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Skill, power and marginal contribution in committees

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Abstract
Power is an important basic concept in Political Science and Economics. Applying an extended version of the uncertain dichotomous choice model proposed, the objective of this paper is to clarify the relationship between two different types of power a voter may have: skill-dependent (s-d) power and marginal contribution (mc). It is then shown that, under the optimal committee decision rule, inequality in skills may result in higher inequality of the two types of power and that the distribution of the second type of power (mc) can be even more unequal than the distribution of the first type of s-d power. Using simulations, and assuming evenly spread skills, this possibility is proved to be robust. The significance of the finding is due to the effect of power on reward, whether it is defined in terms of status or in terms of monetary payment.

Keywords
Decisional skills; inequality; marginal contribution; skill-dependent power

1. Introduction

Political power has attracted much attention in Political Science. In this study, we present and disentangle two different types of a voter's power. Considerable effort

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has been devoted to the measurement of the first type of power within committees, which stresses the pivotal role of a voter applying a game theoretic approach and to its various applications that focus on the evaluation of the power distribution in local, national and international organizations. Such power is partly affecting the status of the committee members (individual members or representatives of different interest groups, regions, states or countries) so it may capture political reward. The distribution of this type of power is important for understanding the performance of the committee and, in particular, the decisions it makes, the role played by the committee members and their reward.

In neo-classical Economics, the common second type of power is the marginal contribution (mc) of the voters. This type of power is important because it may capture economic reward by affecting the allocation of resources and, in particular, of the income distribution. In the special case of committee decision-making, the mc of the voters is well defined, provided that the committee's objective is agreed upon. Indeed, this is the situation in our decision-making setting where all the committee members are interested in making the correct decision.

A natural question arising in any political-economic context and, in particular, in our committee decision-making context, is whether there is necessarily a firm relationship between these two types of power. The first objective of this paper is to expose the relationship between these two types of power, within a general version of the celebrated dichotomous choice model proposed by Condorcet (1785). In this extended model, the decision makers can be heterogeneous – that is, have different decisional competencies. Efficiency requires that such heterogeneity be exploited. Therefore, the applied group decision rule is assumed to be optimal. That is, the rule applied by the committee to reach the collective decision assigns the appropriate optimal individual voting weights, which ensures the maximization of the performance of the committee. This optimal rule has been characterized by Nitzan and Paroush (1982) and Shapley and Grofman (1984). Note that optimality of the applied decision rule justifies the sensible efficient policy of recruiting only useful committee members whose inclusion in the committee contributes to the performance of the group. In other words, optimality of the decision rule ensures that all members have a positive mc.

The first type of power index, skill-dependent (s-d) power, on which we focus, has been recently proposed by Ben-Yashar and Nitzan (2019). It is an extended version of the measure proposed by Banzhaf (1965), which was inspired by the power index proposed by Shapley and Shubik (1954). Since this measure takes into account the individual decisional skills when evaluating their probability of being pivotal, it is referred to as s-d power.[1]

The two types of power may affect the individual rewards by influencing their status and income. Ben-Yashar and Nitzan (2019) show that even modest heterogeneity in individual decisional skills may warrant substantial inequality in their s-d power. If reward hinges on this type of power, then modest skill heterogeneity may result in substantial inequality of personal reward. Although this finding sheds new light on the possible justification of unequal distributions of rewards within committees – for example, groups of professionals of seemingly inconsequential diverse personal qualifications (in our case, their decisional competencies), it disregards the possible dependence of reward on the second type of power, the mc to the performance of the group (the probability that a correct decision is made). In order to overcome this shortcoming, we have added to the picture the mc of a decision maker and our second objective is to show that this extension strengthens the positive answer to the question, ‘Can unequal reward be deemed economically warranted?’. Not only that the justified first type of (s-d) power distribution can be very unequal, the distribution of the second type of power, the mcs, can be even more unequal. Using simulations and pursuing a comparative statics analysis for five-, seven- and nine-member committees, we demonstrate the robustness of this finding. The intuitive reason that rewards depending on mc are more unequal is the following: the optimal decision rule increases the decisional role of group members with relatively high skills and reduces the role of individuals with relatively low skills. In turn, the degree of inequality of optimal decisional weights results in an intensified gap between the s-d power of members with relatively low and high skills. This gap is further intensified when we look at the mcs because the different skills of the members play an extra role in creating inequality among their mcs.

