The role of information and voters' interaction in manipulation problem

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Introduction

- One of the problems with collective decision-making is that voters may submit insincere preferences, aiming to achieve a more preferable result or, in other words, manipulate an election.
- K. Arrow (Arrow, 1951) was the founder of an axiomatic approach to studying voting procedures proving that some set of reasonable properties of social choice rules is incompatible.
- The fundamental result in this direction is the Gibbard-Satterthwaite theorem, which states that every non-dictatorial social choice rule with at least three alternatives in its range, is vulnerable to individual manipulation (Gibbard, 1973; Satterthwaite, 1975, Gärdenfors, 1976).

Introduction

- Standard manipulation model:
  - individual manipulation
  - complete information
  - other voters are assumed to be non-strategic
- How an assumption about incomplete information and different assumptions about voters' reasoning influence manipulability?
- Axiomatic studies do not show how often axioms are satisfied or violated $\rightarrow$ statistical investigation

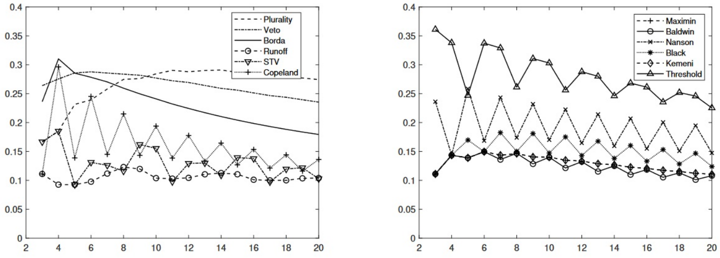
Introduction: models of reasoning

What does a voter take into account when deciding whether to manipulate?

- Non-strategic voters: vote sincerely
- GS-manipulators: choose a strategy that allows achieve a best result if others are non-strategic
- The concept of safe manipulation: individual manipulation, but withing a group (Slinko and White 2014, Peters and Veselova 2023)
- Extending the concept of safe manipulation: other voters can either manipulate or be non-strategic (Elkind et al. 2015, Grandi et al. 2019)
- Manipulators of k-th level of rationality: think about others as being of level $k-1$ (Nagel, 1995, Stahl and Wilson, 1994)
- Voters of k-th level of Cognitive hierarchy: other voters can be of any level of less than k (Camerer et al. 2004)

Standard model of manipulation

The standard model of manipulation: only one voter manipulates, knowing all other voters' preferences and not thinking about their strategic actions.



a) b)

The share of manipulable preference profile among $(m!)^n$ preference profiles with 3 alternatives and the number of voters from 3 to 20

Manipulation under incomplete information

There are 5 voters with preferences P_1, P_2,... P_5. Alternatives a, b, and c are ranked from the best (at the top) to the worst (at the bottom). Plurality rule is used.

P_1	P_2	P_3	P_4	P_5
a	b	c	c	c
b	a	a	a	a
c	c	b	b	b

Has voter 1 an incentive to misrepresent her preference in order to achieve a better voting result (manipulate)?

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P_1	P_2	P_3	P_4	P_5
a	?	?	?	?
b	?	?	?	?
c	?	?	?	?

$$F(\boldsymbol{P}) = c$$

Has voter 1 an incentive to misrepresent her preference in order to achieve a better voting result (manipulate)?

Manipulation under incomplete information

Public information is defined by Poll Information Function (PIF).

P_1	P_2	P_3	P_4	P_5
a	?	?	?	?
b	?	?	?	?
c	?	?	?	?

& $F(\boldsymbol{P}) = c$

⇩

P_1	P_2	P_3	P_4	P_5
a	c	c	c	c
b	a	a	a	a
c	b	b	b	b

P_1	P_2	P_3	P_4	P_5
a	b	b	c	c
b	a	a	a	a
c	c	c	b	b

P_1	P_2	P_3	P_4	P_5
a	a	b	c	c
b	b	a	a	a
c	c	c	b	b

P_1	P_2	P_3	P_4	P_5
a	a	c	c	c
b	b	a	a	a
c	c	b	b	b

$\cdots$

If there is an insincere preference order and at least one possible situation in which manipulation makes her better off and nothing changes in all other possible situations, then a voter has an incentive to manipulate under PIF.

Manipulation under incomplete information

Public information is defined by Poll Information Function (PIF).

P_1	P_2	P_3	P_4	P_5
a	?	?	?	?
b	?	?	?	?
c	?	?	?	?

