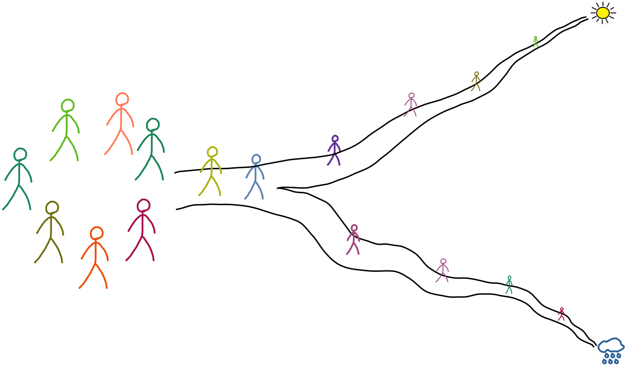
Public Projects with Preferences and Predictions

or, "Mixing Auctions and Futarchy"[1]



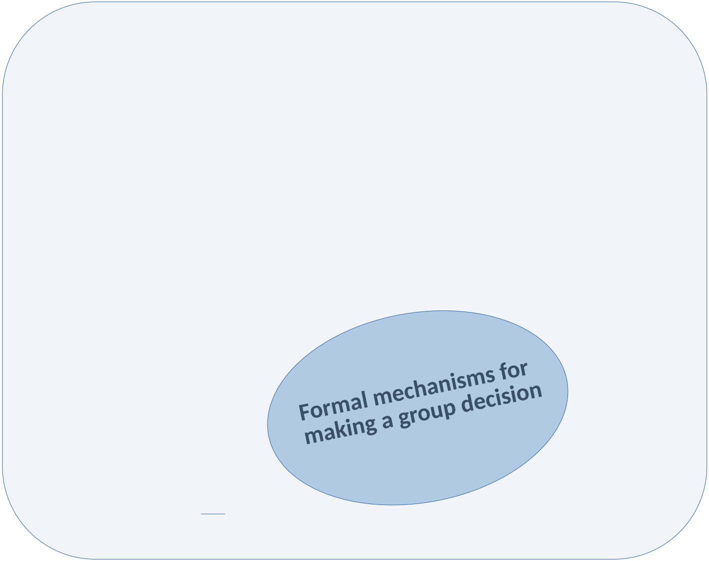
Bo Waggoner
University of Colorado, Boulder

Edge Esmeralda
June 19, 2024

[1] Based on joint work with Mary Monroe. Supported by the Ethereum Foundation.

Intro and background

Governance



Governance

- single-shot
- well-defined rules
- environment may be low-trust

Formal mechanisms for making a group decision

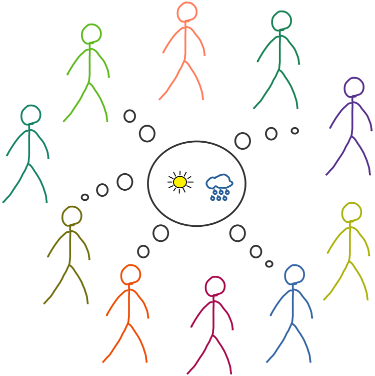
Formal mechanisms for making a group decision

Two paradigms for decision making:

- Information aggregation
- Preference aggregation

Information aggregation

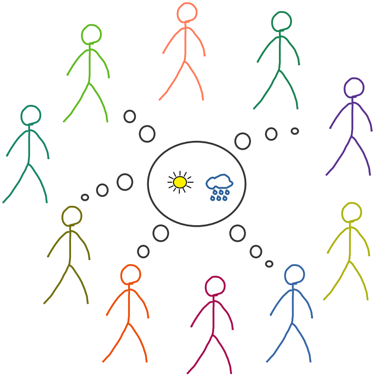
Information aggregation: discussion, consensus, . . .



Information aggregation

Information aggregation: discussion, consensus, . . .

Common aggregation mechanisms: *separate from decisionmaking*
prediction markets, wagering mechanisms, forecasting competitions, . . .



