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Article

Flexibility in committee size and the effect on collective performance: The unanimity rule

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Abstract: This paper contributes to the understanding of how flexibility in the number of members in a decision-making committee in a multistage project can enhance the accuracy and efficiency of the decisions taken. While most projects typically employ a fixed number of decision makers, the paper demonstrates the advantages of adjusting the committee size according to the project's varying complexity at different phases of the project. In particular, we show that allowing for flexibility in the size of a committee increases the likelihood of reaching a correct decision under the unanimity rule. We analyze this issue when the decision maker's competence is independent of the state of nature and when it is not. The results are compared to those under the simple majority rule.

Keywords: committee size; unanimity rule; simple majority rule
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1. Introduction

Many collective decisions are based on the unanimity rule. Under the unanimity rule a certain alternative is selected only if supported by all decision makers. Otherwise, the other alternative is chosen. For example, in countries where the jury system is used, the collective decision-making rule is typically the unanimity rule. Unanimous support by all jurors is required in order to convict a defendant. Otherwise, if at least one juror supports the alternative, the defendant is acquitted.

The unanimity rule in decision-making, where decisions require the agreement of all participants, has been widely studied in the context of economics, political science, and organizational theory. Ben-Yashar and Nitzan (1998) explore the quality and structure of organizational decision-making, focusing on the role of unanimity in committees. They find that under the unanimity rule, where each decision maker is decisive, the decision maker's power must be counterbalanced by high quality. Ben-Yashar and Nitzan (2001) further develop these ideas by examining the robustness of different organizational architectures, including the unanimity rule. They argue that while the unanimity rule can be robust in certain organizational structures, it may not be the most efficient rule. Ben-Yashar and Danziger (2016) analyze how to allocate experts into committees that use the unanimity rule to make decisions. They find that the optimal allocation of experts is extremely asymmetric. To achieve the optimal allocation, therefore, one needs only to rank the experts in terms of their competences and then allocate additional experts such that an expert's competence tends to vary inversely with the size of his committee. Feddersen and Pesendorfer (1998), in their study on unanimous jury verdicts, argue that the unanimity rule can lead to strategic voting, where jurors may vote against their true beliefs to conform with the majority. Sah and Stiglitz (1986, 1988) offer a comprehensive analysis of decision-making architectures, comparing the unanimity rule with other voting rules. They argue that while the unanimity rule ensures that decisions reflect the preferences of all members, it may also lead to inefficiencies. Romme (2004), Ali et al. (2008) and Rijnbout and McKimmie (2014) give the exact conditions under which the unanimity rule is preferred to all other rules.

The size of a committee (such as a court or jury) is often fixed and mandatory. Our results establish that, under the unanimity rule, such a restriction is disadvantageous for committees that are naturally more vulnerable to nonattendance. More explicitly, we analyze the effect of the flexibility in the size of a committee on the likelihood of arriving at a correct decision when the competence of the decision makers is not dependent on the state of nature and when it is. The possible dependence of the competence of the decision makers on state of nature may also play a significant role in the collective probability. The dependence of the competence of decision makers on the state of nature is represented by probabilities of voting correctly, where each probability is associated with a different state of nature. This implies a higher probability of voting correctly in one state of nature relative to the other (For a discussion on the dependence of the competence of decision makers on the state of nature, see Sah and Stiglitz (1986, 1988).

The simple majority rule is the most common voting method in democracy and hence a widely studied rule in voting theory. Our result is not valid in committee such as courts, expert committees, or boards of directors, where the applied decision rule is simple majority rule. We show that under simple majority rule, a fixed and mandatory number of decision makers is justified because it yields a higher probability of reaching the correct decision.

This paper holds particular significance in the field of infrastructure policy and development, as it offers a novel approach to enhancing decision-making processes. By examining the impact of committee size flexibility under the unanimity rule and the simple majority rule, the paper provides policymakers with practical insights that can lead to more effective governance frameworks, ultimately improving the planning and execution of infrastructure projects.

The findings of this paper have the potential to transform decision-making frameworks in infrastructure projects, by proposing a path toward more adaptive and resilient governance frameworks. By aligning the research question with the practical needs of infrastructure development, this paper bridges the gap between theory and practice, providing a solid foundation for more informed and effective policy decisions.

2. The model

The model assumes that a committee consisting of members must choose between two possible alternatives, one of which is the correct decision. Each member of the committee, much like a juror, makes their choice independently, and the probability that a member will choose the correct decision is given. This probability reflects each member's competence. The model focuses on a situation where the unanimity rule is used to make the final decision. This means that all members of the committee must agree on a specific decision. The model assumes that every member prefers the correct decision, but they do not know in advance which alternative is correct.

