LEVEL *r* CONSENSUS AND STABLE SOCIAL CHOICE

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Level r Consensus and Stable Social Choice*

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Abstract

We propose the concept of level r consensus as a useful property of a preference profile which considerably enhances the stability of social choice. This concept involves a weakening of unanimity, the most extreme form of consensus. It is shown that if a preference profile exhibits level r consensus around a given preference relation, the associated majority relation is transitive. In addition, the majority relation coincides with the preference relation around which there is such consensus. Furthermore, if the level of consensus is sufficiently strong, the Condorcet winner is chosen by all the scoring rules. Level r consensus therefore ensures the Condorcet consistency of all scoring rules, thus eliminating the tension between decision rules inspired by ranking-based utilitarianism and the majority rule.

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1 Introduction

A major goal of social choice theory is to search for reasonable ways of aggregating individual preferences into a social preference relation. Arrow's [1] impossibility theorem brought a serious challenge to such aspiration by showing that any social welfare function defined over an unrestricted domain, that satisfies the unanimity and the independence of irrelevant alternatives axioms must be dictatorial. Unanimity is a weak property requiring that if all individuals share a particular preference relation, this common relation must be the social preference relation. Unanimity is such a weak and sensible requirement that its violation would render any preference aggregation rule unacceptable. As a result, the search for reasonable preference aggregation rules has focused on domain restrictions and on the weakening of the independence axiom.

Among the many attempts to find reasonable aggregation rules, one can identify four approaches which can be considered as unanimity geared. The best-known approach is based on a unanimity that is not about a particular preference relation, but about the pattern of preferences. Alternative forms of domain restrictions, notably single-peakedness of preference relations, impose this type of weakened, implicit unanimity. In the latter case for instance, given any three alternatives, there is a unanimous agreement that a particular alternative is never the worst alternative among the three (see Sen [26]). The second approach looks for a unanimously supported metric-based compromise. It postulates an agreed-upon metric on the set of preference relations and, given a preference profile, seeks a social preference relation that is closest to it, namely one that minimizes the sum of its distances to the individual preference relations in the profile. Baigent [3], Kemeny [11], Nitzan [15], and Nurmi [18, 19] adopt this approach. The third approach also applies a plausible metric on the set of all possible preference profiles, but seeks a social choice rule that yields an outcome which is as close as possible to be unanimously preferred. In other words, the distance between the given preference profile and a profile where the chosen alternative is unanimously supported is minimized. See Campbell and Nitzan [4], Farkas and Nitzan [5], Lehrer and Nitzan [13], Nitzan [14], Nitzan [16] for instances of this approach. Finally, the fourth approach is a probabilistic one. It postulates the existence of a unanimously supported true social preference relation and assumes that the preference profile is a noisy sample of it. Specifically, it assumes that the probability that any individual's ranking of any two alternatives coincides with the true ranking is higher than 1/2, and looks for a maximum-likelihood estimator that delivers a preference relation that maximizes the probability of having induced the realized preference profile. See Young [27] for a representative of this approach.

In the present paper we propose a new unanimity-inspired approach which is based on strengthening the unanimity requirement. The reason why the unanimity axiom is very weak is that it "bites" only in those rare instances of extreme preference homogeneity where individual preference relations are identical. In this paper, instead of requiring the social preference relation to coincide with the unanimous preference relation (when it exists), we require it to be one around which there is some level of consensus. A preference profile exhibits consensus of level r around some preference relation (the consensus preference), if whenever a subset of r preference relations is at least as close to the consensus preference as any other disjoint subset of r preference relations, the number of individuals whose preference relations belong to the former subset is at least as large as the number of those whose preference relations belong to the latter.[1] Clearly, looking for consensus around some preference relation is more challenging when preferences are heterogeneous than in the extreme event of unanimous preferences. While there is a natural consensus around a unanimous preference relation, there may still be some kind of consensus around some preference relation, even in cases of heterogeneous preferences. The proposed approach looks for preference aggregation rules that select a social preference relation around which such consensus exists.

Several levels of consensus are defined, one more stringent than the other. Consensus of level 1 is more difficult to achieve than consensus of level 2, and so on, and all of them are achieved when there is unanimity about the preference relation. The least demanding level

[1]Several other attempts have been made to formalize and measure consensus. See, for example, García-Lapresta and Pérez-Román [9]. For a survey of various consensus theories, see Hudry and Monjardet [10].

of consensus is level $K!/2$, where K is the number of alternatives over which preferences are defined. The definition of consensus rests on a given metric on the set of preferences and thus different metrics induce different notions of consensus. Our results suggest that when applying the inversion metric, the existence of consensus of level r, for some $r \leq K!/2$, considerably enhances the stability of social choice. Specifically, it implies the transitivity of the induced majority relation and that the majority relation is the one around which consensus exists. Furthermore, the existence of a sufficiently strong level of consensus, namely for $r \leq (K-1)!$, ensures the selection of the same Condorcet winning alternative by majority rule and by all scoring rules. In that sense, it eliminates the tension between the majority rule and decision rules inspired by ranking-based utilitarianism.