Decisions based on information

Decisions based on information

Decision markets:[2]

- We all want to maximize V, some number to be measured one year from now

[2] Hanson (1999); Othman and Sandholm (2010)

Decisions based on information

Decision markets:[2]

- We all want to maximize V, some number to be measured one year from now
- Run a prediction market for $V_{\text{yes}} :=$ "V if we adopt the proposal"

[2] Hanson (1999); Othman and Sandholm (2010)

Decisions based on information

Decision markets:[2]

- We all want to maximize V, some number to be measured one year from now
- Run a prediction market for $V_{\text{yes}} :=$ "V if we adopt the proposal"
- Simultaneously run a prediction market for V_{no}

[2] Hanson (1999); Othman and Sandholm (2010)

Decisions based on information

Decision markets:[2]

- We all want to maximize V, some number to be measured one year from now
- Run a prediction market for $V_{\text{yes}} :=$ "V if we adopt the proposal"
- Simultaneously run a prediction market for V_{no}
- If $V_{\text{yes}} > V_{\text{no}}$, adopt the proposal
  - Cancel all trades in the "no" market
  - In one year, resolve the "yes" market and pay out

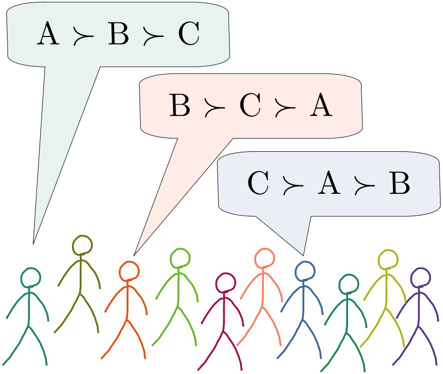
[2] Hanson (1999); Othman and Sandholm (2010)

Decisions based on preferences

Decisions based on preferences

Two paradigms for preference aggregation:

- Ranked-choice voting (normative, axiomatic) *not a focus today*
- Mechanism design (utilitarian)



Preferences: mechanism design

Example: second-price auction. *decide who gets an item*

Preferences: mechanism design

Example: second-price auction. *decide who gets an item*

Assume: each person attaches a number ("utility") to each outcome; try to maximize sum of utilities.

Preferences: mechanism design

Example: second-price auction. *decide who gets an item*

Assume: each person attaches a number ("utility") to each outcome; try to maximize sum of utilities.

Generally assume: utility is interchangeable with money ("quasilinear utility").

Preferences: mechanism design

Example: second-price auction. *decide who gets an item*

Assume: each person attaches a number ("utility") to each outcome; try to maximize sum of utilities.

Generally assume: utility is interchangeable with money ("quasilinear utility").

General example: VCG mechanism.
"Pick the welfare-maximizing choice; charge each person their externality on everyone else."

Mixing paradigms

Can mechanisms aggregate preferences and information?

Mixing paradigms

Can mechanisms aggregate preferences and information?

- Hanson (2000; 2007): Futarchy
  - Vote on a measure of outcomes (i.e. oracle)
  - Run a decision market

Mixing paradigms

Can mechanisms aggregate preferences and information?

- Hanson (2000; 2007): Futarchy
  - Vote on a measure of outcomes (i.e. oracle)
  - Run a decision market

- Schoenebeck and Tao (2021)
  - Hidden state of the world (e.g. proposal is a good/bad idea)
  - Participants have a private signal i.i.d. conditioned on state
  - Participants have a private preference (always adopt, always reject, contingent)
  - Run a "wisdom of the crowd" poll, aggregate and select

Mixing paradigms

Can mechanisms aggregate preferences and information?

