(k) r_m(k+1) \\ &= \frac{1}{2} R^\infty(m, q) + \frac{1}{2} (1-q) \sum_{k=0}^{\mathbf{m}-1} \theta_{(m,q)}(k+1) \cdot r_m(k) + \frac{1}{2} q \sum_{k=0}^m \theta_{\mu(m,q)}(k) \cdot r_m(k+1) \end{aligned}$$

Since

$$\forall j \in [0; m-1], r_m(j+1) = r_m(j) + \frac{1}{2^{m-1}} \binom{m-1}{j}$$

we have

$$R^\infty(m+1, q) = R^\infty(m, q) + \frac{1}{2^m} \sum_{k=0}^{m-1} \binom{m-1}{k} \left[q \cdot \theta_{(m,q)}(k) - (1-q) \cdot \theta_{(m,q)}(k+1) \right]$$

which implies that:

$$\text{sgn} \{ R^\infty(m+1, q) - R^\infty(m, q) \} = \text{sgn}(L)$$

where

$$\begin{aligned} L &= \sum_{k=0}^{m-1} \binom{m-1}{k} \left[q \cdot \theta_{(m,q)}(k) - (1-q) \cdot \theta_{(m,q)}(k+1) \right] \\ L &= \sum_{k=0}^{m-1} \binom{m-1}{k} q^{k+1} \cdot (1-q)^{m-k} \left[\binom{m}{k} - \binom{m}{k+1} \right] \end{aligned}$$

In the sequel we assume that m is odd, as the proof is broadly similar if m is even. We have:

$$\begin{aligned} L &= \sum_{k=0}^{\frac{m-3}{2}} \binom{m-1}{k} q^{k+1} \cdot (1-q)^{m-k} \left[\binom{m}{k} - \binom{m}{k+1} \right] \\ &+ \sum_{k=\frac{m+1}{2}}^{m-1} \binom{m-1}{k} q^{k+1} \cdot (1-q)^{m-k} \left[\binom{m}{k} - \binom{m}{k+1} \right] \end{aligned}$$

In the second term, we let $j = m - k - 1$

$$\begin{aligned} L &= \sum_{k=0}^{\frac{m-3}{2}} \binom{m-1}{k} q^{k+1} \cdot (1-q)^{m-k} \left[\binom{m}{k} - \binom{m}{k+1} \right] \\ &+ \sum_{j=0}^{\frac{m-3}{2}} \binom{m-1}{m-j-1} q^{m-j} (1-q)^{j+1} \left[\binom{m}{m-j-1} - \binom{m}{m-j} \right] \end{aligned}$$

$$\begin{aligned}
L &= \sum_{k=0}^{\frac{m-3}{2}} \binom{m-1}{k} q^{k+1} (1-q)^{m-k} \left[\binom{m}{k} - \binom{m}{k+1} \right] \\
&\quad + \sum_{j=0}^{\frac{m-3}{2}} \binom{m-1}{j} q^{m-j} (1-q)^{j+1} \left[\binom{m}{j+1} - \binom{m}{j} \right] \\
L &= \sum_{j=0}^{\frac{m-3}{2}} \left[\binom{m}{j+1} - \binom{m}{j} \right] \binom{m-1}{j} \left[q^{m-j} (1-q)^{j+1} - q^{j+1} (1-q)^{m-j} \right]
\end{aligned}$$

We observe that:

$$\begin{aligned}
&\forall j \in \llbracket 0; \frac{m-3}{2} \rrbracket, \binom{m}{j+1} - \binom{m}{j} > 0 \\
&\forall j \in \llbracket 0; \frac{m-3}{2} \rrbracket, \forall q > \frac{1}{2}, q^{m-j} (1-q)^{j+1} - q^{j+1} (1-q)^{m-j} > 0,
\end{aligned}$$

and conclude that:

$$\text{if } q > \frac{1}{2}, \quad \text{sgn} \{R^\infty(m+1, q) - R^\infty(m, q)\} = \text{sgn} \{L\} > 0$$

Owing to symmetry in q around $\frac{1}{2}$ we have:

$$R^\infty(m+1, q) - R^\infty(m, q) \begin{cases} > 0 \text{ if } q > \frac{1}{2} \\ = 0 \text{ if } q = \frac{1}{2} \\ < 0 \text{ if } q < \frac{1}{2} \end{cases}$$

QED

Proof of Proposition 3

Unanimity

Unanimity for the right option in round $n+1$ can have two premises :

- Unanimity was already reached in round n (transition probability 1)
- In round n , $m-1$ members were right (transition probability $\frac{m-1}{m}$)

Then if we denote by $R^n(m, q)$ the probability that unanimity for the right decision is reached in round n , $R^n(m, q)$ is a growing sequence of n .

For unanimity rule, discussion is then always beneficial to the quality of the decision.

Majority voting ¹⁸

Let $v = \begin{pmatrix} 0 \\ \vdots \\ 1 \\ \vdots \\ 1 \end{pmatrix} \leftarrow \text{rank } \frac{m+1}{2}$ be the vector of size $m+1$ whose components

strictly below $\frac{m+1}{2}$ are 0, and the others 1.