The relevance of this model pertains to real-world scenarios where unanimous agreement is required, such as in jury deliberations or other committee-based decision-making processes. Understanding how the competence of the members and the size of the committee influence the likelihood of reaching the correct decision is crucial for designing effective decision-making frameworks across various contexts. We assume two alternatives, 1 and −1, one of which is the correct decision and is thus preferred by all n members of a committee, where n is a positive integer (Earlier studies of two-alternative models include Condorcet (1785), Grofman (1975), Grofman et al. (1983), Feld and Grofman (1984), Nitzan and Paroush (1982), Owen et al. (1989), Berend and Paroush (1998), Austen-Smith and Feddersen (2006), Dietrich and List (2013), and Bozbay et al. (2014)). Consider, for example, a jury of n members that hear a defendant, and must decide whether to convict or acquit him. In state of nature 1, the defendant is found guilty, while in state of nature −1, the defendant is found innocent. As is common in decision problems, the identity of the correct decision, which is preferred by all the jurors involved, is unknown. There are two correct decisions: 1 when the state of nature is 1 and −1 when the state of nature is −1. Each juror chooses (independently of the other jurors) one of the two decisions, 1 or −1, with probability p of choosing the correct decision regardless of whether the correct decision is 1 or −1. Thus, p, $½ < p < 1$, reflects the juror's competence. The unanimity rule is applied in order to aggregate the jurors' decisions. We denote the unanimity rule by f_h and we denote the collective probability of a group of n jurors reaching a correct decision under the unanimity rule by $\pi^n_{f_h}(p)$. Assume that the prior probability that each alternative is correct is ½ (This assumption implies unbiasedness and is highly plausible when analyzing jury decisions. It is widely used; see, e.g., Ladha (1992), Berend and Paroush (1998), and Young (1988)). Formally,

$$\pi^n_{f_h}(p) = \frac{1}{2}(p)^n + \frac{1}{2}(1-(1-p)^n)$$

If the correct decision is 1, the probability of a correct decision is equal to the probability that all the jurors support this alternative. If the correct decision is −1, then the probability of a correct decision is equal to the probability that at least one juror supports −1.

3. The results

Let $\pi^{n+k}_{f_h}(p)$ and $\pi^{n-k}_{f_h}(p)$ denote the probability that groups consisting of $n+k$ and $n-k$ members, respectively, choose the correct decision under the unanimity rule**.** That is, the number of decision makers is larger or smaller by k relative to n. Let us denote by α the probability that the size of the group is $n+k$ and by $1-\alpha$ the probability that the size of the group is $n-k$. Assuming that $\alpha = \frac{1}{2}$, we obtain the following result.

Theorem 1. *If* $n-k > 1$, *then* $\frac{\pi^{n+k}_{f_h}(p)+\pi^{n-k}_{f_h}(p)}{2} \geq \pi^n_{f_h}(p)$.

Proof.

$$\frac{1}{4}(p)^{n+k}+\frac{1}{4}\left(1-(1-p)^{n+k}\right)+\frac{1}{4}(p)^{n-k}+\frac{1}{4}\left(1-(1-p)^{n-k}\right)\geq\frac{1}{2}(p^n+1-(1-p)^n)\Leftrightarrow$$
$$\frac{1}{4}(p^{n+k}+p^{n-k}+2-(1-p)^{n+k}-(1-p)^{n-k})\geq\frac{1}{2}(p^n+1-(1-p)^n)\Leftrightarrow$$
$$p^{n+k}+p^{n-k}+2-(1-p)^{n+k}-(1-p)^{n-k}\geq 2p^n+2-2(1-p)^n\Leftrightarrow$$
$$(1-p)^n-(1-p)^{n+k}+(1-p)^n-(1-p)^{n-k}\geq p^n(1-p^k)+p^n(1-p^{-k})\Leftrightarrow$$
$$(1-p)^n(1-(1-p)^k)+(1-p)^n(1-(1-p)^{-k})\geq p^n(1-p^k)+p^n(1-p^{-k})\Leftrightarrow$$
$$(1-p)^n(1-(1-p)^k+1-(1-p)^{-k})\geq p^n(1-p^k+1-p^{-k})\Leftrightarrow$$
$$\frac{2(1-p)^k-(1-p)^{2k}-1}{(1-p)^k}\geq\frac{p^n}{(1-p)^n}\frac{2p^k-p^{2k}-1}{p^k}\Leftrightarrow$$
$$-\frac{\left(1-(1-p)^k\right)^2}{(1-p)^k}\geq-\frac{p^n}{(1-p)^n}\frac{\left(1-p^k\right)^2}{p^k}\Leftrightarrow$$
$$\left(\frac{1-(1-p)^k}{1-p^k}\right)^2\leq\left(\frac{p}{1-p}\right)^{n-k}\Leftrightarrow\left(\frac{1-(1-p)^k}{1-p^k}\right)^2\left(\frac{1-p}{p}\right)^2\leq\left(\frac{p}{1-p}\right)^{n-k-2}\Leftrightarrow$$
$$\left(\frac{1-(1-p)^k}{1-p^k}\frac{1-p}{p}\right)^2\leq\left(\frac{p}{1-p}\right)^{n-k-2}$$

