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Is Specialization Desirable in Committee Decision Making?

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Abstract Committee decision making is examined in this study focusing on the role assigned to the committee members. In particular, we are concerned about the comparison between committee performance under specialization and non-specialization of the decision makers. Specialization (in the context of project or public policy selection) means that the decision of each committee member is based on a narrow area, which typically results in the *acquirement and use* of relatively high expertise in that area. When the committee members' expertise is already determined, specialization *only* means that the decision of each committee member is based solely on his/her relatively high expertise area. This form of specialization is potentially inferior relative to non-specialization under which the decision of each committee member is based on different areas, not just his/her relatively high expertise area. Given that the expertise of the committee members is already determined but unknown, our analysis focuses on non-specializing individuals whose decision is based on a decision rule that does not require information on the decision-making skills. Under these realistic assumptions, non-specialization is shown to be preferable over specialization, depending on the aggregation rule applied by the committee. The significance of our approach is not limited to the specific results that we obtain. Rather, it should be viewed as a first step

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toward a deeper examination of the role of individual decision makers in enhancing the performance of collective decision making.

Keywords Project selection · Public policy · Collective decision making · Committee · Uncertain dichotomous choice · Specialization · Simple majority rule

JEL Classification D81 · D71

1 Introduction

Collective decisions are best made by having many people involved in the process of decision making. Typically, large groups of people (committees) can make better decisions than a single person. Thus, in private economic organizations, investment decisions are often made collectively in committees and, in the public sector, project proposals (e.g., building a new toll road) are often evaluated by teams of experts.

This article proposes a new approach to evaluate and improve the performance of committee decision making. Our focus is on the decision-making assignments of the potential decision makers and their particular role both in information gathering and in actual decision making. In contrast to Sah and Stiglitz (1986), who focused on the architecture of collective decision making, the placement of the committee members in the decision-making system and the comparison between the performance of a centralized organization (hierarchy) and a decentralized organization (polyarchy), our distinction between alternative decision-making systems is based on the different roles assigned to the decision-making units: the committee members.

Typically, a committee must evaluate different aspects of a project proposal (the project components) that are critical to its success before deciding whether to invest in the project. In some committees, members may be assigned to assess a particular aspect of a project (e.g., technical feasibility, market potential) or be called upon to provide an overall assessment. Partial evaluation that can be justified by resort to a specialization argument is quite common in making a decision regarding acceptance or rejection of a complex project. Specialization by members of such committees who can acquire expertise (skill) is based on the possibility of each committee member to focus efforts in a narrow area and, in turn, to acquire a relatively high decision-making skill in that area. Thus, under specialization, the decision regarding the project is based on the decisions of the committee members such that each committee member's decision on the project is based just on his/her relatively high expertise area. A final decision to accept or reject is then based on a rule that aggregates the decision makers' votes. In most situations, committee members may evaluate, however, several areas (e.g., financial analysis, knowledge of technology trends, marketing experience, etc.). Conceptually, a manager may evaluate different components of the project, come up with different assessments of the likelihood of success of the project based on the assessment of different components, and aggregate these different assessments to come up with an overall assessment of the project. The individual will arrive at an overall opinion and a vote summarizing his recommendation for the investment. This recommendation is based on his internal aggregation of his different

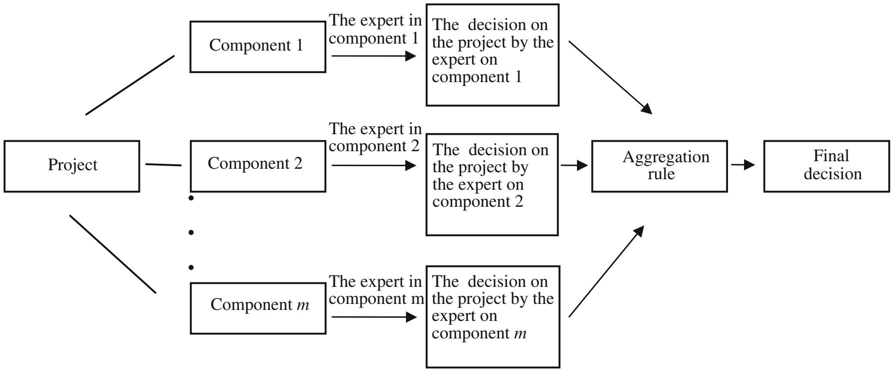

Fig. 1 Specialization

opinions that are based on the evaluation of the different components of the project. In the second stage a final decision to accept or reject is based on a rule that aggregates the decision makers' votes. Non-specialization therefore means that the decision regarding the project is based on the already aggregated decisions of the committee members over all the components of the project. Specialization and non-specialization in committee decision making are schematically illustrated in Figs. 1 and 2. Notice that non-specialization is a two-stage procedure.

The comparison between specialization and non-specialization is important to collective decision making in the private as well as in the public sector. We provide two examples to illustrate the situations that we are concerned about and their relevance to decision making in the economic realm and to public, legislative, and political decision making.

The first example concerns the investment in new ideas and startups in the venture investment industry. It is well-known that specialization in committee decision making often takes place in venture capital firms. In some firms, a partner may focus on just one aspect of the project (e.g., quality of the management team, or the potential of the technology) or he may assess several aspects of the project. After evaluating an investment proposal, a partner in the investment committee can form an opinion on the potential of the overall project. The partner then votes on the project, as any other member of the investment committee. The committee decides whether to accept or reject the project, based on the votes of its members and a pre-determined decision rule.