2 Definitions

Let $A = \{a_1, \ldots, a_K\}$ be a set of $K > 2$ alternatives and let $N = \{1, \ldots, n\}$ be a set of individuals. Also, let $\mathcal{R}$ be the set of binary relations on A, and $\mathcal{P}$ be the subset of complete, transitive and antisymmetric binary relations on A. We will refer to the elements of $\mathcal{P}$ as preference relations or simply as preferences. A *preference profile* or simply a *profile* is a mapping $\pi = (\succsim_1, \ldots, \succsim_n)$ of preference relations on A to the individuals in N. For each individual $i \in N$, $\succsim_i$ represents i's preferences over the alternatives in A. We denote by $\mathcal{P}^n$ the set of preference profiles.

Let $\pi = (\succsim_1, \ldots, \succsim_n)$ be a preference profile. For each preference relation $\succsim \in \mathcal{P}$, $\mu_\pi(\succsim) = |\{i \in N : \succsim_i = \succsim\}|$ is the number of individuals whose preference relation is $\succsim$. More generally, for any subset $C \subseteq \mathcal{P}$ of preference relations, $\mu_\pi(C) = |\{i \in N : \succsim_i \in C\}|$ is the number of individuals whose preference relations are in C.

An *aggregation rule* is a function $f : \mathcal{P}^n \rightarrow \mathcal{R}$ that assigns to each preference profile a social binary relation. An aggregation rule is a *Social Welfare Function* if its range is the subset of transitive binary relations on A.

A well-known social welfare function is the *Borda rule*. In order to define it, consider a preference profile $\pi = (\succsim_1, \ldots, \succsim_n)$. For each individual $i = 1, \ldots, n$ and for each alternative $a \in A$, let $S_i(a) = |\{a' \in A : a \succ_i a'\}|$ be the number of alternatives that are ranked below a according to i's preferences.[2] The Borda rule associates with π the preference relation B_π given by

$$aB_\pi b \Leftrightarrow \sum_{i=1}^{n} S_i(a) \geq \sum_{i=1}^{n} S_i(b).$$

Another example of a social welfare function is given by the family of *Mode rules*. A Mode rule is a social welfare function $f : \mathcal{P}^n \to \mathcal{R}$ such that for each preference profile $\pi = (\succsim_1, \ldots, \succsim_n)$, $f(\pi) = \succsim_i$ where $\mu_\pi(\succsim_i) \geq \mu_\pi(\succsim_j)$ for $j = 1, \ldots, n$. In words, a Mode rule selects one of the most "popular" preference relations in π.

An important example of an aggregation rule is the *Majority rule*, which we define next. Let $a, a' \in A$ be two alternatives. Denote by $C(a \to a') = \{\succsim \in \mathcal{P} : a \to a'\}$ the set of preference relations according to which a is strictly preferred to a'. The majority rule assigns to each preference profile $\pi \in \mathcal{P}$ the binary relation M_π on A defined by

$$aM_\pi a' \Leftrightarrow \mu_\pi(C(a \to a')) \geq \mu_\pi(C(a' \to a)).$$

It is well known that the majority rule does not deliver a transitive binary relation for each preference profile, and thus it is not a social welfare function.

Let $d : \mathcal{P}^2 \to \mathbb{R}$ be a metric on $\mathcal{P}$. That is, for every $\succsim, \succsim', \succsim'' \in \mathcal{P}$, d satisfies

- $d(\succsim, \succsim') \geq 0$
- $d(\succsim, \succsim') = 0 \;\Leftrightarrow \succsim = \succsim'$
- $d(\succsim, \succsim') = d(\succsim', \succsim)$
- $d(\succsim, \succsim'') \leq d(\succsim, \succsim') + d(\succsim', \succsim'')$

[2]Strict preferences and indifference are defined as usual. For $a, b \in A$, $a \succ b \Leftrightarrow (a \succsim b$ and not $b \succsim a)$, and $a \sim b \Leftrightarrow (a \succsim b$ and $b \succsim a)$.

For most of our results we will use the *inversion metric*, which is defined as follows:[3] $d(\succsim, \succsim')$ is the minimum number of pairwise adjacent transpositions needed to obtain $\succsim'$ from $\succsim$. Alternatively, $d(\succsim, \succsim')$ is the number of pairs of alternatives in A that are ranked differently by $\succsim$ and $\succsim'$. Formally, the inversion metric is defined by

$$d(\succsim, \succsim') = \frac{|(\succsim \setminus \succsim') \cup (\succsim' \setminus \succsim)|}{2}.$$

Another known metric is the *discrete* metric. It is defined by

$$d(\succsim, \succsim') = \begin{cases} 0 & \text{if } \succsim = \succsim' \\ 1 & \text{otherwise.} \end{cases}$$

A metric defined on $\mathcal{P}$ allows us to determine which one of any two preference relations is closer to a third one. We are interested in extending this kind of comparison to equal-sized sets of preferences as well. The following definition identifies circumstances where a given set of preferences $C \subseteq \mathcal{P}$ is closer to $\succsim_0$ than an alternative set $C' \subseteq \mathcal{P}$.

Definition 1 Let C and C' be two disjoint nonempty subsets of $\mathcal{P}$ with the same cardinality, and let $\succsim_0 \in \mathcal{P}$ be a preference relation on A. We say that C *is at least as close to* $\succsim_0$ *as* C', denoted by $C \geq_{\succsim_0} C'$, if there is a one-to-one function $\phi : C \to C'$ such that for all $\succsim \in C$, $d(\succsim, \succsim_0) \leq d(\phi(\succsim), \succsim_0)$. We also say that C *is closer than* C' *to* $\succsim_0$, denoted by $C >_{\succsim_0} C'$, if there is a one to one function $\phi : C \to C'$ such that for all $\succsim \in C$, $d(\succsim, \succsim_0) \leq d(\phi(\succsim), \succsim_0)$, with strict inequality for at least one $\succsim \in C$.