- Hanson (2000; 2007): Futarchy
  - Vote on a measure of outcomes (i.e. oracle)
  - Run a decision market
- Schoenebeck and Tao (2021)
  - Hidden state of the world (e.g. proposal is a good/bad idea)
  - Participants have a private signal i.i.d. conditioned on state
  - Participants have a private preference (always adopt, always reject, contingent)
  - Run a "wisdom of the crowd" poll, aggregate and select
- Amanatidis, Birmpas, Lazos, and Marmolejo-Cossío (2022)
  - Motivated by deciding on blockchain protocol updates
  - Experts have beliefs about probability of success of proposal
  - Experts may have ulterior motives
  - Analyzes weighted approval voting

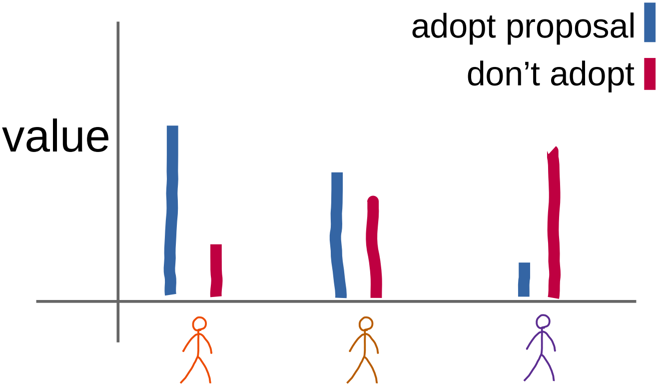
Public Projects with Preferences and Predictions

Mary Monroe and Bo Waggoner, CU Boulder
https://arxiv.org/abs/2403.01042

Public projects

Public projects

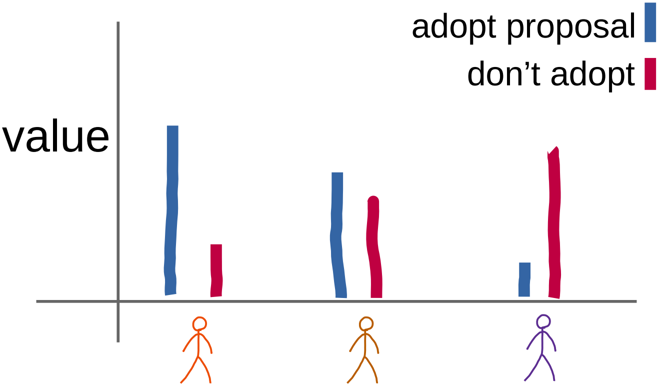
Model: each agent i has a value v_k^i for each option k



Public projects

Model: each agent i has a value v_k^i for each option k

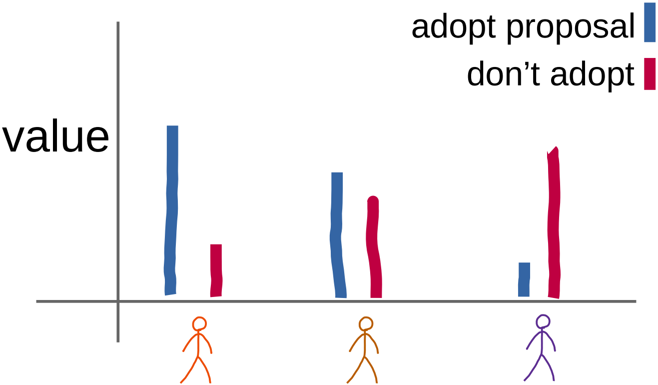
- Welfare of option k: $V_k = \sum_{i=1}^{n} v_k^i$



Public projects

Model: each agent i has a value v_k^i for each option k

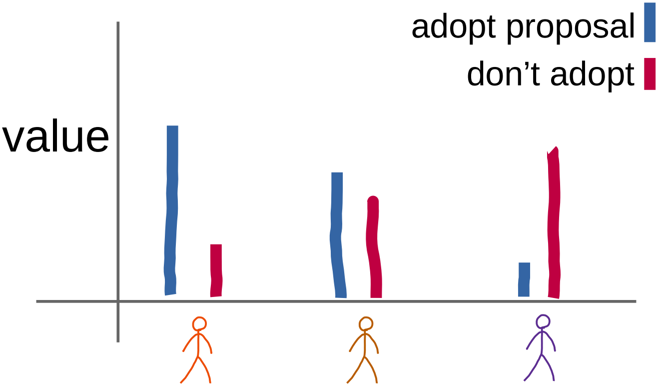
- Welfare of option k: $V_k = \sum_{i=1}^{n} v_k^i$
- Mechanism: collect reports, pick an alternative k^*, assign payments