Then, the probability that a good decision is taken under majority voting if immediately (no discussion) is

$$R^0(m, q) = v \cdot \theta_{(m, q)}$$

While the results of the long run discussion are

$$R^\infty(m, q) = r_m^\infty \cdot \theta_{(m, q)}^{19}$$

Then, proving that a long run discussion is detrimental to a vote under majority voting boils down to proving that

$$\begin{aligned} R^0(m, q) - R^\infty(m, q) &= v \cdot \theta_{(m, q)} - r_m^\infty \cdot \theta_{(m, q)} > 0 \\ R^0(m, q) - R^\infty(m, q) &= \sum_{j=0}^m \left(1_{\{j \geq \frac{m+1}{2}\}} - r_m^\infty(j) \right) \theta_{(m, q)}(j) \\ R^0(m, q) - R^\infty(m, q) &= - \sum_{j=0}^{\frac{m-1}{2}} r_m^\infty(j) \cdot \theta_{(m, q)}(j) + \sum_{j=0}^{\frac{m+1}{2}} (1 - r_m^\infty(j)) \cdot \theta_{(m, q)}(j) \end{aligned}$$

We know from the previous section that $r_m(m-j) = (1 - r_m(j))$
So we can rewrite

$$\begin{aligned} R^0(m, q) - R^\infty(m, q) &= \sum_{j=0}^{\frac{m-1}{2}} r_m^\infty(j) \cdot [\theta_{(m, q)}(m-j) - \theta_{(m, q)}(j)] \\ [\theta_{(m, q)}(m-j) - \theta_{(m, q)}(j)] &= \binom{m}{j} [q^{m-j}(1-q)^j - q^j(1-q)^{m-j}] \end{aligned}$$

As long as $q > \frac{1}{2}$, one can prove by a trivial descending induction that

¹⁸For expository convenience, we prove the result for odd committees. A similar proof gives the result for even ones.

¹⁹This is true no matter what the voting rule is since the process converge towards unanimity in the long run.

$$\forall j \in \llbracket 0; \frac{m-1}{2} \rrbracket, q^{m-j}(1-q)^j - q^j(1-q)^{m-j} \geq 0$$

Then, if the signal quality is above $\frac{1}{2}$,

$$R^0(m, q) - R^\infty(m, q) \geq 0,$$

i.e. the long run discussion is detrimental to the social value of the decision.

On the contrary if $q < \frac{1}{2}$,

$$\text{as } (1-q) > \frac{1}{2} \forall j \in \llbracket 0; \frac{m-1}{2} \rrbracket, q^{m-j}(1-q)^j - q^j(1-q)^{m-j} > 0$$

so that

$$R^0(m, q) - R^\infty(m, q) < 0,$$

i.e. the long run discussion is beneficial to the social value of the decision.

Other voting rules

$$\text{Let } v_r = \begin{pmatrix} 0 \\ \vdots \\ 0 \\ 1 \\ 1 \end{pmatrix} \leftarrow \text{rank } [rm]$$

We let $R_r^0(m, q)$ be the probability that the right option is decided under voting rule r if voted immediately (i.e. without discussion).

$$R_r^0(m, q) = \theta_{(m,q)} \cdot v_r = \sum_{j=0}^m 1_{\{j \geq [rm]\}} \cdot \theta_{(m,q)}(j)$$

$$R_r^0(m, q) = \sum_{j=[rm]}^m \theta_{(m,q)}(j) = \Pr(X_0(m, q) \geq [rm])$$

$R^\infty(m, q)$ still refers to the long-run probability that the good decision is taken. The subscript r needs not to appear as the discussion process converges towards unanimity

$$R^\infty(m, q) = \sum_{j=0}^m \theta_{(m,q)}(j) \cdot r_m^\infty(j)$$

We will interpret $R_r^0(m, q)$ and $R^\infty(m, q)$ as functions of q .

If $q' > q$ one can see that $\theta_{(m, q')}$ stochastically dominates $\theta_{(m, q)}$ ²⁰

Then $q \rightarrow R_r^0(m, q)$ is increasing in q over $[0; 1]$

Because $j \rightarrow r_m^\infty(j)$ is strictly increasing over $[[0; m]]$ and symmetric around $(\frac{m}{2}, \frac{1}{2})$ $q \rightarrow R^\infty(m, q)$ is also increasing in q over $[0; 1]$.

For every voting rule r , we let $q_r \in [\frac{1}{2}; 1]$ be the first q for which $R_r^0(m, q) = R^\infty(m, q)$.

q_r is then the threshold signal quality above which discussion might be harmful for a decision taken under voting rule r .

Because $R_r^0(m, 1) = R^\infty(m, 1) = 1$, we know that q_r exists.

For majority voting $q_{\frac{1}{2}} = \frac{1}{2}$:

- when $q < \frac{1}{2}$ $R_{\frac{1}{2}}^0(m, q) < R^\infty(m, q)$, so that discussion enhances the decision quality
- when $q > \frac{1}{2}$ $R_{\frac{1}{2}}^0(m, q) > R^\infty(m, q)$, so that discussion impairs the decision quality

$\forall q \in [0; 1], r \rightarrow R_r^0(m, q)$ is decreasing

$$\forall q \in [0; 1], r \rightarrow R_r^0(m, q) \text{ is decreasing} \implies \\ r \rightarrow q_r \text{ is increasing.}$$

It means that the quality threshold necessary for the discussion to be harmful increases when the voting rules becomes more stringent.

QED

²⁰If $X_q \sim \mu_{(m, q)}$, $X_{q'} \sim \mu_{(m, q')}$ and $q' > q$

$\forall l \in [[0; m]], \Pr(X_{q'} \geq l) \geq \Pr(X_q \geq l)$

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