Since the term on the right-hand side is not less than 1 if $n-k>1$, it follows that to complete the proof we need to show that the term on the left-hand side is not greater than 1. That is, we need to prove that

$$\left(\frac{1-(1-p)^k}{1-p^k}\frac{1-p}{p}\right)^2\leq 1\Leftrightarrow\frac{1-(1-p)^k}{1-p^k}\frac{1-p}{p}\leq 1\Leftrightarrow 1-p-(1-p)^{k+1}\leq p-p^{k+1}\Leftrightarrow$$
$$p^{k+1}-(1-p)^{k+1}\leq 2p-1$$

This inequality is proved by induction.

If $k=1$, $p^2-(1-p)^2\leq 2p-1\Leftrightarrow 2p-1\leq 2p-1$, which establishes the inequality.

If $k=2$, $p^3-(1-p)^3\leq 2p-1\Leftrightarrow$

$$(2p-1)(p^2+p(1-p)+(1-p)^2)\leq 2p-1\Leftrightarrow p+1-2p+p^2\leq 1\Leftrightarrow p^2+1-p\leq 1\Leftrightarrow$$

$p^2-p\leq 0$, which establishes the inequality.

By induction, assume that for some k,

$p^k-(1-p)^k\leq 2p-1\Leftrightarrow p^k\leq 2p-1+(1-p)^k$.

For $k+1$, we prove that:

$$p^{k+1}-(1-p)^{k+1}\leq 2p-1\Leftrightarrow pp^k-(1-p)(1-p)^k\leq 2p-1\Leftrightarrow p^k\leq\frac{2p-1}{p}+\frac{(1-p)^{k+1}}{p}$$

Therefore, $\frac{2p-1}{p}+\frac{(1-p)^{k+1}}{p}\geq 2p-1+(1-p)^k\Leftrightarrow(2p-1)(1-p)\geq(1-p)^k(p-1+p)\Leftrightarrow 1\geq(1-p)^{k-1}$, which completes the proof. □

For the special case where one group has only one member, the result does not necessarily hold.

Corollary 1. $\frac{\pi_{f_h}^{2n-1}(p)+\pi_{f_h}^{1}(p)}{2}\gtreqless\pi_{f_h}^{n}(p)\Leftrightarrow$

$p^{2n-1}-2p^n+2p-1-(1-p)^{2n-1}+2(1-p)^n\gtreqless 0.$

Proof. See Appendix.

For example, if p = 0.844, n = 4, and k = 3, then $\frac{\pi_{f_h}^{7}(0.844)+\pi_{f_h}^{1}(0.844)}{2}<$

$\pi^4_{f_h}(0.844)$, but if n = 5 and k = 4, then $\frac{\pi^9_{f_h}(0.844)+\pi^1_{f_h}(0.844)}{2} > \pi^5_{f_h}(0.844)$.

In the sequel we present a generalization of Theorem 1 according to which flexibility in the size of a committee increases the likelihood of it reaching a correct decision. Assume that $\alpha \neq \frac{1}{2}$.

Theorem 2. *If* $n - k > 1$*, then* $\alpha\pi^{n+k}_{f_h}(p) + (1-\alpha)\pi^{n-k}_{f_h}(p) \geq \pi^n_{f_h}(p)$.

Proof. We start with an alternative proof of Theorem 1:

$$\pi^n_{f_h}(p) - \pi^{n-1}_{f_h}(p) = \frac{1}{2}\left(p(1-p)^{n-1} - p^{n-1}(1-p)\right).$$

Then, $\pi^n_{f_h}(p) - \pi^{n-1}_{f_h}(p) < 0$ if and only if $\left(\frac{p}{1-p}\right)^{n-1} > \frac{p}{1-p}$. This is satisfied if $n > 1$.