Public projects

Model: each agent i has a value v_k^i for each option k

- Welfare of option k: $V_k = \sum_{i=1}^{n} v_k^i$
- Mechanism: collect reports, pick an alternative k^*, assign payments
- Net utility of agent i: $v_{k^*}^i -$ payment *quasilinear*



Public projects

Model: each agent i has a value v_k^i for each option k

- Welfare of option k: $V_k = \sum_{i=1}^{n} v_k^i$
- Mechanism: collect reports, pick an alternative k^*, assign payments
- Net utility of agent i: $v_{k^*}^i -$ payment *quasilinear*

$$\textbf{Price of Anarchy} = \frac{\mathbb{E}[V_{k^*}]}{\max_k V_k}$$

in the worst-case equilibrium

Public projects: solutions

- **VCG mechanism:** Price of Anarchy $= 0$ *but PoStability* $= 1$

Public projects: solutions

- **VCG mechanism:** Price of Anarchy $= 0$ *but PoStability* $= 1$

Public projects: solutions

- **VCG mechanism:** Price of Anarchy $= 0$ *but PoStability* $= 1$
- **All-pay auction:** Price of Anarchy $\geq 1 - \frac{1}{e} \approx 0.632$

Public projects: solutions

- **VCG mechanism:** Price of Anarchy $= 0$ *but PoStability* $= 1$
- **All-pay auction:** Price of Anarchy $\geq 1 - \frac{1}{e} \approx 0.632$

[3] Eguia, Immorlica, Ligett, Weyl, Xefteris (2019; 2023).

Public projects: solutions

- **VCG mechanism:** Price of Anarchy $= 0$ *but PoStability* $= 1$
- **All-pay auction:** Price of Anarchy $\geq 1 - \frac{1}{e} \approx 0.632$
- **Quadratic Transfers Mechanism:**[3] Price of Anarchy $\to 1$

[3] Eguia, Immorlica, Ligett, Weyl, Xefteris (2019; 2023).

Public projects: solutions

- **VCG mechanism:** Price of Anarchy $= 0$ *but PoStability* $= 1$
- **All-pay auction:** Price of Anarchy $\geq 1 - \frac{1}{e} \approx 0.632$
- **Quadratic Transfers Mechanism:**[3] Price of Anarchy $\to 1$

[3] Eguia, Immorlica, Ligett, Weyl, Xefteris (2019; 2023).

Public projects: solutions

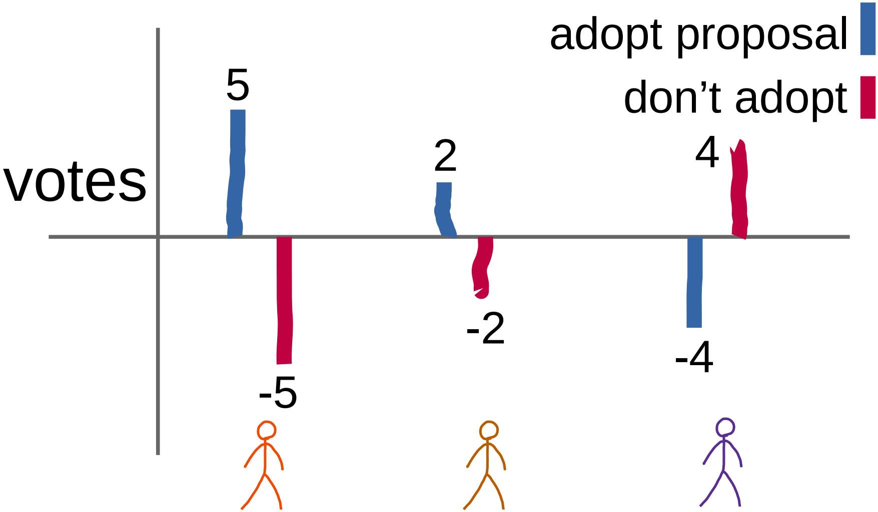
- **VCG mechanism:** Price of Anarchy $= 0$ *but PoStability* $= 1$
- **All-pay auction:** Price of Anarchy $\geq 1 - \frac{1}{e} \approx 0.632$
- **Quadratic Transfers Mechanism:**[3] Price of Anarchy $\to 1$