In other words, C is at least as close as C' to some given preference relation $\succsim_0 \in \mathcal{P}$ if each preference relation $\succsim'$ in C' can be paired with a preference relation $\succsim$ in C that is at least as close to $\succsim_0$, according to d, as $\succsim'$ is. C is closer than C' to $\succsim_0$ if it is at least as close to it as C' and it is not the case that C' is at least as close to $\succsim_0$ as C.

An alternative way to check whether $C \geq_{\succsim_0} C'$ is as follows. Let $d(C, \succsim_0)$ be the list $(d(\succsim, \succsim_0))_{\succsim \in C}$ arranged in a non-decreasing order. Similarly, let $d(C', \succsim_0)$ be the list $(d(\succsim, \succsim_0))_{\succsim \in C'}$ also arranged in a non-decreasing order. Then $C \geq_{\succsim_0} C' \Leftrightarrow d(C, \succsim_0) \leq d(C', \succsim_0)$.

[3]See Kemeny and Snell [12] for a characterization of this metric.

Example 1 Let the set of alternatives be $A = \{a, b, c\}$. The set $\mathcal{P}$ contains six preference relations, given by

$$\begin{aligned} \succsim_1 &= a, b, c \\ \succsim_2 &= a, c, b \\ \succsim_3 &= b, a, c \\ \succsim_4 &= c, a, b \\ \succsim_5 &= b, c, a \\ \succsim_6 &= c, b, a \end{aligned}$$

There are ten ways to partition $\mathcal{P}$ into two subsets with three preference relations each. One such partition is $C_1 = \{\succsim_1, \succsim_2, \succsim_3\}$ and $\overline{C_1} = \{\succsim_4, \succsim_5, \succsim_6\}$. Consider the preference relation $\succsim_1$. It can be checked that the distances of each preference relation in $\mathcal{P}$ to $\succsim_1$, according to the inversion metric, are given by

$$\begin{aligned} d(\succsim_1, \succsim_1) = 0 \\ d(\succsim_2, \succsim_1) = d(\succsim_3, \succsim_1) = 1 \\ d(\succsim_4, \succsim_1) = d(\succsim_5, \succsim_1) = 2 \\ d(\succsim_6, \succsim_1) = 3 \end{aligned}$$

It can also be checked that $C_1 >_{\succsim_1} \overline{C_1}$. Indeed, $d(\succsim_1, \succsim_1) < d(\succsim_4, \succsim_1)$, $d(\succsim_2, \succsim_1) < d(\succsim_5, \succsim_1)$ and $d(\succsim_3, \succsim_1) < d(\succsim_6, \succsim_1)$. Alternatively, $d(C_1, \succsim_1) = (0, 1, 1)$ and $d(\overline{C_1}, \succsim_1) = (2, 2, 3)$. Therefore $d(C_1, \succsim_1) < d(\overline{C_1}, \succsim_1)$, which implies that $C_1 >_{\succsim_1} \overline{C_1}$.

Note that any two disjoint, equal-sized subsets of preference relations contain at most $K!/2$ elements each. Taking this into account and based on the "at least as close to $\succsim_0$" relation defined above, we can now define the concept of consensus.

Definition 2 Let $r \in \{1, 2, \dots K!/2\}$, and let $\succsim_0 \in \mathcal{P}$. A preference profile $\pi \in \mathcal{P}^n$ exhibits *consensus of level* r *around* $\succsim_0$ if

1. for all disjoint subsets C, C' of $\mathcal{P}$ with cardinality r, $C \geq_{\succsim_0} C' \Rightarrow \mu_\pi(C) \geq \mu_\pi(C')$

2. for all disjoint subsets C, C' of $\mathcal{P}$ with cardinality r, $C >_{\succsim_0} C' \Rightarrow \mu_\pi(C) > \mu_\pi(C')$

3. there are disjoint subsets C, C' of $\mathcal{P}$ with cardinality r, such that $C >_{\succsim_0} C'$.

In words, given $1 \leq r \leq K!/2$, a preference profile π exhibits consensus of level r around some preference relation $\succsim_0$, if whenever a subset C of r preference relations is at least as close to $\succsim_0$ as another disjoint subset C' of r preference relations, the number of preference relations in π that belong to C is at least as large as the number of preference relations in π that belong to C', and strictly larger whenever C is closer to $\succsim_0$ than C'. Furthermore, there must be two such subsets where the relations are strict.