Moreover,

$$\begin{aligned}\pi^n_{f_h}(p) - \pi^{n-1}_{f_h}(p) - \left(\pi^{n-1}_{f_h}(p) - \pi^{n-2}_{f_h}(\mathrm{p})\right) \\ &= \frac{1}{2}\left(p(1-p)^{n-1} - p^{n-1}(1-p) - p(1-p)^{n-2} + p^{n-2}(1-p)\right) \\ &= \frac{1}{2}(-p^2(1-p)^{n-2} + p^{n-2}(1-p)^2).\end{aligned}$$

This last term is positive if $\left(\frac{p}{1-p}\right)^{n-2} > \left(\frac{p}{1-p}\right)^2$. In such a case, if $n-2>2$, then $\pi^n_{f_h}(p)$ has a positive second-order derivative.

Hence,

$$\begin{aligned}\pi^{n+k}_{f_h}(p) - \pi^n_{f_h}(p) + \pi^{n-k}_{f_h}(p) - \pi^n_{f_h}(p) \\ &= \sum_{\ell=0}^{k-1}\left(\pi^{\ell+1+n}_{f_h}(p) - \pi^{\ell+n}_{f_h}(p)\right) - \sum_{\ell=0}^{k-1}\left(\pi^{-\ell+1+n}_{f_h}(p) - \pi^{-\ell+n}_{f_h}(p)\right) \\ &= \sum_{\ell=0}^{k-1}\left(\pi^{-\ell+1+n}_{f_h}(p) - \pi^{\ell+n}_{f_h}(p)\right) - \left(\pi^{-\ell+1+n}_{f_h}(p) - \pi^{-\ell+n}_{f_h}(p)\right) > 0.\end{aligned}$$

Since $\pi^{n+k}_{f_h}(p) < \pi^n_{f_h}(p) < \pi^{n-k}_{f_h}(p)$, if $n-k \geq 2$, it follows that there exists α such that $\alpha\pi^{n+k}_{f_h}(p) + (1-\alpha)\pi^{n-k}_{f_h}(p) = \pi^n_{f_h}(p)$. □

Theorem 2 indicates that flexibility in the number of committee members can greatly enhance the efficiency and accuracy of decision-making in infrastructure projects. By adjusting the committee size according to the project's varying complexity at different stages of the project, decisions become better informed and more robust. This flexibility in committee size allows the decision-making process to adapt to changing circumstances, such as unforeseen environmental or budgetary challenges, ensuring that the process remains responsive and effective throughout the project's lifecycle. Moreover, flexible decision-making frameworks can streamline processes and improve collaboration among stakeholders, enabling decision-makers to focus on the most critical issues as they arise. Thus, flexibility in committee size leads to more accurate decisions, reduced risks, and more successful project outcomes.

This result is not valid for groups such as courts, expert committees, or boards of directors where the applied decision rule is simple majority rule. In such settings, a fixed and mandatory number of decision makers is justified because it yields a higher probability of reaching the correct decision. To see this, let f_m denote simple majority rule and let $\pi^n_{f_m}(p)$ denote the collective probability that a group consisting of $n = 2k + 1$ members reach a correct decision under simple majority rule. We isolate two members of the original group and rewrite $\pi^n_{f_m}(p)$ as $p^2A + (1 - (1 - p)^2)B + C$, where:

$$A = \binom{2k-1}{k-1} p^{k-1}(1-p)^k$$
$$B = \binom{2k-1}{k} p^k(1-p)^{k-1}$$
$$C = \sum_{i=k+1}^{2k-1} \binom{2k-1}{i} p^i(1-p)^{2k-1-i}$$

Suppose now that the above two members decide correctly. Hence, in order to obtain a majority, $k - 1$ out of $2k - 1$ members are required to decide correctly. This requirement is described by term A. When at least one of the two members decides correctly, then a majority is obtained if k out of $2k - 1$ members decide correctly. This requirement is described by term B. Finally, term C presents the sum of probabilities for obtaining a majority of at least $k + 1$ out of the $n - 1$ members. The probability that the group reaches the correct decision without the two members (i.e., a group of $2k - 1$ members) is $B + C$. Therefore, adding two members increases the probability that the group reaches the correct decision since:

$$p^2A + (1 - (1 - p)^2)B + C - (B + C) > 0 \Leftrightarrow p^2A - (1 - p)^2B > 0$$

This condition is always satisfied since $\frac{B}{A} = \frac{p}{1-p}$ and, indeed, by the Condorcet jury theorem (1785), the marginal extension of a group is always advantageous when members have the same competence.