QTM: agent i submits votes a_k^i for or against each option k; pays $\sum_k (a_k^i)^2$; mechanism picks $k^* \sim \mathbf{p}$ randomly where

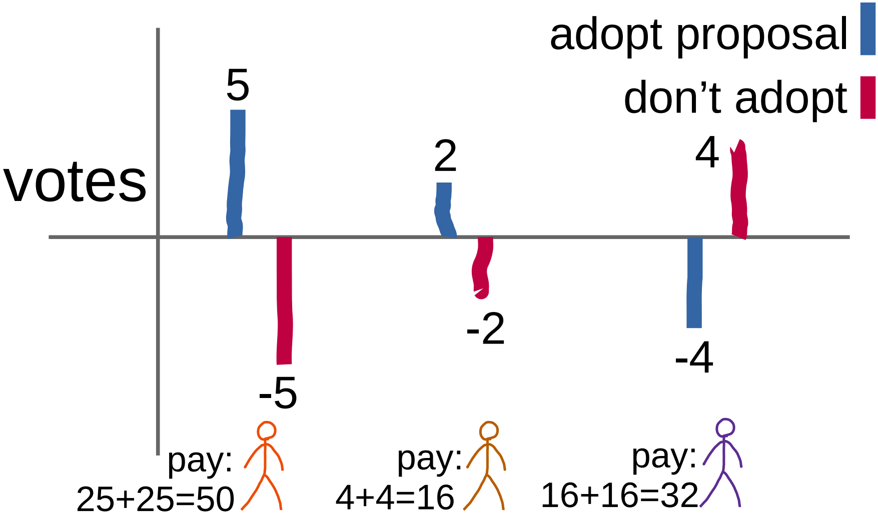
$$p_k = \frac{e^{A_k}}{e^{A_1} + \cdots + e^{A_m}}.$$

[3] Eguia, Immorlica, Ligett, Weyl, Xefteris (2019; 2023).

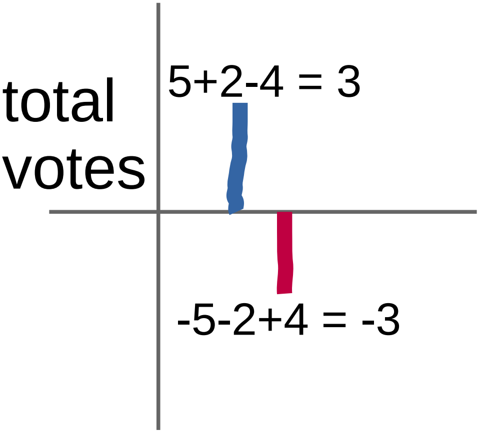
QTM: example



QTM: example


adopt proposal
don't adopt
votes
5
-5
2
-2
4
-4
pay:
25+25=50
pay:
4+4=16
pay:
16+16=32

QTM: example



adopt proposal

don't adopt

$$p_1 = \frac{e^3}{e^3 + e^{-3}} \approx 99.75\,\%$$

$$p_2 = \frac{e^{-3}}{e^3 + e^{-3}} \approx 0.25\,\%$$

With predictions

Goal: incorporate **information aggregation** to group decisionmaking.

With predictions

Goal: incorporate **information aggregation** to group decisionmaking.

Model: for each alternative k,

- it has an unknown *external welfare impact* B_k;
- participant i has a self-interested value v_k^i, as before.

With predictions

Goal: incorporate **information aggregation** to group decisionmaking.