The second example concerns political decision making in the public sector. Consider the case of a committee of Ministers trying to decide whether to allow casinos to be built in a country. The policy decision to build casinos would have widespread consequences for the economy, for many years to come. There are the economic benefits—through the creation of jobs, increase in tourist arrivals, and multiplier effects filtering to the rest of the economy—as well as potential social costs, through the possible increase in problem gambling, potential increase in crime, money-laundering, etc. Since multinational companies will be invited to bid for the casino concessions with a 30-year lease, a government decision to go ahead cannot be reversed. In the

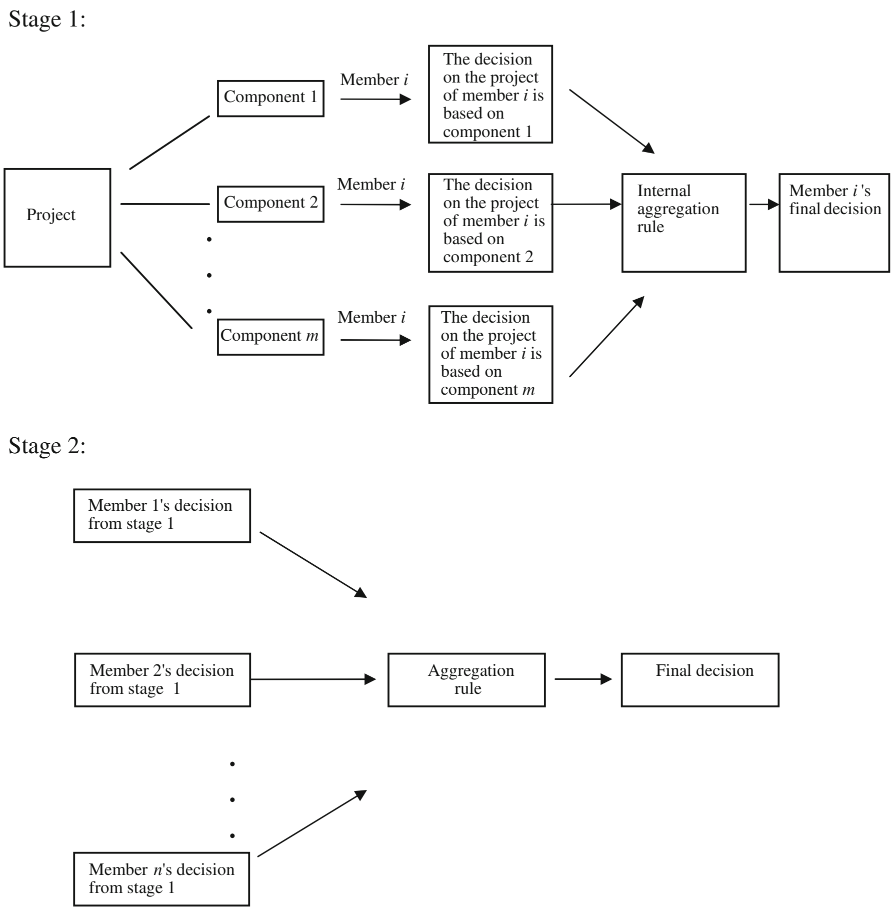

Fig. 2 Non-Specialization

committee, each minister is unlikely to be an expert in all the different aspects of the policy under consideration. The Minister in charge of Industry and Trade may have a better grasp of the economic impacts, compared with the Home Affairs Minister, who would have a deeper appreciation of social consequences associated with the government decision. In such a situation, should the Prime Minister ask each Minister in the committee to evaluate all aspects of the policy and vote (i.e., as non-specialists, according to our definition), or to evaluate only one aspect of the policy and vote (i.e., as a specialist)?

In general, the evaluation of a component of a project or policy alternative allows a decision maker to infer imperfectly the overall quality of the project or policy under consideration. Specialization in the evaluation process means that the decision regarding the project or policy is based on skills of those who are the experts in the various components of the project. In most situations, committee members involved in political decision making may possess domain expertise in several areas (e.g., economic benefits, social costs, migration issues, environment impact, etc.). Conceptually, a decision maker may evaluate different components of the policy and come up with different assessments of the likelihood of success of the policy based on the assessment of different components, and aggregate these different assessments to come up with an overall assessment of the policy. Non-specialization therefore means that the decision regarding the policy is based on the already aggregated skills of the committee members over all the components of the policy.

In our setting, the decision-making skills of the committee members are already determined, thus specialization only means that each committee member's decision on the project is based just on his/her relatively high expertise area. This weaker form of specialization is potentially inferior relative to non-specialization under which the decision of each committee member is based on all relevant areas, not just his/her relatively high expertise area. Given that committee members' expertise is already determined but unknown, the main objective of this article is to examine whether the common use of specialization can be justified.

The issue on which this article focuses is related to the literature on collective decision making under uncertainty, which is concerned with the choice of appropriate organizational aggregation rules to mitigate decision errors that are committed when decision makers are fallible, Ben-Yashar and Kraus (2002), Ben-Yashar and Nitzan (1997), Berend and Sapir (2005, 2007), Koh (1992, 1994, 2005), Nitzan and Paroush (1982), Sah (1991), and Sah and Stiglitz (1985, 1986, 1988), Sapir (1998, 2004). To date, the literature on the optimal decision rule in collective fallible decision making has focused on the overall project assessment by decision makers.