Theorem 3. $\pi^n_{f_m}(p) \geq \alpha\pi^{n+k}_m(p) + (1 - \alpha)\pi^{n-k}_{f_m}(p)$.

Proof. $\pi^n_{f_m}(p) - \pi^{n-2}_{f_m}(p) = p^2A - (1 - p)^2B = \binom{2k-1}{k} p^k(1-p)^k(2p-1)>0$

Moreover,

$$\begin{aligned}\pi^n_{f_m}(p) - \pi^{n-2}_{f_m}(p) - \left(\pi^{n-2}_{f_m}(p) - \pi^{n-4}_{f_m}(p)\right) \\ &= \binom{2k-1}{k} p^k(1-p)^k(2p-1) \\ &- \binom{2k-3}{k-1} p^{k-1}(1-p)^{k-1}(2p-1) \\ &= \binom{2k-3}{k-1} p^{k-1}(1-p)^{k-1}(2p-1)\left(p(1-p)\frac{2(2k-1)}{k} - 1\right)\end{aligned}$$

which is negative under our assumption that $p > 0.5$. It follows that $\pi^n_{f_m}(p)$ has a negative second-order derivative.

Hence,

$$\begin{aligned}\pi^{n+k}_{f_m}(p) - \pi^n_{f_m}(p) + \pi^{n-k}_{f_m}(p) - \pi^n_{f_m}(p) \\ &= \sum_{\ell=0}^{k-1}\left(\pi^{\ell+1+n}_{f_m}(p) - \pi^{\ell+n}_{f_m}(p)\right) - \sum_{\ell=0}^{k-1}\left(\pi^{-\ell+1+n}_{f_m}(p) - \pi^{-\ell+n}_{f_m}(p)\right) \\ &= \sum_{\ell=0}^{k-1}\left(\pi^{-\ell+1+n}_{f_m}(p) - \pi^{\ell+n}_{f_m}(p)\right) - \left(\pi^{-\ell+1+n}_{f_m}(p) - \pi^{-\ell+n}_{f_m}(p)\right) < 0\end{aligned}$$

Since $\pi^{n+k}_{f_m}(p) > \pi^n_{f_m}(p) > \pi^{n-k}_{f_m}(p)$, it follows that there exists α such that

$\alpha\pi_{f_m}^{n+k}(p)+(1-\alpha)\pi_{f_m}^{n-k}(p)=\pi_{f_m}^{n}(p)$. □

4. Numerical illustrations

Consider, for example, a jury of 12 members that hear a defendant, and must decide whether to convict or acquit him. As is common in decision problems, the identity of the correct decision, which is preferred by all the jurors involved, is unknown. Each juror chooses (independently of the other jurors) one of the two decisions, convict or acquit, with probability 0.6 of choosing the correct decision. The collective probability of a group of 12 jurors reaching a correct decision under the unanimity rule is:

$$\frac{1}{2}(0.6)^{12}+\frac{1}{2}(1-(1-0.6)^{12})=0.50108$$

Now assume that groups consisting of 14 and 10 members choose the correct decision under the unanimity rule. That is, the number of decision makers is larger or smaller by 2, relatively, to the standard 12-member jury. We show the effect of this flexibility in the size of a committee on the likelihood of arriving at a correct decision. The collective probability of a group of 14 jurors reaching a correct decision under the unanimity rule is:

$$\frac{1}{2}(0.6)^{14}+\frac{1}{2}(1-(1-0.6)^{14})=0.50039$$

The collective probability of a group of 10 jurors reaching a correct decision under the unanimity rule is

$$\frac{1}{2}(0.6)^{10}+\frac{1}{2}(1-(1-0.6)^{10})=0.50297$$

Clearly, the collective probability (the average probability) of the 14- and 10-member juries choosing the correct decision is (0.50039 + 0.50297)/2 = 0.50168, which is greater than the collective probability of 0.50108 of the 12-member jury. This example demonstrates our result (Theorem 1) that under the unanimity rule, the number of members of a decision-making body should not be fixed. Flexibility in the size of the decision-making body may increase the average probability that it reaches the correct decision.

Let us consider another example. Assume a jury of 5 members, where each juror chooses convict or acquit, with probability 0.7 of choosing the correct decision. The collective probability of a group of 5 jurors reaching a correct decision under the unanimity rule is:

$$\frac{1}{2}(0.7)^{5}+\frac{1}{2}(1-(1-0.7)^{5})=0.58282$$

Now assume that groups consisting of 7 and 3 members choose the correct decision under the unanimity rule. Clearly, the collective probability (the average probability) of the 7- and 3-member juries choosing the correct decision is (0.5419 + 0.658)/2 = 0.5995, which is greater than the collective probability of 0.58282 of the 5-member jury. Again, the example demonstrates our result (Theorem 1) that under the unanimity rule, the number of members of a decision-making body should not be fixed. Flexibility in the size of the decision-making body may increase the average probability that it reaches the correct decision.