Example 2 Consider the set $\mathcal{P}$ of preference relations from Example 1. There are ten different ways to partition $\mathcal{P}$ into two subsets, $C, \overline{C}$, of cardinality 3. We have already seen that

$$C_1 = \{\succsim_1, \succsim_2, \succsim_3\} >_{\succsim_1} \{\succsim_4, \succsim_5, \succsim_6\} = \overline{C_1}.$$

Similarly, it can be checked that

$$\begin{aligned} C_2 = \{\succsim_1, \succsim_2, \succsim_4\} &>_{\succsim_1} \{\succsim_3, \succsim_5, \succsim_6\} = \overline{C_2} \\ C_3 = \{\succsim_1, \succsim_3, \succsim_4\} &>_{\succsim_1} \{\succsim_2, \succsim_5, \succsim_6\} = \overline{C_3} \\ C_4 = \{\succsim_1, \succsim_2, \succsim_5\} &>_{\succsim_1} \{\succsim_3, \succsim_4, \succsim_6\} = \overline{C_4} \\ C_5 = \{\succsim_1, \succsim_3, \succsim_5\} &>_{\succsim_1} \{\succsim_2, \succsim_4, \succsim_6\} = \overline{C_5} \end{aligned}$$

Also, for the remaining five partitions $\{C, \overline{C}\}$, we have that neither $C \geq_{\succsim_1} \overline{C}$ nor $\overline{C} \geq_{\succsim_1} C$. Let π be a preference profile containing 3 copies of $\succsim_1$, one copy of $\succsim_3$, one copy of $\succsim_4$ and 2 copies of $\succsim_5$. It can be checked that $\mu(C_i) > \mu(\overline{C_i})$ for $i = 1, 2, 3, 4, 5$. Consequently, we conclude that the profile π exhibits consensus of level 3 around $\succsim_1$. On the other hand, π does not exhibit consensus of level 2 around $\succsim_1$. To see this, note that although $\{\succsim_2, \succsim_4\}$ is closer than $\{\succsim_5, \succsim_6\}$ to $\succsim_1$ (indeed, $d(\succsim_2, \succsim_1) = 1 < d(\succsim_5, \succsim_1)$ and $d(\succsim_4, \succsim_1) = 2 < 3 = d(\succsim_6, \succsim_1)$), we have that $\mu(\{\succsim_2, \succsim_4\}) = 1 < 2 = \mu(\{\succsim_5, \succsim_6\})$.

3 Consensus and Majority Rule

In this section we show some striking implications of the existence of consensus around some preference relation. But before turning to this task, we first show that there is a hierarchy in the levels of consensus: they are ordered by strength, the strongest being consensus of level 1 and the weakest consensus of level $K!/2$.

Proposition 1 Let r be an integer between 1 and $K!/2-1$. If $\pi \in \mathcal{P}^n$ exhibits consensus of level r around $\succsim_0$, then it exhibits consensus of level $r+1$ as well around $\succsim_0$.

Proof : Assume $\pi \in \mathcal{P}^n$ exhibits consensus of level r around $\succsim_0$. We need to show that conditions 1, 2, and 3 in Definition 2 are satisfied.
1. Let $C = \{\succsim_1, \ldots, \succsim_{r+1}\}$ and $C' = \{\succsim'_1, \ldots, \succsim'_{r+1}\}$ be two disjoint subsets of $\mathcal{P}$ with cardinality $r+1$ such that $C \geq_{\succsim_0} C'$. Then, there is a one-to-one function $\varphi : C \to C'$ such that $d(\succsim_i, \succsim_0) \leq d(\varphi(\succsim_i), \succsim_0)$ for all $i = 1, \ldots r+1$. Assume, without loss of generality, that $\varphi(\succsim_i) = \succsim'_i$ for all $i = 1, \ldots r+1$. We need to show that $\mu_\pi(C) \geq \mu_\pi(C')$.
Assume by contradiction that

$$\mu_\pi(C) < \mu_\pi(C') \tag{1}$$

Then, there must be two preference relations $\succsim_i \in C$ and $\succsim'_i \in C'$ such that $\mu_\pi(\succsim_i) < \mu_\pi(\succsim'_i)$.
Assume without loss of generality that

$$\mu_\pi(\succsim_{r+1}) < \mu_\pi(\succsim'_{r+1}). \tag{2}$$

Assume also without loss of generality that

$$\mu_\pi(\succsim_1) - \mu_\pi(\succsim'_1) \geq \mu_\pi(\succsim_i) - \mu_\pi(\succsim'_i) \qquad \forall i = 1, \ldots, r.$$

Consider the subsets $C_{-1} = \{\succsim_2, \ldots, \succsim_{r+1}\}$ and $C'_{-1} = \{\succsim'_2, \ldots, \succsim'_{r+1}\}$. Since $C \cap C' = \emptyset$, and since C is at least as close as C' to $\succsim_0$, we have that $C_{-1} \cap C'_{-1} = \emptyset$, and C_{-1} is at least as close as C'_{-1} to $\succsim_0$ as well. Since π exhibits consensus of order r around $\succsim_0$, we must have

$$\mu_\pi(C_{-1}) \geq \mu_\pi(C'_{-1}). \tag{3}$$

Since $\mu_\pi(C_{-1}) = \sum_{k=2}^{r+1} \mu_\pi(\succsim_k)$ and $\mu_\pi(C'_{-1}) = \sum_{k=2}^{r+1} \mu_\pi(\succsim'_k)$, there must be some $k = 2, \ldots, r+1$ such that $\mu_\pi(\succsim_k) \geq \mu_\pi(\succsim'_k)$. Further, given (2) this k cannot be $r+1$. As a result,

$$\mu_\pi(\succsim_1) - \mu_\pi(\succsim'_1) \geq 0. \tag{4}$$

But then, using (3) and (4)

$$\mu_\pi(C) = \mu_\pi(C_{-1}) + \mu_\pi(\succsim_1) \geq \mu_\pi(C'_{-1}) + \mu_\pi(\succsim'_1) = \mu_\pi(C')$$

which contradicts (1).

