Which Voting Rule Is More Manipulable? Results from Simulation Studies

Tobias Lindner MdB   Klaus Nehring   Clemens Puppe | Freudenstadt, 11 September 2011

KARLSRUHE INSTITUTE OF TECHNOLOGY, UNIVERSITY OF CALIFORNIA AT DAVIS

Manipulability of Voting Rules

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- A **voting rule** F on a set X of social states selects a (unique) $x \in X$ for every profile $(\succ^1, \succ^1, \ldots, \succ^n)$ of preferences over X.
- F is **strategy-proof** if $F(\succ^1, ..., \succ^i, ..., \succ^n) \succeq^i F(\succ^1, ..., \succ'^i, ..., \succ^n)$

Theorem (Gibbard-Satterthwaite)

If $\#X \geq 3$, then the only strategy-proof voting rule on an unrestricted preference domain is the dictatorship of one individual.

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The Median Voter Theorem

Theorem (Black 1942/58, Moulin 1980)

*Suppose that social states can be ordered from left to right such that all preferences are **single-peaked**, then there exist non-degenerate strategy-proof voting rules. E.g. choosing the median of the individual peaks defines an anonymous, neutral and strategy-proof voting rule.*

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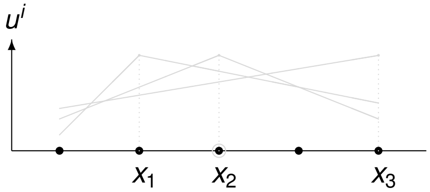

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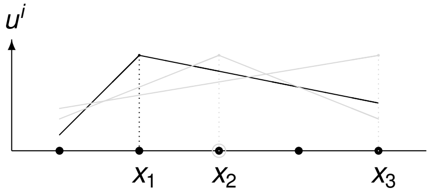

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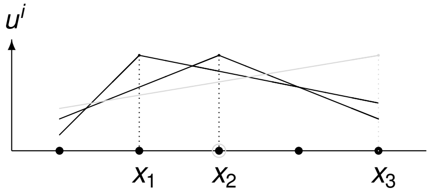

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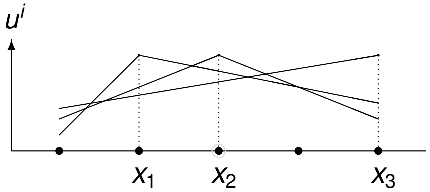

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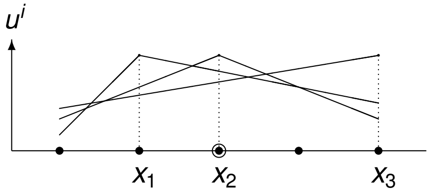

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- Nehring/Puppe (2007/2010) demonstrate the existence of non-dictatorial and strategy-proof voting rules for classes of generalized single-peaked preferences.
- Unfortunately, for many economically relevant domains all strategy-proof voting rules are dictatorial, even under generalized single-peakedness.

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- What happens in such domains?
- If all non-dictatorial voting rules are manipulable, which of those are **less** manipulable than others? (Throughout, we will assume that F respects **unanimity**: if all individuals happen to agree that x is best, then $F(...) = x$.)
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1. Voting on the Simplex
   - Peaks-Only Preference Aggregation
   - Voting Rules
2. Setting of the Simulation Studies
   - Basic Settings and Parameters
   - Variables Measuring Manipulability
3. Preliminary Results

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The (K,L)-Simplex

Definition ((K,L)-Simplex)

A **(K,L)-Simplex** is the set

$$X = \{x \in \mathbb{R}^K : \sum_{j=1}^{K} x_j = L, x_j \geq 0\}$$

Economic Applications:

- budget allocation problem where x_j is the money amount spent on (public) good j and L the total budget,
- aggregation of probability distributions ($L = 1$), where x_j is the probability of j

If $K \geq 3$, all strategy-proof voting rules on X are dictatorial, even under generalized single-peaked preferences (See Nehring and Puppe 2010).

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Peaks-Only Preference Aggregation

- Let $d(x, y) = \frac{1}{2} \sum_{j=1}^{K} |x_j - y_j|$ denote the **distance** between x and y, e.g. in the public goods context the number of dollars that have to be shifted to get from allocation x to y.
- We assume that an agent i has (generalized) single-peaked preferences on X (with respect to that distance) and submits a **proposal** $w^i \in X$ (the peak).
- Denote by $p(w)$ the number of agents who proposed w.

Definition (Voting Rule on the Simplex)

A **voting rule** on the simplex is a mapping

$$F(w^1, w^2, \ldots, w^n) = x \in X$$

which assigns to each profile of peaks $(w^1, w^2, \ldots, w^n)$ an element x in the simplex.

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The Midpoint Rule

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- A midpoint minimizes the sum of distances to every peak.