This result is not valid for groups such as supreme court panels, expert committees, or boards of directors, where the applied decision rule is simple majority rule. In such settings, a fixed and mandatory number of decision makers is justified because it yields a higher probability of reaching the correct decision. To see this, assume a committee of 5 members, where each member chooses to adopt or reject a policy, with probability 0.7 of choosing the correct decision. The collective probability of a group of 5 members reaching a correct decision under the simple majority rule is $(0.7)^5 + 5(0.7)^4(1-0.7)^1 + 10(0.7)^3(1-0.7)^2 = 0.83692$. Now assume that committees consisting of 7 and 3 members choose the correct decision under the simple majority rule. The collective probability of a group of 7 members reaching a correct decision under the simple majority rule is:

$$(0.7)^7 + 7(0.7)^6(1-0.7)^1 + 21(0.7)^5(1-0.7)^2 + 35(0.7)^4(1-0.7)^3 = 0.873964$$

The collective probability of a group of 3 members reaching a correct decision under the simple majority rule is:

$$(0.7)^3 + 3(0.7)^2(1-0.7)^1 = 0.784$$

The collective probability (the average probability) of the 7- and 3-member committees choosing the correct decision is (0.873964 + 0.784)/2 = 0.82895, which is less than the collective probability of 0.83692 of the 5-member committee.

This example demonstrates our result (Theorem 3) that under the simple majority rule, a mandatory number of decision makers is justified because it yields a higher probability of reaching the correct decision.

5. The decision maker’s competence is dependent on the state of nature

The possible dependence of the decision maker’s competence on the state of nature may also play a significant role in reaching the correct decision. In many decision-making contexts, the decision maker’s competence is higher in one state of nature than in another. To illustrate this, let’s consider the composition of judges in a court setting who are tasked with deciding whether a defendant is guilty or innocent. Here, we delineate two states of nature: one where the defendant is guilty and the other where the defendant is innocent. When assessing the judges’ competence, we must take into account that judges who lack specific legal experience as prosecutors or defense lawyers prior to their judicial appointment rely on general legal experience and training. Consequently, they decide on the defendant’s guilt or innocence independently of the state of nature. On the other hand, there are judges who bring extensive experience from their prior roles as prosecutors or defense attorneys before assuming the bench. These judges possess skills and insights that may vary depending on the specific state of nature. These judges thus may have state-dependent competence. The judge who is a former prosecutor (defense lawyer) has a better sense of when the defendant is guilty than when the defendant is innocent (when the defendant is innocent than when the defendant is guilty). Accordingly, we refer to judges with former experience as prosecutors or defense lawyers as having state-dependent competence. Specifically, in state of nature 1, i.e., when the defendant is guilty, the judge’s competence is p_1, whereas in state of nature -1, i.e., when the defendant is innocent, the judge’s competence is p_2. These probabilities represent the competence such that for each judge, $\frac{p_1+p_2}{2} > \frac{1}{2}$. For judges whose competence is independent of the state of nature, the competence is $p = p_1 = p_2$. Sah (1991) and Sah and Stiglitz (1988) relax the symmetry assumption on the states of nature by allowing the decision-making skills of each voter to depend on the state of nature).

When the competence of the decision makers depends on the state of nature, our result of that flexibility in the size of a group increases the likelihood of it reaching a correct decision under the unanimity rule is valid only under certain conditions. The term $\pi_{f_h}^n(p_1, p_2)$ represents the collective probability that a group consisting of n decision makers reach a correct decision under the unanimity rule when the decision makers' competence is dependent on the state of nature. When the decision makers' competence depends on the state of nature, the collective probabilities of reaching a correct decision in states 1 and -1 are represented by $\pi_{f_h}^n(p_1)$ and $\pi_{f_h}^n(p_2)$, respectively. Thus, we obtain:

$$\pi_{f_h}^n(p_1, p_2) = \frac{1}{2}\pi_{f_h}^n(p_1) + \frac{1}{2}\pi_{f_h}^n(p_2)$$

Theorem 4. *If* $p_1 < p_2, then \frac{\pi_{f_h}^{n+k}(p_1,p_2)+\pi_{f_h}^{n-k}(p_1,p_2)}{2} > \pi_{f_h}^n(p_1, p_2)$.