In this article, we are interested in the situation where decision makers are able to assess the quality of the project by evaluating components of the project. Our emphasis is on the significance of the role assigned to each of the decision makers. We first clarify why, given already acquired decision-making skills, non-specialization is superior to specialization which is based on less information (partial evaluation of the project), provided that the aggregation process is optimal (i.e., the decisions of non-specializing committee members and the collective decisions are optimal). Since the already determined decision-making skills are usually unknown, optimal decisions are impossible. In other words, the optimal decisions cannot be made when the decision-making skills, the parameters that enable the identification of the optimal decision rules, are unknown. Our main result establishes that under such circumstances, even under homogenous decision makers, where the decision-making skills for each component are the same for all the decision makers, the common weaker form of specialization that implies partial evaluation of the project can be superior to non-specialization. This finding is based on the assumption that the same decision rule is applied by the committee under specialization and non-specialization and that the decisions of non-specializing individuals are based on an internal aggregation rule that does not require information on their decision-making skills. Under the first extreme case that we study, the decision of each non-specializing individual is based on the internal aggregation rule that randomly chooses one component of the project. In this case, specialization is superior to non-specialization, when the committee applies the simple majority rule. In general, specialization is superior to non-specialization when the probability of making the correct collective decision using a particular aggregation rule by the committee is monotonic and satisfies second-order positive monotonicity (i.e., the marginal contribution of decision-making skill is positive and increases with its relative ranking in terms of decision-making skills), as under the simple majority rule. Under the second extreme case that we study, the decision of each non-specializing individual is based on the simple majority internal aggregation rule that equally takes into account all his/her decisions on the different project components.[1] In this case we provide sufficient conditions for the inferiority of specialization. These preliminary findings illustrate the significance of the role assigned to committee members, beyond the significance of the architecture of the decision-making system, in determining the performance of the collective decision-making system.

The article is structured as follows. The framework that enables comparison of group performance under specialization and non-specialization is presented in Sect. 2. The superiority of non-specialization over specialization under already determined committee members' expertise is discussed in Sect. 3. The comparison between specialization and non-specialization, given that expertise is already determined, but unknown, is presented in Sect. 4. Section 5 contains an illustrative example and a brief summary.

2 The model: specialization versus non-specialization

A committee faces a stream of projects, which may be interpreted broadly to include investment proposals or policy options facing a government or the legislature. The committee has to decide whether to accept or reject each project or policy that it receives (henceforth we use the term project, but our framework is applicable in various public, political, and legislative settings). There are two possible types of projects: (G)ood and (B)ad. A project consists of m components (e.g., technology, market potential for an investment proposal; social costs and economic benefits for a policy option) that jointly determine the quality of the project.

Suppose there are n independent decision makers (individuals). Our results are derived for $n = m$. For further discussion of this assumption see Sect. 2.3. All the decision makers share the same purpose, to decide correctly, i.e., to accept a good project and reject a bad one. Let p_{ij} denote the probability that decision maker i correctly infers the true quality of the project, conditional on the evaluation of only the jth component of the project. Hence, we may index decision maker i's expertise in reviewing component j by $p_{ij} \geq \frac{1}{2}$. These fixed probabilities are assumed to be given and independent. We represent the organization's decision-making skills by the following matrix:

$$\boldsymbol{p} = \begin{pmatrix} p_{11} & \cdots & p_{1m} \\ \vdots & \ddots & \vdots \\ p_{n1} & \cdots & p_{nm} \end{pmatrix} \tag{1}$$

[1] In the neuro-economics literature there is a debate on whether the brain acts as a dual or unitary system when taking a decision (see Rustichini (2008)). This question can provide a behavioral justification or at least a preliminary analogy to the two types of internal aggregation rules studied in this article.

We shall refer to *specialized decision making* as the case where each decision maker gives a recommendation to accept or reject the project, based on a partial evaluation of just one component of the project, such that the decision maker is the expert in that particular component. Each committee member expresses his opinion regarding the acceptance of the project by making a 'Yes' (1) or 'No' (-1) decision. Given the decisions of the different decision makers, a collective organizational decision, i.e., the final decision, to accept or reject the project is then arrived at by the committee applying an aggregation rule, denoted by f^{S}; $f^{\mathrm{S}} : \{-1, 1\}^n \rightarrow \{-1, 1\}$.

In our study, *non-specialized decision making* refers to the case where each decision maker evaluates the entire project (all the components of the project), and then votes 'Yes' (1) or 'No' (-1) regarding the acceptance of the project, which is based on his internal aggregation rule. Again, a final decision to accept or reject is based on a rule, denoted by f^{NS}; f^{NS}: $\{-1, 1\}^n \rightarrow \{-1, 1\}$, that aggregates the decision makers' votes. Among other possible monotonic aggregation rules, f^{S} or f^{NS} may refer to a simple majority rule. Recall that the difference between specialized (S) individual decision making and non-specialized (NS) individual decision making is due to the difference in the information used by the individual in the two cases. A specializing individual makes his decision on the basis of the component in which he is the expert, whereas a non-specializing individual makes his decision using an internal aggregation rule that takes into account his possibly different opinions that are based on the assessment of the different components of the project.

2.1 The collective probability: specialization in decision making

Let $\tilde{p}_i = (p_{i1}, \ldots, p_{im})$ denote the vector of decision-making skills of decision maker i. For arbitrarily fixed $1 \leq k \leq m$, let $q_k = \max_{1 \leq l \leq n} p_{lk}$ and $i = \arg\max_{1 \leq l \leq n} p_{lk}$. Then the decision maker i is the expert in component k.

In our decision-making setting, specialization refers to the situation where every decision maker assesses the quality of a project on the basis of a single component of the project, such that the decision maker is the expert in that particular component. It is assumed that each decision maker is the expert in only one of the project components and the expertise is in different components. The vector of m-element decision-making expertise is given by

$$\tilde{q} = (q_1, .., q_i, .., q_m) \tag{2}$$

For an aggregation rule f^{S}, that is applied in the case of specialization, and a vector of specialized decision-making skills $\tilde{q}$, let $\Pi(f^{\mathrm{S}}, \tilde{q})$ denote the probability of making the right decision regarding a project.