Definition (Midpoint)

An allocation $m(p) \in X$ is a **midpoint** if

$$m(p) = argmin_{x \in X} \sum_{w \in X} p_w d(x, w)$$

- Let $M(p)$ denote the set of midpoints. Evidently, $M(p)$ need not be a singleton but it is always non-empty.

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Natural single valued selection for Midpoint Rule: the "shadow voter selection". Give *every point* in the simplex in addition a mass of ϵ (shadow voter): $\tilde{p}(w) := \epsilon + p(w)$

Theorem

For $\lim_{\epsilon \to 0}$ *we have* $\widetilde{M}(p) \subseteq M(p)$ *and* $\left|\widetilde{M}(p)\right| = 1$*, i.e. a unique midpoint.*

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The possibility to influence the set of Midpoints is restricted.

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Under the midpoint rule, an agent cannot move the midpoint (metrically) closer to his/her own peak by misrepresentation.

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- This rule selects the mean of peaks:

Definition (Mean Rule)

$$F^{Mean}(w^1, w^2, \ldots, w^n) := (\bar{w}_1, \bar{w}_2, \ldots, \bar{w}_K)$$

where

$$\bar{w}_j = \frac{1}{n}\sum_{i=1}^{n} w_j^i$$

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- The “Normalized Median Rule” takes the coordinate wise median and normalizes it to the simplex:

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where w_j^{med} is the median of coordinate j and $c = \sum_{j=1}^{K} w_j^{med}$

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- The "Normalized Median Rule" takes the coordinate wise median and normalizes it to the simplex:

Definition (NMedian Rule)

$$F^{NMedian}(w^1, w^2, \ldots, w^n) := \left(\frac{w_1^{med}}{c} L, \frac{w_2^{med}}{c} L, \ldots, \frac{w_K^{med}}{c} L \right)$$

where w_j^{med} is the median of coordinate j and $c = \sum_{j=1}^{K} w_j^{med}$

The SeqMedian Rule

- The "Sequential Median Rule" takes the coordinate wise median and adjusts it to the simplex **in a fixed order**:

Example

Let $K = 3$, $L = 21$ and $w_1^{med} = 7$, $w_2^{med} = 10$, $w_3^{med} = 6$. Note that $\sum_{j=1}^{3} w_j^{med} > L$. The w_j^{med} are adjusted in ascending order $(1, 2, 3)$.

$$F^{SeqMedian}(7, 10, 6) = (7, 10, 4)$$

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Let $K = 3$, $L = 21$ and $w_1^{med} = 3$, $w_2^{med} = 4$, $w_3^{med} = 8$. Note that $\sum_{j=1}^{3} w_j^{med} < L$. The w_j^{med} are adjusted in ascending order $(1, 2, 3)$.

$$F^{SeqMedian}(3, 4, 8) = (3, 4, 14)$$

- Evidently, the SeqMedian Rule depends on the order of coordinates.

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- Peaks-Only Preference Aggregation
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- Basic Settings and Parameters
- Variables Measuring Manipulability

3 Preliminary Results

Basic Settings

- written in Java, using parallel computing
- $L = 1$, variation of K
- discretization of the simplex by a grid, e.g. $K = 3, L = 1$ by a $(3, 99)$-grid (voting over 5050 alternatives).

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1. The (true) peaks of the agents are drawn by a pseudorandom number generator
2. Agents are acting in a random order and determine their best responses (i.e. their utility maximizing announced peak) given the announced peaks of the other agents
3. Say that a voting situation *converges*, if no agent changes his or her announced peak after a finite number of manipulations
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Parameters of the Simulations

- K and grid size (normalized to $L = 1$)
- peak distribution: uniform, Dirichlet, bi-modal
- preferences of the agents: Cobb-Douglas, CES, “metric” single-peaked
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Extent of Manipulation

- number of agents manipulating
- number of pivotal agents
- number of manipulations
- maximum utility gain of an agent given the true peaks

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Effect of Manipulation

- distance between outcome under true peaks and outcome under announced peaks (after convergence)
- average deviation (of an agent) between true and announced peaks
- sum of utility gains/losses
- comparison of sum of utilities to utilitarian maximum and expected utility under random dictatorship
  - normalize an agent's utility such that $u^i\left(\vec{0}\right) := 0$ and $u^i\left(w^i\right) := 1$ and compute $s(x) := \sum_i^n u^i(x)$
  - scale $s(x)$ such that 1 is the utilitarian maximum and 0 the expectation under random dictatorship
  - **for later**: "utility loss" = loss in this scale

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- sample size 1000
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Extent of Manipulation

Table: number of agents = 5

	MANIPULATIONS	MAXUTILGAIN	PERCAGMANI
MEAN	12,11	7,41%	99,98%
MIDPOINT	16,19	1,94%	59,60%
NMEDIAN	2,4	0,38%	34,96%
SEQMEDIAN	2,46	0,74%	38,54%