Proof. $\pi_{f_h}^n(p_1, p_2) - \pi_{f_h}^{n-1}(p_1, p_2) = \frac{1}{2}\left(p_2(1-p_2)^{n-1} - (p_1)^{n-1}(1-p_1)\right)$

This is negative iff:

$$\left(\frac{p_1}{1-p_2}\right)^{n-1} > \frac{p_2}{1-p_1} \Leftrightarrow \left(\frac{p_1}{1-p_2}\right)^{n-2} > \left(\frac{p_2(1-p_2)}{p_1(1-p_1)}\right)$$

$$\pi_{f_h}^n(p_1, p_2) - \pi_{f_h}^{n-1}(p_1, p_2) - \left(\pi_{f_h}^{n-1}(p_1, p_2) - \pi_{f_h}^{n-2}(p_1, p_2)\right) =$$
$$\frac{1}{2}\left(p_2(1-p_2)^{n-1} - p_1^{n-1}(1-p_1) - p_2(1-p_2)^{n-2} + p_1^{n-2}(1-p_1)\right) =$$
$$\frac{1}{2}\left(-(p_2)^2(1-p_2)^{n-2} + p_1^{n-2}(1-p_1)^2\right).$$

Then, $\pi_{f_h}^n(p_1, p_2)$ has a positive second-order derivative iff:

$$\left(\frac{p_1}{1-p_2}\right)^{n-2} > \left(\frac{p_2}{1-p_1}\right)^2 \Leftrightarrow \left(\frac{p_1}{1-p_2}\right)^n > \left(\frac{p_2}{1-p_1}\right)^2\left(\frac{1-p_2}{p_1}\right)^2 \Leftrightarrow$$
$$\left(\frac{p_1}{1-p_2}\right)^n > \left(\frac{p_2(1-p_2)}{p_1(1-p_1)}\right)^2$$

Since the term on the right-hand side is less than 1 if $p_1 < p_2$, while the term on the left-hand side is greater than 1, it follows that if $p_1 < p_2$ then there is a positive second-order derivative, which completes the proof. □

6. Conclusion

The paper demonstrates that the primary advantage of flexibility in the number of committee members lies in the ability to adjust the number of experts according to the specific needs of each stage in the decision-making process. When the number is not fixed, the committee can ensure that each decision is made based on the necessary knowledge and expertise relevant to the task at hand, leading to higher-quality decisions.

This approach can significantly improve the quality of decision-making in real-world applications, such as public transportation planning, renewable energy project development, urban infrastructure renovation, and crisis management.

For instance, when a large city plans a new public transportation system, the committee initially focuses on basic technical aspects such as station locations and route design, and therefore consists of a small number of engineering and urban planning experts. However, as discussions shift to more complex issues like environmental impacts or maintenance costs, the committee can expand by adding additional experts in these fields. This flexibility in the number of experts ensures that decisions are made optimally, considering all the critical aspects of the project.

In another example, during the development of a solar power plant, the decision-making committee operates at various stages of the project. Initially, when the focus is on technical feasibility, the committee may consist of a small group of technical experts. However, as environmental or economic considerations arise, the number of experts increases as needed. This flexibility allows the committee to operate dynamically and respond to the changing needs of the project.

Similarly, during the renovation of a city's water system, the committee might start with a small number of experts focused on technical aspects. However, when it becomes necessary to examine the impact on the local community or conduct additional studies, additional committee members can be brought in. This flexibility in committee size ensures that decisions are made based on comprehensive and expert information.

Finally, in a crisis, such as a pipeline burst or the collapse of transportation infrastructure, an emergency committee may start with a small number of experts for initial identification and response. As the implications of the crisis become clearer and more complex solutions are required, the number of committee members expands to include experts from areas like economics, law, and public health. This approach allows the committee to respond flexibly and dynamically to the situation, maximizing the ability to make timely and accurate decisions.

The unanimity rule ensures that every decision is made with the full agreement of all committee members. This is crucial in infrastructure projects where broad consensus is necessary, especially for decisions with long-term impacts, such as the construction of bridges, power plants, or water facilities. In high-risk projects, ensuring full agreement can help prevent potential disasters. However, this rule can also lead to significant delays, particularly when there are strong disagreements among committee members. These delays can increase costs and hinder the project's ability to proceed on schedule. In an unanimity-based process, a small minority can block important decisions, even when the overwhelming majority supports them, potentially resulting in stalled or failed projects. Despite these challenges, the unanimity rule may be preferred in complex projects with broad, long-term impacts. In such cases, ensuring that all opinions are considered and that critical risks are avoided is paramount.

