Strictly Proper Decision Markets

A reminder about Problem set 2

- Due in 8 days
- Project proposals are due less than a week after
- Literature review is an opportunity to get a head start on the proposal and projects

What is a Decision Market?

- It’s a lot like a prediction market

Discuss: Why do we speculate?

- What are we running prediction markets for?

History: Hanson writes an article

To me, the most sensible pivotal principles are at the meta level — they are about how exactly we should aggregate info on the efficiency, and other consequences, of policies. For example, I think decision markets can go a long way toward giving us better info on the effects of policies. I also think we should do a lot more randomized policy experiments. And I support more and better cost benefit analyses, though it is admittedly hard for ordinary voters to evaluate their objectivity.

Hanson’s decision markets

Hanson’s decision markets

Possible Policies

Quantitative Easing

Helicopter Money

No stimulus

Adopting NDGP

Hanson's decision markets

Possible Policies	**Effect on GDP**
Quantitative Easing	
Helicopter Money	
No stimulus	
Adopting NDGP	

Hanson's decision markets

Possible Policies	**Effect on GDP**
Quantitative Easing	
Helicopter Money	?
No stimulus	
Adopting NDGP	

Hanson's decision markets

Possible Policies	**Effect on GDP**
Quantitative Easing	
Helicopter Money	?
No stimulus	
Adopting NDGP	

Run a prediction market!

Hanson's decision markets

Possible Policies	Effect on GDP
Quantitative Easing	+.3%
Helicopter Money	+.9%
No stimulus	-.8%
Adopting NDGP	+1.7%

Hanson's decision markets

Possible Policies	Effect on GDP
Quantitative Easing	+.3%
Helicopter Money	+.9%
No stimulus	-.8%
Adopting NDGP	+1.7%

Hanson's decision markets

Possible Policies	**Effect on GDP**
Quantitative Easing	+.3% (?)
Helicopter Money	+.9%(+1.5%)
No stimulus	-.8% (?)
Adopting NDGP	+1.7% (+1.1%)

Philosophy: Markets with agency

Art's vocation is to unveil the *truth* in the form of sensuous artistic configuration, to set forth the reconciled opposition just mentioned [the common world of earthly temporality, and a realm of thought and freedom], and so to have its end and aim in itself, in this very setting forth and unveiling.

Hegel

Philosophy: Markets with agency

If Hegel had written the whole of his logic and then said, in the preface or some other place, that it was merely an experiment in thought in which he had even begged the question in many places, then he would certainly have been the greatest thinker who had ever lived. As it is, he is merely comic.

Kierkegaard

Philosophy: Markets with agency

You love the accidental. A smile from a pretty girl in an interesting situation, a stolen glance, that is what you are hunting for, that is a motif for your aimless fantasy. You who always pride yourself on being an observateur must, in return, put up with becoming an object of observation.

Kierkegaard

Philosophy: Markets with agency

And thus the native hue of resolution
Is sicklied o'er with the pale cast of thought;
And enterprises of great pith and moment,
With this regard, their currents turn awry,
And lose the name of action.

Hamlet

Markets where actions matter

- Othman and Sandholm
  - Single expert decision making
- Chen and Kash
  - Single expert decision making (generally)
- Shi, Conitzer, Guo
  - Principal-aligned scoring rules
- Boutilier
  - Self-interested experts

Modeling Decision Markets

Modeling Decision Markets

- A decision maker considers
- A set of possible actions, A
  - E.g. up, down, invest in project A, hire person B, implement policy X, travel to Istanbul, etc.
- A set of outcomes of interest, O
  - Will we see a profit? Will public welfare increase? Will I eat some kebab?
- And wants to learn the mapping from actions (A) to outcomes (O) to make an informed decision

Modeling Decision Markets

		Outcomes $\mathcal{O}$	
		Profit	Loss
Actions $\mathcal{A}$	Springfield	$\frac{2}{3}$	$\frac{1}{3}$
	Greenville	$\frac{2}{5}$	$\frac{3}{5}$

Step 1: Elicit action-outcome matrices

Discuss: What are other examples?