2. Let $C = \{\succsim_1, \ldots, \succsim_{r+1}\}$ and $C' = \{\succsim'_1, \ldots, \succsim'_{r+1}\}$ be two disjoint subsets of $\mathcal{P}$ with cardinality $r+1$ such that $C >_{\succsim_0} C'$. Then, there is a one to one function $\varphi : C \to C'$ such that $d(\succsim_i, \succsim_0) \leq d(\varphi(\succsim_i), \succsim_0)$ for all $i = 1, \ldots r+1$. Assume, without loss of generality, that $\varphi(\succsim_i) = \succsim'_i$ for all $i = 1, \ldots r+1$. We need to show that $\mu_\pi(C) > \mu_\pi(C')$. Assume by contradiction that

$$\mu_\pi(C) \leq \mu_\pi(C'). \tag{5}$$

Since $C >_{\succsim_0} C'$, there is $j \in \{1, \ldots, r+1\}$ such that $d(\succsim_j, \succsim_0) < d(\succsim'_j, \succsim_0)$ and $d(\succsim_i, \succsim_0) \leq d(\succsim'_i, \succsim_0)$ for $i \neq j$. Assume, without loss of generality, that $j = r+1$. Let $C_{-r} = C \setminus \{\succsim_r\}$ and $C'_{-r} = C' \setminus \{\succsim'_r\}$. These two sets have cardinality r. By construction $C_{-r} >_{\succsim_0} C'_{-r}$. Since, by hypothesis, π exhibits consensus of order r around $\succsim_0$, we have that $\mu_\pi(C_{-r}) > \mu_\pi(C'_{-r})$. Therefore there are two preference relations, $\succsim_i \in C_{-r}$ and $\succsim'_i \in C'_{-r}$, such that $\mu_\pi(\succsim_i) - \mu_\pi(\succsim'_i) > 0$. Let $C_{-i} = C \setminus \{\succsim_i\}$ and $C'_{-i} = C' \setminus \{\succsim'_i\}$. Since $C \cap C' = \emptyset$, and since $C >_{\succsim_0} C'$, we have that $C_{-i} \cap C'_{-i} = \emptyset$, and that C_{-i} is at least as close as C'_{-i} to $\succsim_0$ as well. Since π exhibits consensus of order r around $\succsim_0$, we must have that

$$\mu_\pi(C_{-i}) \geq \mu_\pi(C'_{-i}). \tag{6}$$

On the other hand, by the contradiction hypothesis, $\mu_\pi(C) \leq \mu_\pi(C')$; therefore

$$\mu_\pi(C_{-i}) + \mu_\pi(\succsim_i) \leq \mu_\pi(C'_{-i}) + \mu_\pi(\succsim'_i)$$

But since $\mu_\pi(\succsim_i) - \mu_\pi(\succsim'_i) > 0$, we obtain that $\mu_\pi(C_{-i}) < \mu_\pi(C'_{-i})$, which contradicts (6).

3. It remains to show that there exist disjoint subsets C, C' of $\mathcal{P}$ with cardinality $r+1$ such that $C >_{\succsim_0} C'$. Since $\pi \in \mathcal{P}^n$ exhibits consensus of level r around $\succsim_0$, there are disjoint subsets $C(r) = \{\succsim_1, \dots \succsim_r\}$ and $C'(r) = \{\succsim'_1, \dots \succsim'_r\}$ of $\mathcal{P}$ with cardinality r, such that $C(r) >_{\succsim_0} C'(r)$. That is, there is a one to one function $\varphi : C \to C'$ such that $d(\succsim_i, \succsim_0) \leq d(\varphi(\succsim_i), \succsim_0)$ for all $i = 1, \dots, r$, with strict inequality for some $i \in \{1, \dots, r\}$. Choose $\succsim_{r+1}, \succsim'_{r+1} \in \mathcal{P} \setminus (C(r) \cup C'(r))$ and assume, without loss of generality, that $d(\succsim_{r+1}, \succsim_0) \leq d(\succsim'_{r+1}, \succsim_0)$. Then, by extending φ so that $\varphi(\succsim_{r+1}) = \succsim'_{r+1}$, we can see that $C = \{\succsim_1, \dots \succsim_{r+1}\}$ and $C' = \{\succsim'_1, \dots \succsim'_{r+1}\}$ are the two sets we are looking for. □

We now turn to the implications of r consensus on the outcomes of the majority rule. The next theorem shows that despite not being a social welfare function, if a profile exhibits the weakest possible level of consensus with respect to the inversion metric, the majority rule associates with it a transitive binary relation.

Theorem 1 Let $\pi \in \mathcal{P}$ be a preference profile that exhibits consensus of level $K!/2$ around $\succsim_0 \in \mathcal{P}$ with respect to the inversion metric. Then M_π, the binary relation assigned by the majority rule to π, coincides with $\succsim_0$. In particular, M_π is transitive.