In the next section, we present the symmetric uncertain dichotomous choice setting. The two types of power, a voter’s s-d power and his mc, are formally defined in Section 3. The two types of power are related in Section 4. This section also illustrates by means of numerical examples the relationship between the two types of power. If the two types of power were essentially identical, then it would have been sufficient to examine the effect of skill variability on reward based on just one type of power. But our first result establishes that the relationship between the two types of power is not simple. Therefore, it is interesting to compare the effect of skill inequality on the two types of power that apparently affect reward in terms of status, income or both. And this is precisely what we do in Section 5. This section presents the possibility of larger variability of mc relative to that of s-d power. It also contains comparative statics analysis based on simulations that illustrate the relationship between inequality of individual skills and inequality of the two types of power. The main robust finding of the simulations is that inequality of the mcs and of the s-d power are directly related to skill inequality and that inequality of mc is higher than that of the s-d power. Section 6 summarizes the findings.

2. The symmetric uncertain dichotomous choice model

Consider a committee $N = \{1, \dots, n\}$ that chooses one of the alternatives 1 and -1 one of which is the correct choice and, therefore, preferred by all the decision makers. The two alternatives are symmetric. The symmetry between the two alternatives has two aspects. First, the priors of the two states of nature determining whether an alternative is correct or incorrect are equal and, secondly, the net benefits of a correct decision under the two states of nature are equal. The state of nature ω, therefore, satisfies $\omega \in \{1, -1\}$ and $\alpha = \mathrm{Prob}(\omega = 1) = 1/2$. As is common in decision problems, the identity of the correct alternative is unknown, depending on the state of nature. The symmetry assumption implies that the objective of the group (and each of its members) can be stated in terms of the collective probability of making a correct decision rather than the expected benefit of the group. The problem of maximizing this probability is, therefore, equivalent to the problem of maximizing the expected benefit of the group.

Every decision maker selects sincerely one alternative, 1 or -1. We denote by x_i individual i's decision, $x_i \in \{1, -1\}$. Individual i chooses the correct alternative with probability p_i, which reflects his competence, $p_i = \text{Prob}(x_i = \omega), p_i \in (1/2, 1)$. We assume independent competencies and denote the skill vector of the group members by $p = (p_1, \ldots, p_n)$. With no loss of generality, it is assumed that group members are ordered by their skills.[2] The collective decision is based on the decisions of the individual committee members. It is made by a decisive aggregation rule f that assigns 1 or -1 to any decision profile $x = (x_1, x_2, \ldots, x_n)$ – that is, $f : \{1, -1\}^N \to \{1, -1\}$.

The collective decision rule that optimizes the decision-making process – that is, maximizes the collective probability of making a correct decision – is a weighted majority rule (Nitzan and Paroush, 1982; Shapley and Grofman, 1984). Specifically, the optimal aggregation rule is $f^*(x_1, \ldots, x_n, p) = \text{sign}\left(w_1^* x_1 + \cdots + w_n^* x_n\right)$, where $w_i^* = \ln\left(\frac{p_i}{1-p_i}\right)$ and $\text{sign}(m) = 1$, if $m > 0$ and -1 otherwise. The probability of obtaining a decision profile x, given the state of nature ω and the skill vector p, is given by

$$g(x : \omega, p) = \prod_{i \in N : x_i = \omega} p_i \prod_{i \in N : x_i = -\omega} (1 - p_i)$$

In our study, the committee applies the optimal decision rule. This assumption ensures that the committee members vote sincerely.[3] Under this assumption, an individual's 'skill-dependent power' is the probability that he is pivotal for the correct vote, given the distribution of skills in the group. An alternative different conception of power depends not on whether the individual has changed his vote, but on whether he has left or joined the group. This results in the individual's 'marginal contribution,' or the improvement in group accuracy when he joins the group. We proceed with the formal introduction of these two types of power.