2.2 The collective probability: non-specialization in decision making

In this case, each decision maker evaluates all the components of the project and not only the component in which he is the expert. When a decision maker evaluates the whole project, he takes on the role of a *generalist* in arriving at an overall opinion regarding the acceptability of the project. Since he has the opportunity to review different project components, he may formulate different opinions regarding the quality of the project after the evaluation of different components. In the context of political decision making, a politician tasked to evaluate the policy options may arrive at different views about the quality of a policy proposal based on separate evaluations of the economic benefits and the social impact. He or she will then formulate an overall opinion before casting his vote on the issue. Similarly, in the investment context, when a partner in the investment committee of a venture capital firm assesses the different aspects of a start-up (e.g., technology sophistication, market potential, management team, etc.), he may arrive at different opinions regarding the prospects of the company based on the evaluation of different aspects. Finally, he will arrive at an overall opinion and a vote summarizing his recommendation for the investment. This recommendation is based on his internal aggregation of his different opinions that are based on the evaluation of the different components of the project.

The internal aggregation rules play an important role by determining $\tilde{z}$, the vector of the overall decision-making expertise of the n decision makers:

$$\tilde{z} = (z_1, \ldots, z_n) \tag{3}$$

where $z_i = \Pi(f, \tilde{p}_i)$ denotes the probability that individual i with vector skills $\tilde{p}_i$ would make the right decision using the internal decision rule f.

For an aggregation rule f^{NS}, which is applied in the case of non-specialization, and a vector of overall decision-making expertise $\tilde{z}$, let $\Pi(f^{\mathrm{NS}}, \tilde{z})$ denote the probability of making the right decision regarding a project, based on the summarized votes of the decision makers regarding the project.

2.3 Assumptions and some properties of decision rules

We introduce below some simplifying assumptions that enable us to focus on the comparison between specialization and non-specialization. First, it is assumed that $n = m$, i.e., the number of decision makers is equal to the number of components. When n is not equal to m, the tradeoff between the number of decision makers and their skills becomes an important issue. While this is an interesting aspect of the decision problem, we shall not consider it in this article as it distracts attention from our main focus. Second, it is assumed that the same aggregation (decision) rules are used whether the evaluation process involves specialization or non-specialization. That is, $f^{\mathrm{NS}} = f^{\mathrm{S}}$. Or, in those cases when these aggregation rules are different, it is assumed that the optimal (possibly different) aggregation rules are used whether the evaluation process involves specialization or non-specialization. Without this assumption, the relationship between the different characteristics of the aggregation rules and the vector of decision-making skills becomes an important issue. Again, this aspect of the decision problem is not considered here, since it is not the main focus of this article.

For the analysis in this article, we will consider only *monotonic* functions.

A function $t(\underline{x})$ is *monotonic* if :

$$\forall_{i,1\leq i\leq n},\ \forall_{\varepsilon>0}$$
$$\forall i,\ t(\underline{x}) - t(\underline{x}/x_i - \varepsilon) > 0 \text{ where } (\underline{x}/x_i - \varepsilon) = (x_1, \ldots, x_i - \varepsilon, \ldots x_n).$$

The function $t(\underline{x})$ satisfies *second-order positive monotonicity*[2] if

$$\forall i,\ j,\ t(\underline{x}) - t(\underline{x}/x_i - \varepsilon) > t(\underline{x}) - t(\underline{x}/x_j - \varepsilon) \Leftrightarrow x_i > x_j$$

where ε is a positive number.

The function $t(\underline{x})$ satisfies *second-order negative monotonicity* if

$$\forall i,\ j, t(\underline{x}) - t(\underline{x}/x_i - \varepsilon) < t(\underline{x}) - t(\underline{x}/x_j - \varepsilon) \Leftrightarrow x_i > x_j$$

where ε is a positive number.

Let $\Pi(f, \tilde{p})$ denote the probability that the correct decision is made using the rule f, where $\tilde{p} = (p_1, \ldots, p_n)$ is the vector of decision-making skills of the members of group N. In Lemma 1 (Lemma 2) we relate to the simple majority rule (hierarchy and polyarchy rules).

Lemma 1 $\Pi(f_{\mathrm{m}}, \tilde{p})$ *is monotonic and satisfies second-order positive monotonicity, where* f_{m} *is the simple majority rule.*

Proof See Ben-Yashar and Paroush (2000).

Let f_{h} denote the hierarchy rule, i.e., the decision is to accept the project provided that acceptance is the unanimous decision and f_{p} denote the polyarchy rule where a single acceptance is sufficient for the decision to accept the project.

Lemma 2 $\Pi(f_{\mathrm{h}}, \tilde{p})$ *and* $\Pi(f_{\mathrm{p}}, \tilde{p})$ *are monotonic and satisfy second-order negative monotonicity.*

Proof See Appendix.

3 The desirability of non-specialization in decision making

Since the expertise of the committee members is already determined, specialization only means that the decision of each committee member on the project is based solely on his/her relatively high expertise area. This weaker form of specialization results in inferior performance relative to non-specialization that efficiently utilizes the decision-making skills. Such efficiency is obtained when every non-specializing decision maker decides optimally, i.e., his decision is based on the optimal decision rule, which takes into account his skills $\tilde{p}_i$ and his specific actual decisions regarding the project that

[2] In Ben-Yashar and Paroush (2000), second-order positive monotonicity is referred to as *dimensionally strict monotonicity*.

are based on the components of the project. Hence, the probability that a non-specializing decision maker would reach a correct decision for the project is $z_i = \Pi(f^*, \tilde{p}_i)$, which denotes the probability that he would make the right decision using the optimal (internal) decision rule f^* (such an optimal rule maximizes the probability that the decision maker makes the correct choice, given his decisions on the various project components). Clearly, since specialization gives up some useful information, we get:

Proposition 1 *If the non-specializing committee members decide optimally, then non-specialization is preferred to specialization.*

Proof Since $z_i = \Pi(f^*, \tilde{p}_i)$, it follows that for every decision maker i, it holds that $\forall j, z_i \geq p_{ij}$, hence, $\forall i, z_i \geq q_k$. We therefore obtain that $\tilde{z} \geq \tilde{q}$.