Proof : Let $a, b \in A$ be two alternatives. We need to show that $aM_\pi b \Leftrightarrow a \succsim_0 b$. If $a = b$ the result is immediate. So assume that $a \neq b$, and further assume without loss of generality that $a \succ_0 b$. Partition $\mathcal{P}$ into the two sets $C(a \to b)$ and $C(b \to a)$. These sets contain $K!/2$ elements each. Consider the one-to-one function $\varphi : C(a \to b) \to C(b \to a)$ defined as follows: for each $\succsim \in C(a \to b)$, let $\varphi(\succsim) \in \mathcal{P}$ be the preference relation that is obtained from $\succsim$ by switching a and b in the ranking. Since $a \succ_0 b$, $d(\succsim, \succsim_0) < d(\phi(\succsim), \succsim_0)$ for all $\succsim \in C(a \to b)$, where d is the inversion metric. In other words, according to the inversion metric, $C(a \to b)$ is closer to $\succsim_0$ than $C(b \to a)$ is. Since there is consensus of level $K!/2$ around $\succsim_0$, this implies that $\mu_\pi(C(a \to b)) > \mu_\pi(C(b \to a))$, which means that $aM_\pi b$. Conversely, if $aM_\pi b$ we must have $\mu_\pi(C(a \to b)) \geq \mu_\pi(C(b \to a))$. It follows that $a \succsim_0 b$ since otherwise, by the previous argument we would have that $\mu_\pi(C(b \to a)) > \mu_\pi(C(a \to b))$. Given that $\succsim_0$ is transitive we obtain that M_π, is transitive. □

The next example shows that the fact that a preference profile π exhibits consensus of level $K!/2$ around some preference relation does not imply that the Borda rule will assign this preference relation to π.

Example 3 We have seen in Example 2 that profile π exhibits consensus of level 3 around $\succsim_1$. Consistent with Theorem 1, the majority rule applied to π yields a transitive order. In contrast, it can be verified that the preference relation assigned by the Borda rule is not $\succsim_1$ but $\succsim_3$. Moreover, the Borda rule does not select the Condorcet winning alternative, which is alternative a.

4 Rationalizability

Theorem 1 shows that, under the inversion metric, if a profile exhibits consensus of level $K!/2$ around $\succsim_0$, then $\succsim_0$ coincides with the binary relation assigned to π by the majority rule. This suggests the following definition.

Definition 3 We say that aggregation rule $f : \mathcal{P}^n \to \mathcal{R}$ is *rationalizable by consensus of level* r (or r*-rationalizable*, for short), if whenever profile $\pi \in \mathcal{P}^n$ exhibits consensus of level r around $\succsim_0$, we have $f(\pi) = \succsim_0$. We also say that f is *rationalizable* if it is r-rationalizable for every $r = 1, \dots, K!/2$.

Claim 1 If f is $r+1$-rationalizable, then it is also r-rationalizable.

Proof : Assume f is $r+1$-rationalizable. Let $\pi \in \mathcal{P}^n$ be a profile that exhibits consensus of level r around $\succsim_0$. We need to show that $f(\pi) = \succsim_0$. By Proposition 1, π exhibits consensus of level $r+1$ as well. Since f is $r+1$-rationalizable, $f(\pi) = \succsim_0$. □

Corollary 1 The majority rule is rationalizable.

Proof : By Claim 1 it is enough to show that the majority rule is $K!/2$-rationalizable. But this follows from Theorem 1. □

The following result shows that if we replace the inversion metric by the discrete metric, the family of mode rules are also rationalizable.

Proposition 2 Let $\pi \in \mathcal{P}^n$ be a preference profile that exhibits consensus of level $K!/2$ around $\succsim_0 \in \mathcal{P}$ with respect to the discrete metric. Then, $\mu_\pi(\succsim_0) > \mu_\pi(\succsim)$ for all $\succsim \in \mathcal{P}$.

Proof :
Assume that

$$\mu_\pi(\succsim_0) \leq \mu_\pi(\succsim) \text{ for some } \succsim \in \mathcal{P}. \tag{7}$$

We will show that π does not exhibit consensus of level $K!/2$ around $\succsim_0$. Consider a partition $\{C_0, C_1\}$ of $\mathcal{P} \setminus \{\succsim_0, \succsim\}$ into two subsets of equal cardinality, $K!/2-1$, and assume without loss of generality that $\mu_\pi(C_0) \leq \mu_\pi(C_1)$. Now let $C = C_0 \cup \{\succsim_0\}$ and $C' = C_1 \cup \{\succsim\}$. It follows from (7) that $\mu_\pi(C) \leq \mu_\pi(C')$. But according to the discrete metric, we have that $C >_{\succsim_0} C'$. If π exhibited consensus of level $K!/2$ around $\succsim_0$ we would have that $\mu_\pi(C) > \mu_\pi(C')$.

□

The following result is an immediate corollary of Claim 1 and Proposition 2.

Corollary 2 The mode rules are rationalizable.

5 Consensus and Scoring Rules

Sometimes one is not interested in the social preference relation but only in its maximal elements. In that case, instead of focusing on social welfare functions one should concentrate on social choice rules. A social choice rule assigns to each preference profile a set of chosen alternatives. Formally, a *social choice rule* is a function $g : \mathcal{P}^n \to 2^A$.