3. s-d power and the mc to the group decision

For $S \subseteq N$, let $x^S \in \{1, -1\}^N$ be the profile satisfying $x_i^S = 1$, for every $i \in S$ and $x_j^S = -1$, for every $j \in N \backslash S$. Notice that in the profile $x^{S \backslash \{i\}}$, individual i switches his decision relative to the profile x^S.

In the general case of an n-member committee of decision makers, individual i's s-d power index proposed by Ben-Yashar and Nitzan (2019), his probability of being pivotal given the skill vector p and the corresponding optimal rule f^* takes the following form:

$$\psi_i^{SD}(p) = \sum_{S \subseteq N,\, S \ni i} \tfrac{1}{2} \left| f^*\left(x^S, p\right) - f^*\left(x^{S \backslash \{i\}}, p\right) \right| g\left(x_{-i}^S\right)$$

where x_{-i} denotes the decision vector x excluding individual i's decision. Because of the symmetry assumption, with no loss of generality, we can assume that 1 is the correct decision and -1 is the incorrect one. So

$$g\left(x_{-i}^{S}\right) = \text{Prob}\left(x_j = 1, \forall j \in S \setminus \{i\} \text{ and } x_j = -1, \forall j \in N \setminus S\right)$$
$$= \prod_{j \in S \setminus \{i\}} p_j \prod_{j \in N \setminus S} (1 - p_j).$$

Note that if $f\left(x^S, p\right) = f\left(x^{S\setminus\{i\}}, p\right)$, then i switching his choice from $x_i = 1$ to $x_i = -1$ is not pivotal. If $f\left(x^S, p\right) \neq f\left(x^{S\setminus\{i\}}, p\right)$, then if switching his choice, i is pivotal.

To present the second type of power, which is based on the examination of his impact when he leaves or joins the group, let us denote by $v(p)$ be the maximal expected probability that committee N makes a correct decision. Then,

$$v(p) = \max_f \sum\nolimits_{x \in X(1:f)} \alpha g(x:1,p) + \sum\nolimits_{x \in X(-1:f)} (1-\alpha) g(x:-1,p)$$

where

$$X(1:f) = \{x : f(x) = 1\} \text{ and } X(-1:f) = \{x : f(x) = -1\}$$

The mc of individual i, $\varphi_i^{MC}(p)$, is

$$\phi_i^{MC}(p) = v(p) - v\left(p_{N\setminus\{i\}}\right)$$

where p_M denotes the skill vector of all the group members in M.

In the following result, we present an alternative expression of $v(p)$, which will be useful in the next section where the relationship between the two types of power is exposed. Specifically, $v(p)$ can be rewritten in terms of $f^*(x,p)$ as follows:

Lemma 1: $v(p) = \sum_x \frac{1}{4} f^*(x,p)(g(x:1,p) - g(x:-1,p)) + \frac{1}{2}$

Proof: Let $w(p)$ be the expected utility. $w(p) = \sum_{\omega \in \{1,-1\}} \sum_x \text{Prob}(\omega) f^*(x,p) g(x:\omega,p)$. Since Prob $(\omega) = 1/2$, using $f^*(x,p)$, we obtain that $w(p) = \sum_x \frac{1}{2} f^*(x,p)(g(x:1,p) - g(x:-1,p))$.
Note that the expected utility is given by:

$$w(p) = v(p) - (1 - v(p)) = 2v(p) - 1$$
$$\Rightarrow v(p) = \frac{1}{2} w(p) + \frac{1}{2}$$

Rearranging terms in the above equation completes the proof.