(1) If f^{S} and f^{NS} are the optimal aggregation rules under specialization and non-specialization, respectively, we have $\Pi(f^{\mathrm{NS}}, \tilde{z}) \geq \Pi(f^{\mathrm{S}}, \tilde{z})$.
By the monotonicity of $\Pi(f, \tilde{p})$, $\tilde{z} > \tilde{q}$ implies that $\Pi(f^{\mathrm{S}}, \tilde{z}) \geq \Pi(f^{\mathrm{S}}, \tilde{q})$.
It follows therefore that $\Pi(f^{\mathrm{NS}}, \tilde{z}) \geq \Pi(f^{\mathrm{S}}, \tilde{q})$.

(2) If f^{S} and f^{NS} are not the optimal aggregation rules but identical monotonic aggregation rules, then, since $\tilde{z} > \tilde{q}$, by the monotonicity of $\Pi(f, \tilde{p})$, it follows that $\Pi(f^{\mathrm{NS}}, \tilde{z}) \geq \Pi(f^{\mathrm{S}}, \tilde{q})$.

□

To sum up, non-specialization is the preferred mode for making an overall project assessment, when the non-specializing individuals decide optimally, provided that the rules applied by the committee are optimal or that identical rules are used under specialization and non-specialization.

Generally, determining whether specialization or non-specialization is preferable depends on the comparison of the probability vectors $\tilde{z}$ and $\tilde{q}$. Clearly, if one of the vectors is larger than the other, it is straightforward to determine the superiority of specialization versus non-specialization or vice versa. As shown above, this is the case when the non-specializing individuals decide optimally. Non-specialization is preferable, because the decisions of the non-specializing individuals are based on the efficient utilization of all the available information (the decision-making skills of the individuals).[3]

The situation becomes complex when the non-specializing individuals do not decide optimally. In such a case, there is no reason to expect that one of the probability vectors is larger than the other. Hence, the probabilities in the entire matrix have to be considered and this casts doubt on whether the derivation of general results is an interesting task.

The non-specializing individuals cannot decide optimally when the decision-making skills, the parameters that enable the identification of the optimal (internal) decision rules (the internal aggregation rules applied by non-specializing individuals) are unknown. The main objective of this article is to examine whether the common use of specialization in this case can be justified.

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[3] The above results can be considered as yet another manifestation of the basic inferiority of the expert rule, the rule that applies just the highest decision-making skill, relative to the optimal rule, which is based on all the decision-making skills, see Nitzan and Paroush (1982).

4 Unknown decision-making skills

Even-though in this setting specialization is applied in a weak sense, we show that it can still be superior to non-specialization, even in the simple case where decision makers are assumed to be homogeneous, both in their decision-making skills and in the internal aggregation rule they apply under the non-specialization setting.[4] Homogeneous decision-making skills imply that $p_{ij} = p_{lj}$, $\forall i,\ l = 1, \ldots, n$. That is, the decision-making skill for each component is the same for all the decision makers. We therefore denote the (homogenous) expertise to evaluate component j by p_j. The vector of decision-making skills of every individual is denoted by $\tilde{p},\ \tilde{p} = \tilde{p}_i = \tilde{p}_j$, for every $i \neq j$. When project evaluation involves specialization, each decision maker is assigned to one particular component, and it does not matter which decision maker is assigned to which component. The vector of decision-making skills when project evaluation is based on such specialization is given by[5]

$$\tilde{q} = (p_1, p_2, \ldots, p_n) \tag{4}$$

The vector of decision-making skills under non-specialization is, as before, given by $\tilde{z} = (z_1,\ z_2, \ldots, z_n)$.

As in the general case (of heterogeneous expertise), if every non-specializing decision maker decides optimally, non-specialization is preferable to specialization. However, when decision-making skills are unknown, non-specializing decision makers cannot identify the optimal internal aggregation rule. We study below two extreme internal aggregation rules that can be used without any information on decision-making skills that are unknown. Under the first extreme rule, every non-specializing committee member decides whether to accept or reject a project on the basis of only one randomly selected component. For instance, each partner in a venture capital firm may evaluate a prospective investment by randomly selecting an aspect of the startup's business plan to evaluate. In this case, the probability that a decision maker i reaches a correct decision for the project is given by $z_i = \bar{p} = \frac{1}{m} \sum_{j=1}^{m} p_j$ (recall that $n = m$). Due to the assumption regarding the homogeneity of the internal aggregation rules, $\tilde{z} = (\bar{p},\ \bar{p}, \ldots, \bar{p})$.

Under the second extreme internal aggregation rule, every non-specializing committee member decides whether to accept or reject a project using the simple majority rule, that equally takes into account his/her decisions regarding the approval of a project that correspond to its different components.[6] The probability that a decision maker reaches a correct decision for the project is $z_i = \Pi(f_{\mathrm{m}}, \tilde{p})$, where f_{m} denotes

[4] The homogeneity assumption has been very common in the literature on collective decision making in uncertain dichotomous choice and it paved the way as a benchmark case to some of the main findings in this literature.

[5] Note that, although the decision-making skills are unknown, due to the homogeneity assumption, this vector is equivalent to the skills vector of every decision maker.

[6] If lack of knowledge concerning the private signals, i.e., the decision-making skills corresponding to the various components of the project, is interpreted as meaning that individuals have no reason to believe that their signal from one component is any better or any worse than their signal from another component, then the simple majority internal aggregation rule is the plausible rule.

the simple majority rule. Due to the assumption regarding the homogeneity of the internal aggregation rules, $\tilde{z} = (\Pi(f_{\text{m}}, \tilde{p}),\ \Pi(f_{\text{m}}, \tilde{p}), \ldots, \Pi(f_{\text{m}}, \tilde{p}))$.