Model: for each alternative k,

- it has an unknown *external welfare impact* B_k;
- participant i has a self-interested value v_k^i, as before.

Welfare of option k: $W_k = V_k + B_k$.

With predictions

Goal: incorporate **information aggregation** to group decisionmaking.

Model: for each alternative k,

- it has an unknown *external welfare impact* B_k;
- participant i has a self-interested value v_k^i, as before.

Welfare of option k: $W_k = V_k + B_k$.

Challenges:

- Want to elicit accurate information about $\{B_k\}$ ...
- ... but voters may wish to manipulate the information aggregation

With predictions

Goal: incorporate **information aggregation** to group decisionmaking.

Model: for each alternative k,

- it has an unknown *external welfare impact* B_k;
- participant i has a self-interested value v_k^i, as before.

Challenges:

- Want to elicit accurate information about $\{B_k\}$ ...
- ...but voters may wish to manipulate the information aggregation
- ...and predictors may wish to manipulate the decision

With predictions

Goal: incorporate **information aggregation** to group decisionmaking.

Model: for each alternative k,

- it has an unknown *external welfare impact* B_k;
- participant i has a self-interested value v_k^i, as before.

Synthetic-Players Quadratic Transfer Mechanism with Predictions (SQUAP):

With predictions

Goal: incorporate **information aggregation** to group decisionmaking.

Model: for each alternative k,

- it has an unknown *external welfare impact* B_k;
- participant i has a self-interested value v_k^i, as before.

Synthetic-Players Quadratic Transfer Mechanism with Predictions (SQUAP):

1. Run prediction markets to estimate the future impact of each alternative
2. Based on the markets, estimate $B_1, \ldots, B_k$
3. Run QTM with "synthetic players" whose values are $B_1, \ldots, B_k$
   synthetic players make no payments
4. Cancel/resolve prediction markets, as with decision markets.
   Use importance-weighted payoff of Chen et. al (2011)

Results and complications

Theorem

For 2 outcomes, SQUAP achieves a Price of Anarchy $\geq 1 - \frac{2\sqrt{\epsilon}}{T} - \left(\frac{4}{T}\right)^{2/5}$

In other words, Price of Anarchy $\to 1$ as the total possible welfare grows relative to the largest participant value.

Results and complications

Theorem

For 2 outcomes, SQUAP achieves a Price of Anarchy $\geq 1 - \frac{2\sqrt{\epsilon}}{T} - \left(\frac{4}{T}\right)^{2/5}$
where the market liquidity parameter is at most $\epsilon \cdot v_{\max}$, $T = W_{\max}/v_{\max}$, QTM payments are scaled by $\frac{1}{2}v_{\max}$, and $v_{\max} = \max_{i,k} v_k^i$.
In other words, Price of Anarchy $\to 1$ as the total possible welfare grows relative to the largest participant value.

Results and complications

Theorem

For 2 outcomes, SQUAP achieves a Price of Anarchy $\geq 1 - \frac{2\sqrt{\epsilon}}{T} - \left(\frac{4}{T}\right)^{2/5}$
where the market liquidity parameter is at most $\epsilon \cdot v_{\max}$, $T = W_{\max}/v_{\max}$, QTM payments are scaled by $\frac{1}{2}v_{\max}$, and $v_{\max} = \max_{i,k} v_k^i$.
In other words, Price of Anarchy $\to 1$ *as the total possible welfare grows relative to the largest participant value.*

Problem: you can't implement SQUAP.

Results and complications

Theorem

For 2 outcomes, SQUAP achieves a Price of Anarchy $\geq 1 - \frac{2\sqrt{\epsilon}}{T} - \left(\frac{4}{T}\right)^{2/5}$

where the market liquidity parameter is at most $\epsilon \cdot v_{\max}$, $T = W_{\max}/v_{\max}$, QTM payments are scaled by $\frac{1}{2}v_{\max}$, and $v_{\max} = \max_{i,k} v_k^i$.

In other words, Price of Anarchy $\to 1$ *as the total possible welfare grows relative to the largest participant value.*

Problem: you can't implement SQUAP. Need to compute the equilibrium.