& $F(\mathbf{P}) = c$

⇩

P_1	P_2	P_3	P_4	P_5
b	c	c	c	c
a	a	a	a	a
c	b	b	b	b

⇩ c

P_1	P_2	P_3	P_4	P_5
b	b	b	c	c
a	a	a	a	a
c	c	c	b	b

⇩ b

P_1	P_2	P_3	P_4	P_5
b	a	b	c	c
a	b	a	a	a
c	c	c	b	b

⇩ c

P_1	P_2	P_3	P_4	P_5
b	a	c	c	c
a	b	a	a	a
c	c	b	b	b

⇩ c

…

If there is an insincere preference order and at least one possible situation in which manipulation makes her better off and nothing changes in all other possible situations, then a voter has an incentive to manipulate under PIF.

Coalitional manipulation under incomplete information

In every possible situation there is a set of voter's coalition members

P_1	P_2	P_3	P_4	P_5
a	?	?	?	?
b	?	?	?	?
c	?	?	?	?

& $F(\mathbf{P}) = c$

⇩

P_1	P_2	P_3	P_4	P_5
a	c	c	c	c
b	a	a	a	a
c	b	b	b	b

P_1	P_2	P_3	P_4	P_5
a	b	b	c	c
b	a	a	a	a
c	c	c	b	b

P_1	P_2	P_3	P_4	P_5
a	a	b	c	c
b	b	a	a	a
c	c	c	b	b

P_1	P_2	P_3	P_4	P_5
a	a	c	c	c
b	b	a	a	a
c	c	b	b	b

...

A voter has an incentive to manipulate within a coalition if there is a chance of being better off provided that all her coalition members also use the same insincere preference.

Coalitional manipulation under incomplete information

In every possible situation there is a set of voter's coalition members

P_1	P_2	P_3	P_4	P_5
a	?	?	?	?
b	?	?	?	?
c	?	?	?	?

& $F(\mathbf{P}) = c$

⇩

P_1	P_2	P_3	P_4	P_5
b	c	c	c	c
a	a	a	a	a
c	b	b	b	b

⇩ c

P_1	P_2	P_3	P_4	P_5
b	b	b	c	c
a	a	a	a	a
c	c	c	b	b

⇩ b

P_1	P_2	P_3	P_4	P_5
b	b	b	c	c
a	a	a	a	a
c	c	c	b	b

⇩ b

P_1	P_2	P_3	P_4	P_5
b	b	c	c	c
a	a	a	a	a
c	c	b	b	b

⇩ c

…

A voter has an incentive to manipulate within a coalition if there is a chance of being better off provided that all her coalition members also use the same insincere preference.

Coalitional manipulation under incomplete information

In every possible situation there is a set of voter's coalition members

P_1	P_2	P_3	P_4	P_5
a	?	?	?	?
b	?	?	?	?
c	?	?	?	?

& $F(\mathbf{P}) = c$

If at least one voter has an incentive to manipulate, then a preference profile is called manipulable

Manipulablity is the share of manipulable preference profiles in the total number of preference profiles

⇩

P_1	P_2	P_3	P_4	P_5
b	c	c	c	c
a	a	a	a	a
c	b	b	b	b

⇩ c

P_1	P_2	P_3	P_4	P_5
b	b	b	c	c
a	a	a	a	a
c	c	c	b	b

⇩ b

P_1	P_2	P_3	P_4	P_5
b	b	b	c	c
a	a	a	a	a
c	c	c	b	b

⇩ b

P_1	P_2	P_3	P_4	P_5
b	b	c	c	c
a	a	a	a	a
c	c	b	b	b

⇩ c

...

A voter has an incentive to manipulate within a coalition if there is a chance of being better off provided that all her coalition members also use the same insincere preference.

Research questions

In (Veselova, 2023) the analysis of manipulation probability has three directions:

- Sudying the power of a coalition: coalitional manipulability is almost always higher than individual. However, if voters know only the winner after tie-breaking the probability of individual manipulation equals the probability of coalitional manipulation for scoring rules.
- Comparing manipulability of different social choice rules (we consider six popular rules which have polynomial complexity of calculating a winner: plurality rule, Borda rule, veto rule, runoff procedure, STV rule, and Copeland rule).
- Studying the role of information available to voters. How do different types of poll information affect coalitional manipulability?

Results

- We proved that the probability of coalitional manipulation for Plurality and Borda rule under information about winners of the election tends to 1 with the number of voters going to infinity.
- 'The less information is available - the higher is manipulability' hold for all rules under consideration except veto.