4. The relationship between the two types of power

One may think that the mc of individual i is equal simply to the probability of being pivotal times the probability of making the collective decision a correct one – that is, $\varphi_i^{MC}(p) = p_i\psi_i^{SD}(p)$. This conjecture regarding the existence of a simple relationship between the two types of power is false, as shown by the following example.

Example 1: Consider a two-member committee with skills equal to $(0.8, 0.7)$. In this case, the optimal decision rule is the expert rule, the collective decision being made solely by individual 1. Since $v(0.8, 0.7) = 0.8$ and $v(0.7) = 0.7$, individual 1's mc is equal to $\varphi_1^{MC}(0.8, 0.7) = 0.1$. Since individual 1 is always pivotal, $\psi_1^{SD}(0.8, 0.7) = 1$, $\varphi_1^{MC}(0.8, 0.7) = 0.1 \neq p_1\psi_1^{SD}(p) = 0.8$.

So, what then is the relationship between $\varphi_i^{MC}(p)$ and $\psi_i^{SD}(p)$?

The following result establishes the relationship between an individual's mc and his s-d power, assuming that the group applies the optimal decision rule.

Proposition 1: $\boldsymbol{\varphi_i^{MC}(p) = p_i\psi_i^{SD}(p) - N_i(p)}$
where

$$N_i(p) = \sum_{S\subseteq N,\, i\in S} \tfrac{1}{2}\left|f^*\left(x^{S\setminus\{i\}}, p\right) - f^*\left(x_{-i}^S, p_{N\setminus\{i\}}\right)\right| g\left(x_{-i}^S\right)$$

Proof: Let us calculate $\varphi_i^{MC}(p)$.

By symmetry of the optimal voting rule, $f^*(-x) = -f^*(x)$ and $g\ (x : 1, p) = g(-x : -1, p)$. We can, therefore, write $v(p) - v\left(p_{N\setminus\{i\}}\right)$as :

$$\begin{aligned}
&\sum_{S\subseteq N}\left(p_i f^*\left(x^S, p\right) + (1-p_i)f^*\left(x^{S\setminus\{i\}}, p\right) - f^*\left(x_{-i}^S, p_{N\setminus\{i\}}\right)\right)\frac{1}{2}g\left(x_{-i}^S\right)\\
&= \sum_{S\subseteq N}\left(p_i\left[f^*\left(x^S, p\right) - f^*\left(x^{S\setminus\{i\}}, p\right)\right] + f^*\left(x^{S\setminus\{i\}}, p\right) - f^*\left(x_{-i}^S, p_{N\setminus\{i\}}\right)\right)\frac{1}{2}g\left(x_{-i}^S\right)\\
&= p_i\psi_i^{SD}(p) + \frac{1}{2}\sum_{S\subseteq N}\left(f^*\left(x^{S\setminus\{i\}}, p\right) - f^*(x_{-i}^S, p_{N\setminus\{i\}})\right)g\left(x_{-i}^S\right)\\
&= p_i\psi_i^{SD}(p) - \left[-\frac{1}{2}\sum_{S\subseteq N}\left(f^*\left(x^{S\setminus\{i\}}, p\right) - f^*(x_{-i}^S, p_{N\setminus\{i\}})\right)g\left(x_{-i}^S\right)\right]\\
&= p_i\psi_i^{SD}(p) - N_i(p)
\end{aligned}$$

Note that $\sum_{S\subseteq N}\left(f^*\left(x^{S\setminus\{i\}}, p\right) - f^*(x_{-i}^S, p_{N\setminus\{i\}})\right)$ is non-positive since an additional -1 by i makes the decision more likely to be -1.