Under the above decision rules, the comparison between the probability vectors $\tilde{q}$ and $\tilde{z}$ is equivocal, and therefore the question arises whether it is possible to determine whether specialization is preferable to non-specification or vice versa. Recall that we assume that the same rule is applied by the committee under specialization and non-specialization, which is a plausible assumption under lack of information on decision-making skills. Our main finding is that specialization can be superior to non-specialization despite its partial use of information. In the following theorem we establish that, when the non-specializing committee member decides whether to accept or reject a project on the basis of a single randomly selected component of the project, which is certainly not an optimal internal aggregation rule, specialization (non-specialization) becomes the superior mode of decision-making organization, provided that the probability of a correct collective decision under the aggregation rule applied by the committee is monotonic and satisfies second-order positive (negative) monotonicity.

Theorem 1 *Suppose that* $z_i = \bar{p} = \frac{1}{m}\sum_{j=1}^{m} p_j$. *Then specialization is preferable (not preferable) to non-specialization, provided that the probability of making the correct decision under the aggregation rule applied by the committee is monotonic and satisfies second-order positive monotonicity (negative monotonicity).*

Proof [7] A function $\Pi(f, \tilde{p})$ satisfies second-order positive monotonicity if,

$$\forall p_j < p_i, \Pi(f, \tilde{p}) - \Pi(f, \tilde{p}/p_i - \varepsilon) > \Pi(f, \tilde{p}) - \Pi(f, \tilde{p}/p_j - \varepsilon)$$

Equivalently, we can write

$$\forall p_j < p_i,\ \Pi(f, \tilde{p}/p_j - \varepsilon) > \Pi(f, \tilde{p}/p_i - \varepsilon)$$

As a special case for the above inequality take the probabilities vector $(\tilde{p}/p_i + \varepsilon)$ and find that

$$\forall p_j < p_i,\ \Pi(f, \tilde{p}/p_i + \varepsilon, p_j - \varepsilon) > \Pi(f, \tilde{p}). \tag{*}$$

Successive application of (*) completes the proof, where at each step ε is chosen as the smaller of the absolute differences between the mean $\bar{p}$ and the maximum and the minimum respectively, of the p_i. After a finite number of steps, all the arguments p_i will have changed to $\bar{p}$ and we have the result $\Pi(f, \tilde{p}) > \Pi(f, \tilde{\bar{p}})$, where $\tilde{\bar{p}} = (\bar{p}, \bar{p}, \ldots, \bar{p})$. We, therefore, obtain that $\Pi(f, \tilde{q}) > \Pi(f, \tilde{z})$. For a monotonic function that satisfies second-order negative monotonicity, all the signs of the above inequalities are reversed, hence, we have the result $\Pi(f, \tilde{q}) < \Pi(f, \tilde{z})$. □

[7] This proof is based on the same arguments used in Ben-Yashar and Paroush (2000), where only the simple majority rule was considered.

Specialization is thus preferable to non-specialization, provided that the aggregation rule used by the committee is, for example, the simple majority rule. Moreover, if the non-specializing committee members decide whether to accept or reject a project on the basis of a single randomly selected component of the project, specialization is preferable to non-specialization, if the committee applies an optimal aggregation rule (the optimal rules under specialization and non-specialization may differ). That is,

Proposition 2 *Suppose $z_i = \bar{p} = \frac{1}{m}\sum_{j=1}^{m} p_j$. Then specialization is preferable to non-specialization, provided that the aggregation rules applied by the committee are the optimal rules.*

Proof Denote by f^{S} and f^{NS} the optimal aggregation rules under specialization and non-specialization, respectively. In the case of non-specialization, the optimal rule is the simple majority rule, hence $f^{\mathrm{NS}} = f_{\mathrm{m}}$, i.e., $\Pi(f^{\mathrm{NS}}, \tilde{z}) = \Pi(f_{\mathrm{m}}, \tilde{z})$. By Theorem 1, specialization is preferable to non-specialization, provided that the simple majority rule is used, hence, $\Pi(f_{\mathrm{m}}, \tilde{q}) > \Pi(f_{\mathrm{m}}, \tilde{z})$. When f^{S} is the optimal aggregation rule, $\Pi(f^{\mathrm{S}}, \tilde{q}) \geq \Pi(f_{\mathrm{m}}, \tilde{q})$. Hence, $\Pi(f^{\mathrm{S}}, \tilde{q}) \geq \Pi(f_{\mathrm{m}}, \tilde{z}) = \Pi(f^{\mathrm{NS}}, \tilde{z})$. □

Although the comparison between the probability vectors $\tilde{q} = (p_1, p_2, \ldots, p_n)$ and $\tilde{z} = (\bar{p}, \bar{p}, \ldots, \bar{p})$ that are obtained, respectively, under specialization and our first case of non-specialization, is equivocal, the low skills in $\tilde{q}$ are smaller than $\bar{p}$ and the high skills in $\tilde{q}$ are larger than $\bar{p}$. This is the reason why the comparison between the performance of the (same) decision rule used by the committee under specialization and under non-specialization hinges on the comparison between the effect of the change in the low decision-making skills and the effect of the opposite change in the high decision-making skills. Put differently, the outcome of the comparison between performance under specialization and non-specialization depends on whether the monotonic probability of making the correct decision under the rule used by the committee satisfies second-order positive or negative monotonicity. Clearly, under second-order positive (negative) monotonicity, the effect of a change in the higher (lower) decision-making skills is stronger than the effect of a change in the lower (higher) decision-making skills. Therefore, under our first case of non-specialization, and second-order positive (negative) monotonicity, specialization is preferred (inferior) to non-specialization.