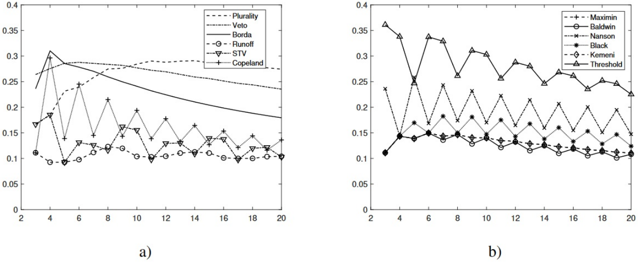

Рис.: The probability of individual manipulation for 3 alternatives depending on the number of voters (complete information)

Results

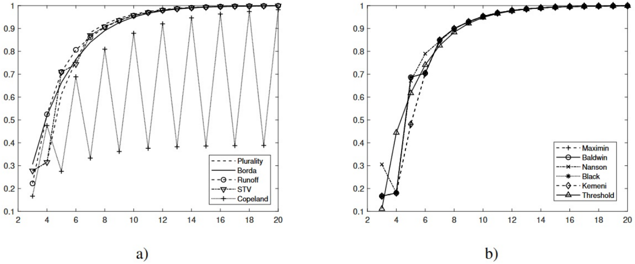

Рис.: The probability of individual/coalitional manipulation for 3 alternatives depending on the number of voters with information about a winner after tie-breaking (1Winner PIF)

The safety of manipulation

- Groups of voters have more opportunities to influence the voting result than single individuals.
- Generally, voters could unite into coalitions and coordinate their actions to manipulate.
- In case communication between voters is restricted it is natural to assume that voters expect other like-minded people to act as they do.

The safety of manipulation

A voter has an incentive to manipulate within a coalition, if there is an insincere preference such that, if all voters in this group report this preference, then the election result is better for them according to the true, sincere preference.

P_1	P_2	P_3	P_4	P_5	P_6	P_7
a	a	a	d	d	d	e
b	b	b	c	c	c	d
c	c	c	b	b	e	a
e	e	e	e	e	a	c
d	d	d	a	a	b	b

S(a)=15, S(b)=13, S(c)=16, S(d)=15, S(e)=11
c wins

P_1	P_2	P_3	P_4	P_5	P_6	P_7
b	b	b	d	d	d	e
a	a	a	c	c	c	d
e	e	e	b	b	e	a
c	c	c	e	e	a	c
d	d	d	a	a	b	b

S(a)=12, S(b)=16, S(c)=13, S(d)=15, S(e)=14
b wins

The safety of manipulation

A manipulation is safe if it never results in a worse alternative if not all members of the group join in the manipulation.

P_1	P_2	P_3	P_4	P_5	P_6	P_7
b	a	a	d	d	d	e
a	b	b	c	c	c	d
e	c	c	b	b	e	a
c	e	e	e	e	a	c
d	d	d	a	a	b	b

S(a)=14, S(b)=14, S(c)=15, S(d)=15, S(e)=12
d wins

The rule F is safely manipulable if there is a safely manipulable preference profile, and unsafely manipulable (UM) if there is an unsafely manipulable preference profile. Rule F is only safely manipulable (OSM) if it is not UM.

The safety of manipulation: results

- We consider scoring rules, runoff procedure, STV, and Copeland rule.
- For each rule we find certain conditions on the number of voters and alternatives allowing for unsafe manipulations.
  - Plurality and veto rule are only safely manipulable
  - For Borda rule an unsafely manipulable preference profile exists when there are at least 5 alternatives
  - Runoff, STV and Copeland rule are OSM for 3 alternatives
- It is proved that if a rule is manipulable within a coalition, then it is also safely manipulable.

Safe manipulation: relation with Slinko and White (2014)

The concept of safe manipulation of Slinko and White (2014)
For a rule F and a preference profile P, according to SW a voter i with group K has an incentive to manipulate if there is a preference $P \in L(X)$ and a set GK with $i \in G$ such that $F(P_G, P_{-G})P_iF(P)$.
Corollary 1 (Peters, Veselova, 2023) If a rule is safely (unsafely) manipulable for some m and n, then is is also safely (unsafely) manipulable according to SW.
Theorem 5 (Peters, Veselova, 2023) If a rule is manipulable, then it is also safely manipulable in our model.

Simultaneous manipulation under incomplete information

- Manipulability of individual manipulation under incomplete information is high (recall results of Part 1)
- What changes if voters take into account other voters' actions (not only of their type)? Does manipulation strategy still work with simultaneous manipulation of others?