Results and complications

Theorem

For 2 outcomes, SQUAP achieves a Price of Anarchy $\geq 1 - \frac{2\sqrt{\epsilon}}{T} - \left(\frac{4}{T}\right)^{2/5}$
where the market liquidity parameter is at most $\epsilon \cdot v_{\max}$, $T = W_{\max}/v_{\max}$, QTM payments are scaled by $\frac{1}{2}v_{\max}$, and $v_{\max} = \max_{i,k} v_k^i$.
In other words, Price of Anarchy $\to 1$ as the total possible welfare grows relative to the largest participant value.

Problem: you can't implement SQUAP. Need to compute the equilibrium.

Proposed solution: use the mechanism

$$p_1 = \frac{e^{A_1 + \frac{p_1 p_2}{v_{\max}}(B_1 - B_2)}}{e^{A_1 + \frac{p_1 p_2}{v_{\max}}(B_1 - B_2)} + e^{A_2 + \frac{p_1 p_2}{v_{\max}}(B_2 - B_1)}}.$$

Results and complications

Theorem

For 2 outcomes, SQUAP achieves a Price of Anarchy $\geq 1 - \frac{2\sqrt{\epsilon}}{T} - \left(\frac{4}{T}\right)^{2/5}$
where the market liquidity parameter is at most $\epsilon \cdot v_{\max}$, $T = W_{\max}/v_{\max}$, QTM payments are scaled by $\frac{1}{2}v_{\max}$, and $v_{\max} = \max_{i,k} v_k^i$.
In other words, Price of Anarchy $\rightarrow 1$ *as the total possible welfare grows relative to the largest participant value.*

Problem: you can't implement SQUAP. Need to compute the equilibrium.

Proposed solution: use the mechanism

$$p_1 = \frac{e^{A_1 + \frac{p_1 p_2}{v_{\max}}(B_1 - B_2)}}{e^{A_1 + \frac{p_1 p_2}{v_{\max}}(B_1 - B_2)} + e^{A_2 + \frac{p_1 p_2}{v_{\max}}(B_2 - B_1)}}.$$

Problem: difficult to analyze (involves fixed-point computation).

SQUAP - comments

What's difficult/cool about the theorem:

- Voters cannot benefit from manipulating the market predictions.
  under an efficient market hypothesis

SQUAP - comments

What's difficult/cool about the theorem:

- Voters cannot benefit from manipulating the market predictions.
  under an efficient market hypothesis
- Predictors cannot benefit by manipulating/casting extra votes.
  Decision markets must use importance-wtd payoff of Chen et al. (2011)

SQUAP - comments

What's difficult/cool about the theorem:

- Voters cannot benefit from manipulating the market predictions.
  under an efficient market hypothesis

- Predictors cannot benefit by manipulating/casting extra votes.
  Decision markets must use importance-wtd payoff of Chen et al. (2011)

- Payments from the voting stage can fund payouts for the prediction market stage.
  need "disagreement" in voting stage

SQUAP - comments

What's difficult/cool about the theorem:

- Voters cannot benefit from manipulating the market predictions.
  under an efficient market hypothesis
- Predictors cannot benefit by manipulating/casting extra votes.
  Decision markets must use importance-wtd payoff of Chen et al. (2011)
- Payments from the voting stage can fund payouts for the prediction market stage.
  need "disagreement" in voting stage

Future work: analyze the above proposed fix (fixed-point).

Discussion

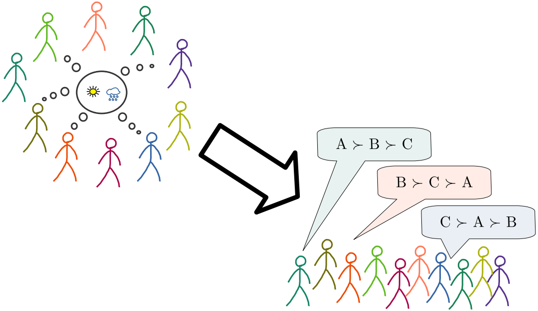
(I) Information aggregation and preferences

In our model: Voters had *fixed* preferences.