By contrast, the simple majority rule allows for quicker decision-making, which can be vital in projects requiring rapid responses, such as in emergencies or when swift repairs are needed. This rule offers greater flexibility, especially when consensus is not essential and compromise between different interests is possible and desirable. However, decisions made under the simple majority rule may not give due consideration to the concerns of a significant minority, particularly in large-scale projects affecting a wide range of stakeholders. This can sometimes lead to hasty decisions that overlook critical information, potentially resulting in operational issues or unforeseen costs in the future. The simple majority rule may be preferable when the speed of decision-making is more important than achieving broad consensus, such as in crisis situations or when quick decisions are necessary to meet deadlines or control costs.

We show that under the unanimity rule, the number of members of a decision-making body should not be fixed. Such flexibility in the size of the decision-making body may increase the average probability that it reaches the correct decision. However, this result is not valid in a decision-making body such as courts, expert committees, or boards of directors where the applied decision rule is simple majority rule. In such settings, a fixed and mandatory number of members of a decision-making body is justified because it yields a higher probability of it reaching the correct decision.

These findings can directly enhance policy-making in infrastructure development by introducing flexibility into decision-making frameworks. Instead of maintaining a fixed committee size, allowing adjustments based on the project's varying complexity at different stages of the project ensures that the decision-making process remains adaptive and responsive to the specific needs at each stage. This flexibility leads to more informed and balanced decisions, particularly in large-scale projects with diverse stakeholder interests.

Policymakers can apply these insights to design decision-making frameworks that prioritize the unanimity rule when the stakes are high and consensus is crucial for the project's success. In projects with significant environmental or social impacts, requiring unanimity or near-unanimity in decision making can help mitigate risks and build public trust. By adjusting the size of decision-making bodies in real-time, policymakers can streamline processes without compromising decision quality.

These findings are applicable in various contexts, such as urban planning, environmental regulation, and public transportation development. In urban planning, flexibility in decision-making bodies can address the dynamic nature of urban growth and the diverse needs of populations. Similarly, in environmental regulation, a flexible approach allows for the inclusion of additional experts as new challenges arise, ensuring that regulations remain relevant and effective.

The present study offers key insights into the dynamics of decision-making frameworks in infrastructure projects, highlighting the importance of flexibility in committee size. These findings have broader implications beyond infrastructure, suggesting that flexible decision-making frameworks can be valuable in various fields requiring complex and high-impact decisions. Such frameworks can enhance governance structures in public administration, corporate governance, and international negotiations, where adaptability and inclusiveness are crucial for optimal outcomes.

By demonstrating the interaction between committee size and decision-making rules, and their impact on decision quality, this research provides a new perspective on optimizing decision-making processes in complex environments. This perspective can guide policymakers, managers, and leaders in designing effective governance frameworks.

Future studies could empirically test the theoretical models presented here by applying them to real-world infrastructure projects, providing concrete evidence of the effectiveness of flexible decision-making frameworks. Expanding research to other sectors, such as healthcare, finance, or environmental management, could reveal how these frameworks operate in different contexts, helping to identify the need for sector-specific adaptations. Longitudinal studies tracking the impact of flexible decision-making frameworks over time would offer valuable insights into their long-term effectiveness and sustainability. Additionally, investigating how advanced technologies, such as artificial intelligence and data analytics, can be integrated into these frameworks may improve decision accuracy and efficiency in complex projects.

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Appendix

Proof of Corollary 1.

$$\frac{1}{4}p^{2n-1}+\frac{1}{4}(1-(1-p)^{2n-1})+\frac{1}{4}(p)^1+\frac{1}{4}(1-(1-p)^1)\gtreqless\frac{1}{2}(p^n+1-(1-p)^n)\Leftrightarrow$$
$$p^{2n-1}+(1-(1-p)^{2n-1})+(p)^1+(1-(1-p)^1)\gtreqless 2(p^n+1-(1-p)^n)\Leftrightarrow$$
$$p^{2n-1}-(1-p)^{2n-1}+(p)^1-(1-p)^1\gtreqless 2(p^n-(1-p)^n)\Leftrightarrow$$
$$p^{2n-1}-2p^n+2p-1\gtreqless(1-p)^{2n-1}-2(1-p)^n\Leftrightarrow$$
$$p^{2n-1}-2p^n+2p-1-(1-p)^{2n-1}+2(1-p)^n\gtreqless 0.\square$$