- And what drawbacks / possibilities are there for each one?

Modeling Decision Markets

		Outcomes $\mathcal{O}$	
		Profit	Loss
Actions $\mathcal{A}$	Springfield	$\frac{2}{3}$	$\frac{1}{3}$
	Greenville	$\frac{2}{5}$	$\frac{3}{5}$

Step 2: Create a decision policy

Modeling Decision Markets

		Outcomes $\mathcal{O}$	
		Profit	Loss
Actions $\mathcal{A}$	Springfield	$\frac{2}{3}$	$\frac{1}{3}$
	Greenville	$\frac{2}{5}$	$\frac{3}{5}$

Review market's closing prediction

Step 2: Create a decision policy

Modeling Decision Markets

Create probability distribution over the actions

Actions $\mathcal{A}$

80%
20%

Outcomes $\mathcal{O}$

	Profit	Loss
Springfield	$\frac{2}{3}$	$\frac{1}{3}$
Greenville	$\frac{2}{5}$	$\frac{3}{5}$

Review market's closing prediction

decision rule d

Step 2: Create a decision policy

Modeling Decision Markets

			Outcomes $\mathcal{O}$	
			Profit	Loss
Actions $\mathcal{A}$	80%	Springfield	$\frac{2}{3}$	$\frac{1}{3}$
	20%	Greenville	$\frac{2}{5}$	$\frac{3}{5}$

Step 3: Pick an action

Modeling Decision Markets

Actions $\mathcal{A}$

Outcomes $\mathcal{O}$

	Profit	Loss
Springfield	$\frac{2}{3}$	$\frac{1}{3}$

Step 4: Observe the outcome

Modeling Decision Markets

$$s : \mathcal{A} \times \mathcal{O} \times \Delta(\mathcal{A}) \times \mathcal{P} \to \mathbb{R} \cup \{-\infty\}$$

Step 5: Score experts

Modeling Decision Markets

Actions (Springfield)

Action-Outcome matrix

$$s : \mathcal{A} \times \mathcal{O} \times \Delta(\mathcal{A}) \times \mathcal{P} \rightarrow \mathbb{R} \cup \{-\infty\}$$

Decision policy (.8, .2)

Outcomes (Profit)

Step 5: Score experts

Modeling Decision Markets

decision scoring rule

$$s : \mathcal{A} \times \mathcal{O} \times \Delta(\mathcal{A}) \times \mathcal{P} \to \mathbb{R} \cup \{-\infty\}$$

scoring rule

$$s : \Delta(\mathcal{O}) \times \mathcal{O} \to \mathbb{R} \cup \{-\infty\}$$

Discuss: why is strict properness important?

- Because it totally is.

Strict Properness *for an expert*

$$\{Q\} = \arg\max_{P \in \mathcal{P}} \sum_{a,o} d_a(P) Q_{a,o} s_{a,o}(d(P), P), \ \forall Q \in \mathcal{P}$$

Strict Properness *for an expert*

$$\{Q\} = \arg\max_{P \in \mathcal{P}} \boxed{\sum_{a,o} d_a(P) Q_{a,o} s_{a,o}(d(P), P)}, \ \forall Q \in \mathcal{P}$$

Strict Properness *for an expert*

expected score

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how likely action a is to be taken given your report p (remember, only one expert so first report is the last report)

Strict Properness *for an expert*

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your belief in the likelihood of outcome o given action a is taken

how likely action a is to be taken given your report p (remember, only one expert so first report is the last report)

Strict Properness *for an expert*

expected score

$$\{Q\} = \arg\max_{P \in \mathcal{P}} \boxed{\sum_{a,o} d_a(P) Q_{a,o} s_{a,o}(d(P), P)}, \ \forall Q \in \mathcal{P}$$