Simultaneous manipulation under incomplete information

We consider and compare 3 models of voters' expectations (Working paper: Veselova, Karabekyan, 2023)

- Model 1: a basic model of "naive"behavior, every voter thinks that others do not manipulate
- Model 2: every voter takes into account that all other voters who have an incentive to manipulate will also manipulate
- Model 3: every voter takes into account that some other potential manipulators will also manipulate

Simultaneous manipulation under incomplete information

- We computed the probability of manipulation for three alternatives, the number of voters from 3 to 20, 12 social choice rules, 4 types of PIF and 3 models of voters' behavior.
- We showed that in combination with uncertainty about other voters' actions decreasing informativeness decreases manipulability
- We showed how zero probability of manipulation is inherited between models of voters' behavior and for different PIFs with a fixed model.
- We proved that for Model 2 for any given number of alternatives for any scoring rule the probability of manipulation becomes 0 when the number of voters exceeds a certain value.

Computations
Model 2

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Plurality	0,00	0,10	0,12	0,14	0,26	0,28	0,25	0,33	0,33	0,30	0,37	0,36	0,34	0,39	0,37	0,36	0,40	0,38
Veto	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Borda	0,22	0,31	0,15	0,15	0,16	0,17	0,19	0,20	0,22	0,23	0,24	0,25	0,26	0,27	0,27	0,28	0,28	0,29
Run-off	0,22	0,38	0,71	0,70	0,65	0,59	0,55	0,59	0,25	0,50	0,35	0,20	0,30	0,26	0,00	0,24	0,00	0,00
STV	0,00	0,10	0,71	0,29	0,00	0,60	0,28	0,14	0,00	0,38	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Copeland	0,06	0,37	0,00	0,29	0,00	0,32	0,00	0,35	0,00	0,36	0,00	0,38	0,00	0,38	0,00	0,39	0,00	0,39
Maximin	0,06	0,22	0,02	0,13	0,44	0,12	0,21	0,09	0,24	0,00	0,27	0,00	0,28	0,00	0,30	0,00	0,31	0,00
Baldwin	0,06	0,22	0,64	0,13	0,17	0,42	0,00	0,09	0,00	0,08	0,00	0,08	0,00	0,08	0,00	0,07	0,00	0,07
Nanson	0,22	0,22	0,25	0,25	0,00	0,21	0,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Black	0,06	0,22	0,64	0,13	0,00	0,32	0,00	0,45	0,00	0,17	0,00	0,16	0,00	0,15	0,00	0,07	0,00	0,07
Kemeny	0,06	0,22	0,02	0,13	0,44	0,12	0,21	0,09	0,24	0,00	0,27	0,00	0,28	0,00	0,30	0,00	0,31	0,00
Threshold	0,06	0,22	0,32	0,14	0,19	0,18	0,23	0,25	0,24	0,27	0,29	0,28	0,30	0,31	0,30	0,32	0,32	0,31

$$I^{M2}(3, n, Winner, F)$$

Computations
Model 2

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Plurality	0,00	0,15	0,00	0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Veto	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Borda	0,31	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Run-off	0,22	0,52	0,71	0,71	0,65	0,32	0,55	0,45	0,25	0,26	0,35	0,00	0,30	0,00	0,00	0,00	0,00	0,00
STV	0,00	0,15	0,71	0,29	0,00	0,62	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Copeland	0,17	0,21	0,00	0,15	0,00	0,20	0,00	0,23	0,00	0,26	0,00	0,28	0,00	0,29	0,00	0,30	0,00	0,31
Maximin	0,17	0,18	0,21	0,57	0,26	0,63	0,00	0,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Baldwin	0,17	0,18	0,43	0,57	0,17	0,50	0,00	0,24	0,00	0,26	0,00	0,28	0,00	0,00	0,00	0,00	0,00	0,00
Nanson	0,31	0,18	0,00	0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Black	0,17	0,18	0,43	0,57	0,00	0,63	0,00	0,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Kemeny	0,17	0,18	0,21	0,57	0,26	0,63	0,00	0,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Threshold	0,11	0,44	0,62	0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