(I) Information aggregation and preferences

In our model: Voters had *fixed* preferences.

Ideal model: voters adjust preferences in response to aggregated information.

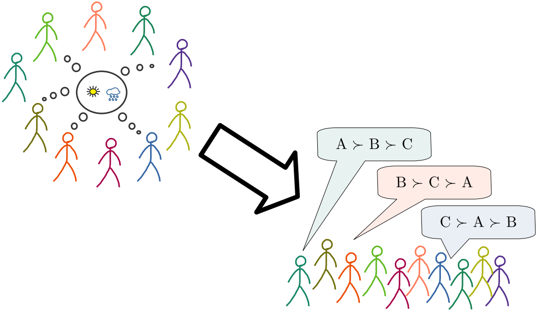


(I) Information aggregation and preferences

In our model: Voters had *fixed* preferences.

Ideal model: voters adjust preferences in response to aggregated information.

Challenge: market manipulation $\implies$ misled voters $\implies$ swing in the outcome.



(II) External welfare impacts

What are the *external welfare impacts* $B_1, \ldots, B_m$?

(II) External welfare impacts

What are the *external welfare impacts* $B_1, \ldots, B_m$?

- Externalities of decision on non-voting parties

(II) External welfare impacts

What are the *external welfare impacts* $B_1, \ldots, B_m$?

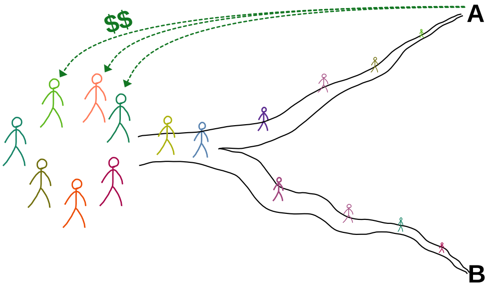
- Externalities of decision on non-voting parties
- Component of mission statement of the organization

(II) External welfare impacts

What are the *external welfare impacts* $B_1, \ldots, B_m$?

- Externalities of decision on non-voting parties
- Component of mission statement of the organization

Key governance question: **how can an organization avoid capture?**



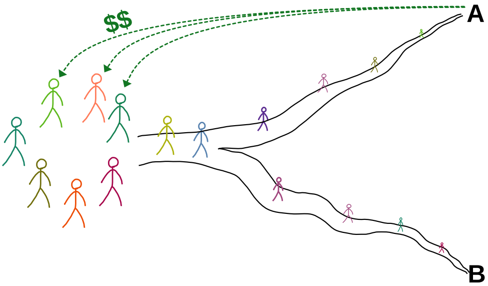
(II) External welfare impacts

What are the *external welfare impacts* $B_1, \ldots, B_m$?

- Externalities of decision on non-voting parties
- Component of mission statement of the organization

Key governance question: **how can an organization avoid capture?**

Potential answer: decide based on preferences (of members) *and* predictions (about the mission).



End

Summary:

- Decisions aggregate both preferences and information
- Proposed SQUAP, combining prediction markets and quadratic voting
- Proved Price of Anarchy bounds (under impractical assumptions)

End

Summary:

- Decisions aggregate both preferences and information
- Proposed SQUAP, combining prediction markets and quadratic voting
- Proved Price of Anarchy bounds (under impractical assumptions)

Open:

- Analysis of "practical SQUAP"
- Better synthesis of information and preference aggregation
- Role of such mechanisms in a governance structure
- Can organizations avoid capture?

End

Summary:

- Decisions aggregate both preferences and information
- Proposed SQUAP, combining prediction markets and quadratic voting
- Proved Price of Anarchy bounds (under impractical assumptions)

Open:

- Analysis of “practical SQUAP”
- Better synthesis of information and preference aggregation
- Role of such mechanisms in a governance structure
- Can organizations avoid capture?

Thanks!