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Strict Properness *for an expert*

expected score

$$\{Q\} = \arg\max_{P \in \mathcal{P}} \boxed{\sum_{a,o} d_a(P) Q_{a,o} s_{a,o}(d(P), P)}, \ \forall Q \in \mathcal{P}$$

score for your prediction given this action and outcome

your belief in the likelihood of outcome o given action a is taken

how likely action a is to be taken given your report p (remember, only one expert so first report is the last report)

Strict Properness *for an expert*

$$\{Q\} = \arg\max_{P \in \mathcal{P}} \sum_{a,o} d_a(P) Q_{a,o} s_{a,o}(d(P), P), \ \forall Q \in \mathcal{P}$$

The *unique* score maximizing prediction is always your true beliefs.

Strict Properness *for a market*

Discuss: why are markets different?

- How many people are in a market? Not one but…

Strict Properness *for a market*

$$\sum_{a,o} \mathbf{d}_a Q_{a,o}\big(s_{a,o}(\mathbf{d}, Q) - s_{a,o}(\mathbf{d}, P')\big) \geq \sum_{a,o} \mathbf{d'}_a Q_{a,o}\big(s_{a,o}(\mathbf{d'}, P) - s_{a,o}(\mathbf{d'}), P')\big),$$

$$\forall Q, P, P' \in \mathcal{P}, \mathbf{d}, \mathbf{d'} \in d(\cdot)$$

Strict Properness *for a market*

$$\sum_{a,o} \mathbf{d}_a Q_{a,o}\big(s_{a,o}(\mathbf{d}, Q) - s_{a,o}(\mathbf{d}, P')\big) \geq \sum_{a,o} \mathbf{d}'_a Q_{a,o}\big(s_{a,o}(\mathbf{d}', P) - s_{a,o}(\mathbf{d}'), P')\big),$$

$$\forall Q, P, P' \in \mathcal{P}, \mathbf{d}, \mathbf{d}' \in d(\cdot)$$

decision policy now arbitrary

Strict Properness *for a market*

$$\sum_{a,o} \mathbf{d}_a Q_{a,o}\big(s_{a,o}(\mathbf{d}, P) - s_{a,o}(\mathbf{d}, P')\big)$$

Strict Properness *for a market*

$$\sum_{a,o} \mathbf{d}_a Q_{a,o}\big(s_{a,o}(\mathbf{d}, P) - s_{a,o}(\mathbf{d}, P')\big)$$

expected score

Strict Properness *for a market*

$$\sum_{a,o} \mathbf{d}_a Q_{a,o}\big(s_{a,o}(\mathbf{d}, P) - \boxed{s_{a,o}(\mathbf{d}, P')}\big)$$

expected score

Strict Properness *for a market*

$$\sum_{a,o} \mathbf{d}_a Q_{a,o}\big(s_{a,o}(\mathbf{d}, P) - \boxed{s_{a,o}(\mathbf{d}, P')}\big)$$

expected score

in a prediction market this term is constant

in a decision market it depends on d, the decision policy, which depends on…

Strictly Proper Pair

Definition 3.5 (*Strictly Proper Pair*). A pair (d, s) is strictly proper if and only if a prediction's expected score is independent of the decision policy

$$\sum_{a,o} \mathbf{d}_a Q_{a,o} s_{a,o}(\mathbf{d}, P) = \sum_{a,o} \mathbf{d}'_a Q_{a,o} s_{a,o}(\mathbf{d}', P), \ \forall Q, P \in \mathcal{P}, \mathbf{d}, \mathbf{d}' \in d(\cdot) \tag{1}$$

and uniquely maximized when an expert predicts its beliefs

$$\{Q\} = \arg\max_{P \in \mathcal{P}} \sum_{a,o} \mathbf{d}_a Q_{a,o} s_{a,o}(\mathbf{d}, P), \ \forall Q \in \mathcal{P}, \mathbf{d} \in d(\cdot) \tag{2}$$