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MEAN	53,09	1,87%	100,00%
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Table: number of agents = 5

	AVDEV	DISTANCE	UTLOSS
MEAN	39,28%	7,38%	1,60%
MIDPOINT	4,86%	4,51%	1,05%
NMEDIAN	1,93%	1,87%	1,05%
SEQMEDIAN	1,74%	4,18%	1,35%

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Table: number of agents = 45

	AVDEV	DISTANCE	UTLOSS
MEAN	43,09%	5,73%	1,02%
MIDPOINT	2,96%	0,88%	0,20%
NMEDIAN	0,07%	0,78%	0,40%
SEQMEDIAN	0,44%	1,40%	0,56%

Effect of Manipulation

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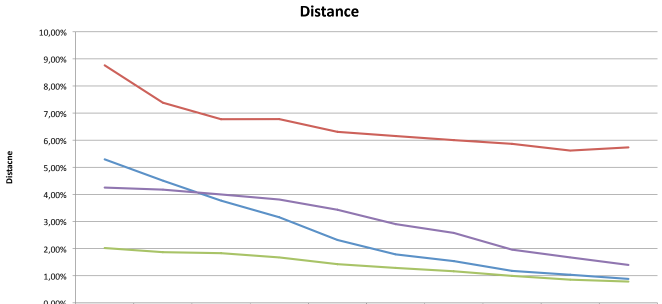

	3	5	7	9	13	17	21	29	37	45
Midpoint	5,29%	4,51%	3,77%	3,16%	2,32%	1,79%	1,54%	1,18%	1,03%	0,88%
Mean	8,76%	7,38%	6,77%	6,78%	6,31%	6,15%	6,00%	5,86%	5,62%	5,73%
NMedian	2,02%	1,87%	1,83%	1,67%	1,43%	1,29%	1,16%	0,99%	0,85%	0,78%
SeqMedian	4,25%	4,18%	4,00%	3,81%	3,43%	2,90%	2,58%	1,96%	1,68%	1,40%

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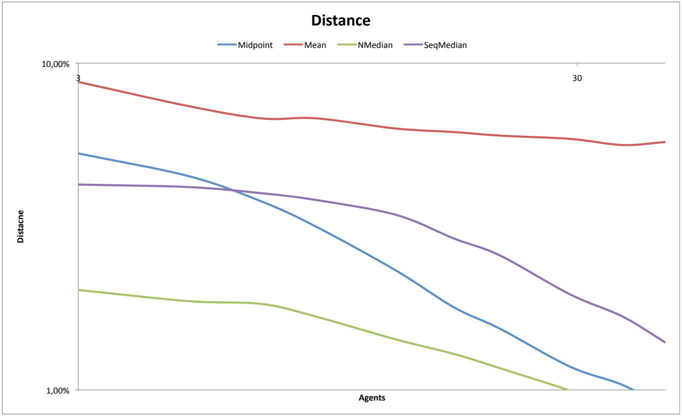

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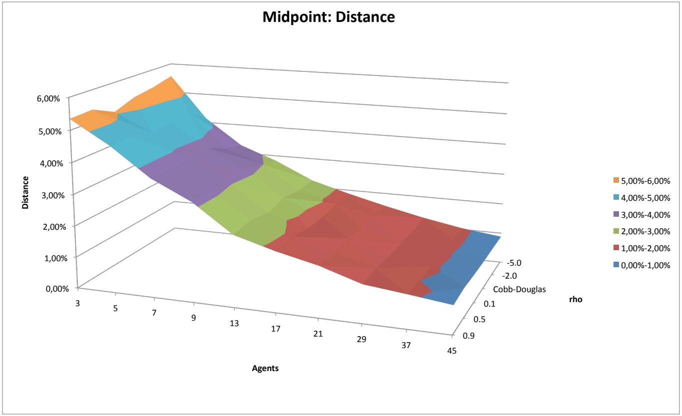

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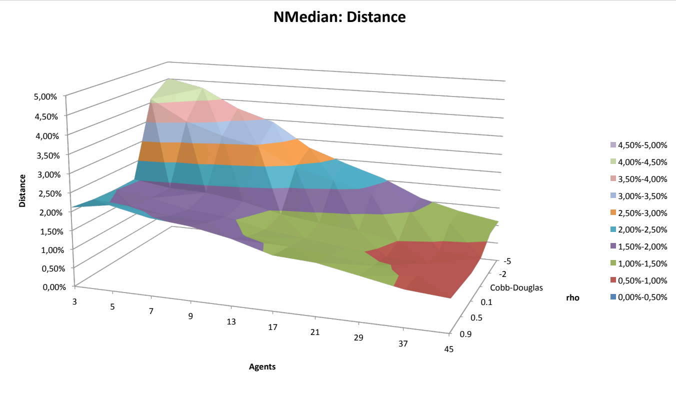

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- What are characteristics of manipulable profiles for different rules?
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