$$I^{M2}(3, n, 1Winner, F)$$

Computations
Model 3

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Plurality	0,00	0,00	0,02	0,03	0,02	0,03	0,04	0,03	0,04	0,04	0,03	0,04	0,04	0,03	0,03	0,03	0,03	0,03
Veto	0,00	0,01	0,02	0,03	0,03	0,05	0,06	0,07	0,08	0,09	0,09	0,10	0,11	0,11	0,12	0,12	0,13	0,13
Borda	0,00	0,00	0,01	0,03	0,03	0,05	0,05	0,06	0,06	0,07	0,07	0,07	0,07	0,07	0,08	0,08	0,08	0,08
Run-off	0,00	0,00	0,00	0,00	0,01	0,03	0,02	0,01	0,01	0,02	0,02	0,03	0,02	0,02	0,02	0,02	0,03	0,04
STV	0,00	0,00	0,00	0,00	0,01	0,00	0,04	0,07	0,00	0,02	0,05	0,02	0,04	0,07	0,01	0,03	0,05	0,03
Copeland	0,00	0,00	0,00	0,03	0,00	0,04	0,00	0,04	0,00	0,04	0,01	0,03	0,01	0,03	0,01	0,03	0,01	0,03
Maximin	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Baldwin	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,01	0,01	0,02	0,01	0,02	0,01	0,02	0,02
Nanson	0,00	0,00	0,01	0,01	0,08	0,02	0,12	0,04	0,14	0,06	0,16	0,08	0,16	0,09	0,17	0,09	0,17	0,10
Black	0,00	0,00	0,01	0,00	0,02	0,00	0,03	0,01	0,04	0,01	0,04	0,02	0,05	0,02	0,05	0,03	0,06	0,03
Kemeny	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Threshold	0,00	0,02	0,00	0,06	0,05	0,03	0,11	0,07	0,05	0,11	0,09	0,08	0,12	0,11	0,10	0,13	0,12	0,12

$$I^{M2}(3, n, Profile, F) - I^{M3}(3, n, Profile, F)$$

Computations
Model 3

	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Plurality	0,00	0,15	0,00	0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Veto	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Borda	0,31	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Run-off	0,22	0,52	0,71	0,57	0,37	0,32	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
STV	0,00	0,15	0,71	0,29	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Copeland	0,17	0,21	0,00	0,15	0,00	0,20	0,00	0,23	0,00	0,26	0,00	0,28	0,00	0,29	0,00	0,30	0,00	0,31
Maximin	0,17	0,18	0,21	0,57	0,26	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Baldwin	0,17	0,18	0,43	0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Nanson	0,31	0,18	0,00	0,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Black	0,17	0,18	0,43	0,57	0,00	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Kemeny	0,17	0,18	0,21	0,57	0,26	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Threshold	0,11	0,44	0,62	0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

$$I^{M3}(3, n, 1Winner, F)$$

Theoretical results

- **Proposition 3** (Working paper: Veselova, Karabekyan, 2023) Suppose, π' is at least as informative as π''. Then for any $M \in \{M1, M2, M3\}$, for any rule F, number of voters n, and number of alternatives m if $I^M(m, n, F, \pi') = 0$, then $I^M(m, n, F, \pi'') = 0$.
- **Theorem 1** (Working paper: Veselova, Karabekyan, 2023) For any scoring rule F and any number of alternatives m there is a finite number of voters n^*, such that for all $n > n^*$ it holds $I^{M2}(m, n, F, 1Winner) = 0$

Model 2 и Model 3 in terms of cognitive hierarchy models

- Manipulation in Model 2 = "does a naive strategy work for a level-2 manipulator under PIF π?"
- Manipulation in Model 3 = "does a naive strategy work for a level-2 Cognitive hierarchy voter under π?"
- $I^{M2}(m, n, F, \pi)$, $I^{M3}(m, n, F, \pi)$ - the share of preference profiles for which manipulation with naive strategy works
- Does there exist any strategy for level-2 CH voters??

The number of profiles manipulable by level-2 CH voters under 1Winner PIF

	3	4	5	6	7	8	9	10	11	12	13	14	15
Plurality	0,00	0,15	0,00	0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Veto	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Borda	0,43	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Run-off	0,22	0,64	0,71	0,57	0,37	0,12	0,00	0,00	0,00	0,00	0,00	0,00	0,00
STV	0,00	0,15	0,71	0,39	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Copeland	0,44	0,36	0,60	0,29	0,64	0,31	0,66	0,32	0,67	0,32	0,68	0,32	0,68

Conclusion

- The study allows to get a better understanding of vulnerability or non-vulnerability of social choice rules to manipulation.
- We argue that information available to voters and their view of other voters' behavior are the crucial aspects that affect individual manipulation incentives.
- The result of the comparison of rules and the choice of the best one is highly dependent on the model's assumptions and framework.

Thank you!