As already noted, $p_i\psi_i^{SD}(p)$ is the probability that individual i determines the collective decision and makes it a correct one whereas the second expression $N_i(p)$ is the expected probability of turning a correct decision to an incorrect one due to the participation and incorrect decision of individual i. The proposition clarifies then why $\varphi_i^{MC}(p) \neq p_i\psi_i^{SD}(p)$. The reason is that the computation of i's mc requires consideration of the case that i is valuable by being absent. The firm relationship between $\varphi_i^{MC}(p)$ and $\psi_i^{SD}(p)$ is emphasized by the fact that

$$\varphi_i^{MC}(p) = 0 \Leftrightarrow \psi_i^{SD}(p) = 0$$

Returning to the above example and applying Proposition 1, we obtain the correct computation of 1's mc.

Example 1: Consider a two-member committee for $p = (0.8, 0.7)$, we get that

$$\varphi_1^{MC}(0.8, 0.7) = 0.8\psi_1^{SD}(0.8, 0.7)$$
$$-\frac{1}{2}\left(\left|f^*((-1, 1), (0.8, 0.7)) - f^*((1), (0.7))\right|g(1) + \left|f^*((-1, -1), (0.8, 0.7)) - f^*((-1), (0.7))\right|g(-1)\right)$$
$$= 0.8*1 - \frac{1}{2}(|-1 - 1|0.7 + |-1 - -1|0.3) = 0.8 - 0.7 = 0.1$$

A more complicated example of a three-member committee illustrates the numerical application of Proposition 1.

Example 2: Now consider another illustration, assuming a three-member group with $p = (0.9, 0.9, 0.6)$ and the application of the optimal decision rule:

$$\psi_1^{SD}(0.9, 0.9, 0.6) = 0.9 \cdot 0.4 + 0.1 \cdot 0.6 = 0.36 + 0.06 = 0.42$$

The mc of individual 1 is, therefore, equal to:

$$\varphi_1^{MC}(0.9, 0.9, 0.6) = 0.9\psi_1^{SD}(0.9, 0.9, 0.6)$$
$$-\frac{1}{2}\left(\left|f^*((-1, 1, 1), (0.9, 0.9, 0.6)) - f^*((1, 1), (0.9, 0.6))\right|g(1, 1)\right.$$
$$+ \left|f^*((-1, -1, 1), (0.9, 0.9, 0.6)) - f^*((-1, 1), (0.9, 0.6))\right|g(-1, 1)$$
$$+ \left|f^*((-1, 1, -1), (0.9, 0.9, 0.6)) - f^*((1, -1), (0.9, 0.6))\right|g(1, -1)$$
$$\left.+ \left|f^*((-1, -1, -1), (0.9, 0.9, 0.6)) - f^*((-1, -1), (0.9, 0.6))\right|g(-1, -1)\right)$$
$$= 0.9*0.42 - \frac{1}{2}(0*g(1, 1) + 0*g(-1, 1) + |-2|*0.9*0.4 + 0*g(-1, -1))$$
$$= 0.9*0.42 - 0.9*0.4 = 0.018$$

Given the non-trivial relationship between the two types of power, no wonder that the distributions of s-d power and mc may differ and, in particular, inequality of the two types of power can be different. Given that reward may depend on the two types of power, such difference may have important implications on the individual or social incentives to invest in skills. We proceed with the comparison of these inequalities and, finally, with an analysis of their sensitivity to changes in inequality of the individual decisional skills.

5. Comparison of inequality of skills, s-d power and mc

Let us start by clarifying that the inequality of mc can be considerably higher than that of the s-d power and that both are higher than the inequality of skills. This is done assuming a five-member committee and even a modest variability in the decisional skills of the group members.