Under our second case of non-specialization, where $f_{\mathrm{m}}$is the internal aggregation rule used by every non-specializing individual, the comparison between the probability vectors $\tilde{q} = (p_1, p_2, \ldots, p_n)$ and $\tilde{z} = (\Pi(f_{\mathrm{m}}, \tilde{p}), \Pi(f_{\mathrm{m}}, \tilde{p}), \ldots, \Pi(f_{\mathrm{m}}, \tilde{p}))$ is again equivocal and, as in the first case, the low skills under specialization (the low components in $\tilde{q}$) are smaller than the corresponding skills in $\tilde{z}$ (the identical probability $\Pi(f_{\mathrm{m}}, \tilde{p})$). However, now the high skills in $\tilde{q}$ are not necessarily larger than $\Pi(f_{\mathrm{m}}, \tilde{p})$. That is, under non-specialization, all the decision-making skills may increase and not just those of the less competent ones. This is the reason why when the non-specializing committee members are assumed to resort to simple majority rule when making the decision about the acceptability of the project, we can only state a sufficient condition for the superiority of non-specialization. That is, non-specialization is preferred to specialization under second-order negative monotonicity.

Theorem 2 *Suppose* $z_i = \Pi(f_{\mathrm{m}}, \tilde{p})$. *Then, non-specialization is preferable to specialization, provided that the probability of making the correct decision under the aggregation rule applied by the committee is monotonic and satisfies second-order negative monotonicity.*

Proof By Theorem 1, when $z_i = \bar{p}$, non-specialization is preferable to specialization, provided that the probability of making the correct decision is monotonic and satisfies second-order negative monotonicity. Hence, $\Pi(f, \tilde{z}) \geq \Pi(f, \tilde{q})$ where $z_i = \bar{p}$. As shown in Ben-Yashar and Paroush (2000), $\Pi(f_{\mathrm{m}}, \tilde{p}) \geq \bar{p}$. By the monotonicity of $\Pi(f, \tilde{z})$, the replacement of $z_i = \bar{p}$ by $z_i = \Pi(f_{\mathrm{m}}, \tilde{p})$ increases $\Pi(f, \tilde{z})$. Hence, $\Pi(f, \tilde{z}) \geq \Pi(f, \tilde{q})$, where $z_i = \Pi(f_{\mathrm{m}}, \tilde{p})$. □

Moreover, if the non-specializing committee members decide whether to accept or reject a project using the simple majority rule, non-specialization is preferable to specialization, provided that the committee also applies the simple majority rule. That is, in such a case, $z_i = \Pi(f_{\mathrm{m}}, \tilde{q})$. According to Nitzan and Paroush (1982), given the homogeneity of $\tilde{z}$, $\Pi(f_{\mathrm{m}}, \tilde{z}) > z_i$. Hence, $\Pi(f_{\mathrm{m}}, \tilde{q}) > \Pi(f_{\mathrm{m}}, \tilde{q})$.

Our result that specialization can still be superior to non-specialization becomes easier to establish in the following simple homogeneous case. Consider the situation of decision makers possessing identical skills over the different components of the project, where $\forall j \neq l$, $p_{ij} = p_{il}$. That is, the decision-making skills of every individual that correspond to the different components of the project are identical.

Let us denote by p^i the homogenous skills of individual i. In this case, under specialization the skills used by the committee are given by $\tilde{q} = (p^m, \ldots, p^m)$ where p^m is the maximum among all the individual p^is. In this case, one decision maker has an advantage in every component.[8] This implies that $\tilde{z}$ is not necessarily larger than $\tilde{q}$, despite the fact that every non-specializing individual decides optimally, i.e., he bases his decision on the optimal internal aggregation rule. Even Proposition 1 is only partly valid. That is, non-specialization is preferred to specialization, provided that the rules applied by the non-specializing individuals and by the committee are optimal.[9] But if the committee applies the same aggregation rule (not the optimal) under specialization and non-specialization, then the outcome of the comparison between specialization and non-specialization is unclear, because $\tilde{q} \geq \tilde{z}$ is not necessarily satisfied.[10]

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[8] Note that in the current setting the assumption that each decision maker is the expert in only one of the project components is no longer valid.

[9] Proof: Recall that $\tilde{q} = (p^m, \ldots, p^m)$. Since $z_m = \Pi(f_{\mathrm{m}}, \tilde{q}) = \Pi(f^{\mathrm{S}}, \tilde{q})$, $\Pi(f^{\mathrm{NS}}, \tilde{z}) \geq \Pi(f^{\mathrm{S}}, \tilde{q})$, where f^{S} and f^{NS} are the optimal aggregation rules under specialization and non-specialization, respectively.

[10] When the decision-making skills are unknown, it is meaningless to discuss the use of a non-optimal rule by a non-specializing individual, because that individual is aware of the homogeneity of his own skills. This awareness implies that he uses the simple majority rule which is the optimal rule. Furthermore, in such a case it is unclear what is the skill vector under specialization, because skills are unknown.

5 An illustrative example and brief summary

Consider a three-member committee, $n = 3$. Let the public project include three components, m=3. The decision making skills of the committee members are presented in the following matrix:

$$p = \begin{pmatrix} 0.9, 0.8, 0.7 \\ 0.9, 0.8, 0.7 \\ 0.9, 0.8, 0.7 \end{pmatrix}$$

Under specialization, the decision-making skills of the committee members are given by $\tilde{q} = (0.9, 0.8, 0.7)$.

Under non-specialization, the decision of every member is based on all three components of the project.

Case 1: Every individual utilizes the optimal internal decision rule, which in this case is the simple majority rule. This yields $\tilde{z} = (0.902, 0.902, 0.902) \geq (0.9, 0.8, 0.7) = \tilde{q}$. Therefore, under any decision rule the committee is better off under non-specialization (as implied by Proposition 1).