A special class of social choice rules consists of *scoring rules*, also known as positional voting rules. Each scoring rule is characterized by a list $S = \{S_1, S_2, \cdots, S_K\}$ of K non-negative scores with $S_1 \geq S_2 \geq \cdots \geq S_K$ and $S_1 > S_K$. Given a preference profile $\pi = (\succsim_1, \ldots, \succsim_n)$, each individual $i = 1, \ldots n$ assigns S_k points, for $k = 1, \ldots, K$, to the alternative that is ranked kth in his preference relation, $\succsim_i$. That is, each agent assigns S_1 points to his most preferred alternative, S_2 points to the second best alternative and so on. The scoring rule associated with the sores in S, denoted by V_S, chooses the alternatives with the maximum total score.

Many social choice rules are instances of scoring rules. For example, the *plurality* rule is the scoring rule associated with the scores $(1, 0, \ldots, 0)$. The *inverse plurality* rule is the scoring rule associated with $(1, \ldots 1, 0)$. More generally, for $1 \leq t \leq K - 1$, the *t-approval voting method*, denoted V_t, is the scoring rule associated with $S_t = (\underbrace{1, \ldots, 1}_{t}, \underbrace{0, \ldots, 0}_{K-t})$. Lastly, the Borda rule is the scoring rule associated with $S_B = (K - 1, K - 2, \ldots, 0)$.

The t approval voting rules, for $t = 1, \ldots, K - 1$, play a central role in the theory of scoring rules since any list of scores $S = \{S_1, S_2, \cdots, S_K\}$ can be written as a non-negative linear combination $S = \sum_{t=1}^{K-1} \alpha_t S_t$ of the $K - 1$ approval voting scores. Based on this fact, Saari [22] showed that if all approval voting methods choose alternative a, then this alternative is chosen by all the scoring methods. Formally, if $a \in V_t(\pi)$ for $t = 1, \ldots K - 1$ then $a \in V_S(\pi)$ for all scores S.[4]

The next theorem establishes that the existence of r consensus, for $r \leq (K - 1)!$, guarantees the invariance of the chosen alternative across all scoring rules.

Theorem 2 Suppose that $r \leq (K - 1)!$. Also, let $\pi \in \mathcal{P}^n$ be a preference profile, $\succsim_0 \in \mathcal{P}$ a preference relation, and $a \in A$ the alternative that is ranked first according to $\succsim_0$. If π

[4]Baharad and Nitzan [2] offer a condition that applies directly on preference profiles which guarantees the above scoring rule invariance.

exhibits consensus of level r around $\succsim_0 \in \mathcal{P}$ according to the inversion metric, then $a \in V_S$ for all scoring rules V_S.

Proof : Let S be a list of scores. Given that S can be written as a non-negative linear combination of the $K-1$ t-approval voting scores S_t, it is enough to show that $a \in V_t(\pi)$ for $t = 1, \dots K-1$.

Fix $t \in \{1, \dots, K-1\}$, and let $b \in A \setminus \{a\}$. Denote by $C(a \xrightarrow{t} b)$ the set of preference relations in $\mathcal{P}$ such that a ranks tth or above, and b ranks strictly below the tth place. Similarly, denote by $C(b \xrightarrow{t} a)$ the set of preference relations in $\mathcal{P}$ such that b ranks tth or above, and a ranks strictly below the tth place. Since $b \in A$ is a fixed but otherwise arbitrary alternative different from a, in order to show that $a \in V_t(\pi)$ we must show that $\mu_\pi(C(a \xrightarrow{t} b)) \geq \mu_\pi(C(b \xrightarrow{t} a))$. By definition, $C(a \xrightarrow{t} b) \cap C(b \xrightarrow{t} a) = \emptyset$. Furthermore, these two sets have equal cardinality, which we denote by c. Therefore, in order to show that $\mu_\pi(C(a \xrightarrow{t} b)) \geq \mu_\pi(C(b \xrightarrow{t} a))$ it is enough to show that π exhibits consensus of level c and that $C(a \xrightarrow{t} b)$ is closer than $C(b \xrightarrow{t} a)$ to $\succsim_0$.

Note that there are $\binom{K-2}{t-1}$ ways to partition the K alternatives into two subsets, one containing t alternatives, one being a, and the other containing $K-t$ alternatives, one of them being b. Therefore the cardinality of $C(a \xrightarrow{t} b)$ (and similarly of $C(b \xrightarrow{t} a)$) is

$$\begin{aligned} c &= \binom{K-2}{t-1} t!(K-t)! \\ &= \frac{(K-2)!}{(K-t-1)!(t-1)!} t!(K-t)! \\ &= (K-1)! \frac{t(K-t)}{K-1} \end{aligned}$$

But since $\frac{t(K-t)}{K-1} \geq 1$ if and only if $(t-1)(K-1-t) \geq 0$ and since $1 \leq t \leq K-1$ we have that $\frac{t(K-t)}{K-1} \geq 1$. Therefore $c \geq (K-1)! \geq r$. Consequently, since π exhibits consensus of level r, Proposition 1 implies that π exhibits consensus of level c as well.