Example 3: Suppose that $(p_1, \ldots, p_5) = (0.8, 0.7, 0.7, 0.7, 0.64)$. In this case, the optimal decision rule is defined by the optimal weights $w_i^* = \ln\left(\frac{p_i}{1-p_i}\right)$, but the corresponding weighted majority rule characterized by different weights is equivalent to the simple majority defined by equal decisional weights. The reason is that the set of winning coalitions under the two rules is identical. The skill differences are, therefore, insufficient to warrant an asymmetric weighted majority rule. Still, applying the first type of power, $\psi_i^{SD}(p)$, presented in Section 3, the normalized s-d power distribution is $(21.73, 19.89, 19.89, 19.89, 18.6)$, reflecting the modest difference in the individual skills. Computation of $\varphi_i^{MC}(p)$ in this case yields that the normalized mc distribution is $(62.7, 11.8, 11.8, 11.8, 1.9)$, which is considerably more unequal. The gap between the (normalized) mc of individual 1 and that of the other relatively equally skilled, equally weighted and almost equally powered group members is substantial. In particular, the difference between the skills of individuals 1 and 5 is just 0.16; however, 1's (normalized) mc, 62.7, is 33 times larger than 1.9, the (normalized) mc of individual 5.

This example provides an unequivocal positive answer to the question, 'Can unequal reward based on s-d-power or on mc be justified, given modest variability in the decisional skills of the group members and even no variability at all in their optimal weights?'. It clearly illustrates that modest skill-heterogeneity can yield higher s-d power inequality and even more extreme inequality in terms of mc. Example 3 deals with one particular case of a five-member committee. Our final task is to generalize the example and demonstrate the relationship between inequality of skills and the two types of power, assuming that skills are evenly distributed over some interval of valuable skills. Our findings are based on simulations carried out for five-, seven- and nine-member committees.

Suppose that individual decisional skills are drawn from the same uniform distribution over some interval of skills contained in the interval of valuable decisional skills [0.5, 1.0]. A parameter $r, 0 \leq r \leq 0.25$, captures dispersion of skills in the following way: skills are assumed to be evenly spaced over the interval $[0.75 - r, 0.75 + r]$, so that when $r = 0$, everyone is identical at 0.75 and when $r = 0.25$ everyone is evenly spread between 0.5 and 1. For each of the six values of the dispersion parameter r that appear on the horizontal axis of the following figures, $0, 0.05, 0.1, 0.15, 0.2$ and 0.25, n individual skills are drawn randomly, $n = 5, 7, 9$ and we then find the expected inequality of skill, the optimal weights assigned to the committee members and, using the formulas $\psi_i^{SD}(p)$ and $\varphi_i^{MC}(p)$, the s-d power and mc in the 1000 cases of the simulation. Inequality is then

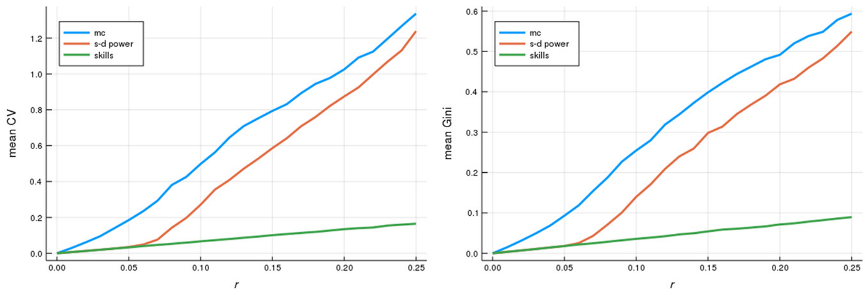

Figure 1. The relationship between mean CV and Gini coefficient of skills mc and s-d power and *r* (*n* = 5).

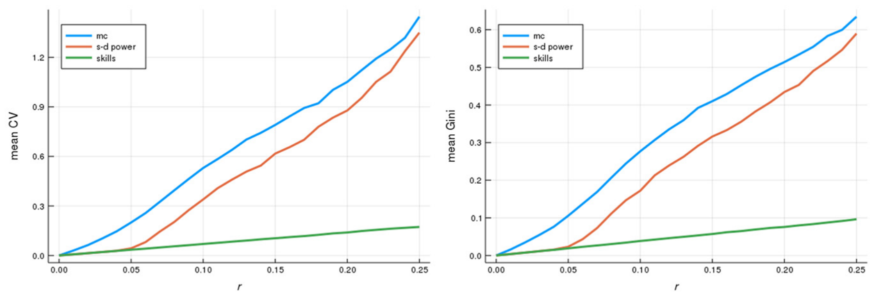

Figure 2. The relationship between mean CV and Gini coefficient of skills, mc and s-d power and *r* (*n* = 7).