Case 2: Individual skills are given but are unknown. As a result, under non-specialization, an individual cannot apply the optimal internal decision rule. Under the first option, where the individual chooses randomly the component on which he bases his decision, we obtain that $\tilde{z} = (0.8, 0.8, 0.8)$. If the committee applies the simple majority rule, which is monotonic and satisfied second-order positive monotonicity, the collective probability of making a correct choice will be equal to 0.896, which is lower than 0.902, the outcome under specialization. If, however, the committee applies the hierarchy rule, which is monotonic yet satisfies second-order negative monotonicity, the collective probability of making a correct choice will be equal to 0.752, which is higher than 0.749, the outcome under specialization, as implied by Theorem 1.[11]

Case 3: Individual skills are given but are unknown. Again, every individual cannot apply the optimal decision rule. Under the second option, he applies the internal simple majority rule, which yields $\tilde{z} = (0.902, 0.902, 0.902)$. If the committee applies a simple majority rule, since $\tilde{z} > \tilde{q}$, its performance under non-specialization is higher than its performance under specialization. If the committee applies the hierarchy rule, then non-specialization is certainly superior to specialization ($0.8664 > 0.749$), as implied by Theorem 2.

Notice that Theorems 1 and 2 are valid for homogeneous decision makers, as in the above example. Under the general case of heterogeneous decision makers, the application of specialization is not feasible without information on the highest decisional skills for every component of the project (see footnote 5). Still, with such information

[11] Under non-specialization and specialization, the collective probability of making a correct choice with the hierarchy rule is equal, respectively, to $\frac{1}{2}(0.8^3) + \frac{1}{2}(1 - 0.2^3) = 0.752$ and $\frac{1}{2}(0.9 \cdot 0.8 \cdot 0.7) + \frac{1}{2}(1 - 0.1 \cdot 0.2 \cdot 0.3) = 0.749$.

it is apparent that the result of the comparison between specialization and non-specialization is ambiguous depending on that information.

We have thus seen that the performance of the decision-making system is affected by the role assigned to the decision-making units. There are situations where specialization is preferred to non-specialization and vice versa. Our preliminary results already illustrate the significance of the role assigned to committee members in determining the performance of the collective decision-making system. Furthermore, these results raise doubt regarding the validity of the advantage of committee decision making relative to individual decision making, namely, the superiority of decision making by many individuals relative to decision making by a single individual, as implied by Condorcet Jury Theorem. Notice that, under the assumption of homogeneous skills, specialization means that the collective judgment is based on the judgment of a single individual and we have pointed out that, certainly, this might be superior to a collective decision based on non-specialization.

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Appendix

Let us prove that $\Pi(f_{\mathrm{h}}, \tilde{p})$ is monotonic and satisfies second-order negative monotonicity. Under the symmetry assumption of the model, the priors of acceptance and rejection of the project to be the correct choice are equal. Recall that under the hierarchy rule, to accept the project, unanimous support is required. Otherwise it is rejected. Hence,

$$\Pi(f_{\mathrm{h}}, \tilde{p}) = \frac{1}{2} \prod_{i \in N} p_i + \frac{1}{2}\Big(1 - \prod_{i \in N} (1 - p_i)\Big)$$

$\Pi(f_{\mathrm{h}}, \tilde{p})$ is monotonic since, $\forall_{i, 1 \le i \le n}, \forall_{\varepsilon > 0}$

$$\begin{aligned}
&\Pi(f_{\mathrm{h}}, \tilde{p}) - \Pi\left(f_{\mathrm{h}}, \tilde{p}/p_i - \varepsilon\right) \\
&\quad = \frac{1}{2} \prod_{l \in N} p_l + \frac{1}{2}\left(1 - \prod_{l \in N} (1 - p_l)\right) \\
&\qquad - \frac{1}{2}(p_i - \varepsilon) \prod_{l \in N, l \neq i} p_l - \frac{1}{2}\left(1 - (1 - (p_i - \varepsilon)) \prod_{l \in N, l \neq i} (1 - p_l)\right) \\
&\quad = \frac{1}{2}\varepsilon \prod_{l \in N, l \neq i} p_l + \frac{1}{2}\varepsilon \prod_{l \in N, l \neq i} (1 - p_l) > 0.
\end{aligned}$$

To prove the second-order negative monotonicity of $\Pi(f_{\mathrm{h}}, \tilde{p})$, notice that

$$\begin{aligned}
&\Pi(f_{\mathrm{h}}, \tilde{p}) - \Pi\left(f_{\mathrm{h}}, \tilde{p}/p_i - \varepsilon\right) - \big(\Pi(f_{\mathrm{h}}, \tilde{p}) - \Pi(f_{\mathrm{h}}, \tilde{p}/p_j - \varepsilon)\big) \\
&\quad = \frac{1}{2}\varepsilon\left(\prod_{l \in N, l \neq i} p_l + \prod_{l \in N, l \neq i} (1 - p_l)\right) - \frac{1}{2}\varepsilon\left(\prod_{l \in N, l \neq j} p_l + \prod_{l \in N, l \neq j} (1 - p_l)\right) \\
&\quad = \frac{1}{2}\varepsilon\left(\left(\prod_{l \neq i, l \neq j} p_l\right)(p_j - p_i) + \left(\prod_{l \neq i, l \neq j} (1 - p_l)\right)(p_i - p_j)\right)
\end{aligned}$$

$$= \frac{1}{2}\varepsilon(p_j - p_i)\left(\prod_{l\neq i, l\neq j} p_l - \prod_{l\neq i, l\neq j}(1-p_l)\right) < 0 \Leftrightarrow p_i > p_j$$

where ε is a positive number.

In a similar way it can be proved that $\Pi(f_{\mathrm{p}}, \tilde{p})$ is monotonic and satisfies second-order negative monotonicity.

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