In order to show that $C(a \xrightarrow{t} b) >_{\succsim_0} C(b \xrightarrow{t} a)$, let $M_i(a \xrightarrow{t} b)$, for each $i = 1, \dots, t$, be the set of preference relations such that alternative a is ranked ith and alternative b is ranked strictly below the tth place. Similarly, let $M_i(b \xrightarrow{t} a)$ be the set of preference relations such that alternative b is ranked ith and alternative a is ranked strictly below the tth place. Let $\phi : M_i(a \xrightarrow{t} b) \to M_i(b \xrightarrow{t} a)$ be the one-to-one function that maps each preference relation $\succsim \in M_i(a \xrightarrow{t} b)$ into the preference relation that is obtained from $\succsim$ by switching alternatives a and b in the preference ranking. Clearly, since a is ranked first in $\succsim_0$, we have that $d(\succsim, \succsim_0) < d(\phi(\succsim), \succsim_0)$ for all $\succsim \in M_i(a \xrightarrow{t} b)$. Noting that $C(a \xrightarrow{t} b) = \cup_{i=1}^{t} M_i(a \xrightarrow{t} b)$ and $C(b \xrightarrow{t} a) = \cup_{i=1}^{t} M_i(b \xrightarrow{t} a)$, we conclude that $C(a \xrightarrow{t} b) >_{\succsim_0} C(b \xrightarrow{t} a)$. □

For a given preference profile, different scoring rules may result in the selection of any of the K alternatives (see, for instance, Fishburn [8], Saari [20, 21, 24]). It is also possible that an alternative, and even a Condorcet winning alternative, will not be selected by any scoring rule (see, Fishburn [6, 7] and Saari [23]). These findings are balanced by the results of Baharad and Nitzan [2] and Saari [22] that specify necessary and sufficient conditions for the selection of the same alternative by all scoring rules. By Proposition 4, level r consensus is a sufficient condition for the selection of the same Condorcet winning alternative by all scoring rules.

We have seen in Example 3 that even if the majority rule yields a transitive preference relation and even if there is consensus of level $K!/2$ around it, a scoring rule may not select the Condorcet winner. The following result shows, however, that level r consensus for $r \leq (K-1)!$ is a sufficient condition for all scoring rules to be Condorcet consistent.

Corollary 3 Let $\succsim_0 \in \mathcal{P}$ be a preference relation and $a \in A$ the alternative that is ranked highest according to $\succsim_0$. If π exhibits consensus of level $r \leq (K-1)!$ around $\succsim_0 \in \mathcal{P}$ according to the inversion metric, then a is the unique Condorcet winner and it is chosen by all scoring rules.

Proof : By Theorem 2, a is chosen by all scoring rules. By Theorem 1, $\succsim_0$ coincides with the binary relation assigned by the majority rule to π. Therefore a is the Condorcet winner. □

We end with an example of a profile of heterogeneous preferences exhibiting consensus of level 1 and another one exhibiting consensus of level 2. In consonance with Corollary 3, all scoring rules, in particular the Borda rule, select in both cases the Condorcet winner.

Example 4 Let the set of alternatives be $A = \{a, b, c\}$ and let $N = \{1, 2, \ldots, 11\}$ be a set of eleven individuals. The preference profile is given by $\pi = (\succsim_1, \ldots, \succsim_{11})$ where

$$\begin{aligned}
\succsim_1 = \succsim_2 = \succsim_3 = \succsim_4 = \succsim_5 &= a, b, c \\
\succsim_6 = \succsim_7 &= a, c, b, \\
\succsim_8 = \succsim_9 &= b, a, c, \\
\succsim_{10} &= c, a, b \\
\succsim_{11} &= b, c, a
\end{aligned}$$

It can be checked that this profile exhibits consensus of level 1.
If we add a twelfth individual with a preference relation given by $\succsim_{12} = c, b, a$, then the resulting profile $(\succsim_1, \ldots, \succsim_{12})$ does not exhibit consensus of level 1. It does, however exhibit consensus of level 2. Consistent with Corollary 3, all scoring rules, in particular the Borda rule, select the Condorcet winning alternative a.

6 Concluding Remarks

In this paper we have proposed the concept of level r consensus and showed that its existence in its mildest form has significant implications. It ensures stability of one of the most extensively studied aggregation rules, namely the simple majority rule. Specifically, we show that under the inversion metric, when a preference profile exhibits level r consensus around a given preference relation, this preference relation is the one assigned by the majority rule to that profile which furthermore turns out to be transitive. The corresponding social choice function therefore selects the Condorcet winning alternative. Additionally, if the level of consensus is strong enough ($r \leq (K-1)!$), this chosen alternative is also the choice of all scoring rules. In other words, not only does the existence of r consensus ensure stability under simple majority, it also ensures the Condorcet consistency of all scoring rules. That is, it eliminates the tension between the simple majority rule and the scoring rules (in particular, the Borda rule). The existence of r consensus thus simultaneously resolves two of the major problems in social choice theory.

The two unanimity geared metric approaches mentioned in the introduction, the ones used in Farkas and Nitzan [5] and in Kemeny [11] respectively, are different from our level r consensus approach. Whereas the latter is based on a new preference domain restriction, the former two approaches do not impose any domain restriction; in fact one of their notable advantages is that they can be applied to any given preference profile. Interestingly, the simple majority rule is rationalized by the level r consensus approach, provided that one applies the inversion metric. This is in contrast to the outcome obtained under the two alternative metric approaches. Indeed, under the first one, for any given preference profile, the application of the inversion metric results in the rationalization of the Borda rule, and under the second one, the application of the inversion metric need not result in either the simple majority rule nor the Borda rule. However, as mentioned above, if a preference profile exhibits consensus of any level r, then there exists a Codorcet winner which is selected by Kemeny's rule (see Nurmi [18]), and if the consensus is sufficiently strong, the Borda rule is also Condorcet consistent.

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