measured in terms of the coefficient of variation (CV), $CV = \frac{\text{standard deviation}}{\text{mean}}$ and in terms of the Gini coefficient. The comparative static results are presented in Figures 1–3 for five-, seven- and nine-member committees. They are separately presented for the two measures of inequality, CV and the Gini coefficient. As is clearly visible from the figures, the findings are robust. Skill variability generates higher inequality of the two types of power. Whereas both types of power are directly related to skill inequality, inequality of the mcs is always higher than that of the s-d power. The reason is that, in the computation of the mcs, the different skills of the members play an extra role in creating inequality, as evident from Proposition 1.

6. Summary

Starting with the presentation of the general s-d power of an individual who belongs to an *n*-member committee making dichotomous decisions, we have proceeded with the introduction of an individual mc to the performance of the committee (the probability that a correct collective decision is made). These variables play a role in the determination of the distribution of the group members' reward because they are apparently related to status and payment. We first exposed the

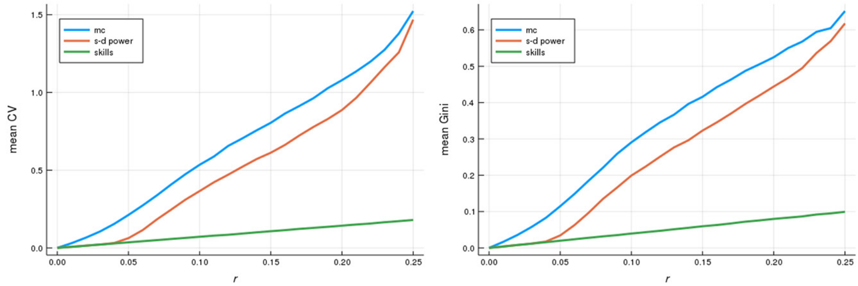

Figure 3. The relationship between mean CV and Gini coefficient of skills, mc and s-d power and r (n = 9).

relationship between an individual's mc and his s-d power. Our first result, Proposition 1, is an application of the result proved by Nitzan and Paroush (1982) and Shapley and Grofman (1984), the identification of the optimal group decision rule, because the two types of power measure on which we focus apply the optimal voting weights. This result links the extended s-d power measure of Banzhaf (1965) and Shapley-Shubik (1954) and optimal judgmental competence, two literatures that have generally been totally distinct from one another until their recent joint treatment in Ben-Yashar and Nitzan (2019). The later study has demonstrated that differences in skill level can justify huge differences in s-d power. Introducing into the model the committee members' mcs, we have shown that, if the committee applies the optimal decision rule, the distribution of the mcs can be even more unequal than the distribution of s-d power. This has been illustrated by applying a particular example of a five-member committee. We then presented simulation results generated for five-, seven- and nine-member committees, establishing that when skills are evenly distributed over some interval of valuable skills, skill inequality generates higher inequality of the two types of power. Both inequality of the mcs and of the s-d power are directly related to skill inequality. But inequality of mc is always higher than that of the s-d power.

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Notes

1. The justification of why we need a new measure of power that takes into account decisional skills is spelled out in Ben-Yashar and Nitzan (2019).
2. Earlier studies of two such alternative models include Austen-Smith and Banks (1996), Nitzan and Paroush (1982), Ben-Yashar and Nitzan (1997), Dietrich and List (2013) and Young (1988). A recent survey of the model and its extensions appears in Nitzan and Paroush (2018).
3. As is well known, (Ben-Yashar and Milchtaich, 2007), under the optimal decision rule the voters have no incentives to behave strategically.

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