Strictly Proper Pair

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$$\sum_{a,o} \mathbf{d}_a Q_{a,o} s_{a,o}(\mathbf{d}, P) = \sum_{a,o} \mathbf{d}'_a Q_{a,o} s_{a,o}(\mathbf{d}', P), \ \forall Q, P \in \mathcal{P}, \mathbf{d}, \mathbf{d}' \in d(\cdot) \tag{1}$$

and uniquely maximized when an expert predicts its beliefs

$$\{Q\} = \arg\max_{P \in \mathcal{P}} \sum_{a,o} \mathbf{d}_a Q_{a,o} s_{a,o}(\mathbf{d}, P), \ \forall Q \in \mathcal{P}, \mathbf{d} \in d(\cdot) \tag{2}$$

strict properness *for an expert*

makes prior prediction constant

Strictly Proper Pair

PROPOSITION 3.6. *Every strictly proper pair (d, s) is strictly proper for both an expert and a market.*

PROPOSITION 3.7. *For every pair $(d, \bar{s})$ that is strictly proper* for a market, *there exists a strictly proper pair (d, s) such that every prediction has the same expected net score*

$$\sum_{a,o} \mathbf{d}_a Q_{a,o}\big(\bar{s}_{a,o}(\mathbf{d}, P) - \bar{s}_{a,o}(\mathbf{d}, P')\big) \;=\; \sum_{a,o} \mathbf{d}_a Q_{a,o}\big(s_{a,o}(\mathbf{d}, P) - s_{a,o}(\mathbf{d}, P')\big),$$

$$\forall Q, P, P' \in \mathcal{P}, \mathbf{d} \in d(\cdot)$$

Strict Properness Summary

- Different constraints for a single expert and many experts in a market
- A strictly proper pair is strictly proper for both
- These describe all of strictly proper *for a market* pairs (minus some uninteresting basically the same set)
- But not quite all of strict properness *for an expert*

Strictly Proper Decision Markets

Randomly taking any action is necessary

THEOREM 4.1 (FULL SUPPORT IS NECESSARY FOR A STRICTLY PROPER PAIR). *If a pair* (d, s) *is strictly proper,* d *has full support.*

Randomly taking any action is necessary

THEOREM 4.1 (FULL SUPPORT IS NECESSARY FOR A STRICTLY PROPER PAIR). *If a pair (d, s) is strictly proper, d has full support.*

PROOF. Assume, for a contradiction, that d is a decision rule without full support and s is a decision scoring rule such that (d, s) is strictly proper. Let P^* be a prediction such that $d_{a'}(P^*) = 0$ for some action a', which must exist by our assumption that d does not have full support, and let Q and Q' be two action-outcome matrices differing only on action a'. Then we have

$$\begin{aligned} &\sum_{a,o} d_a(P^*) Q_{a,o}\big(s_{a,o}(d(P^*), P) - s_{a,o}(d(P^*), \bar{P})\big) \\ = &\sum_{a,o} d_a(P^*) Q'_{a,o}\big(s_{a,o}(d(P^*), P) - s_{a,o}(d(P^*), \bar{P})\big), \ \forall P, \bar{P} \in \mathcal{P} \end{aligned}$$

implying the same prediction maximizes the expected value of an expert who believes Q or Q', and since this prediction cannot be both Q and Q' at the same time, the pair (d, s) violates Equation (2) and so must not be strictly proper, a contradiction as desired. □

Randomly taking any action is sufficient

$$s_{a,o}(\mathbf{d}, P) = \frac{1}{\mathbf{d}_a} \bar{s}_o(P_a)$$

Randomly taking any action is sufficient

$$s_{a,o}(\mathbf{d}, P) = \frac{1}{\mathbf{d}_a} \bar{s}_o(P_a)$$

take a strictly proper scoring rule

Randomly taking any action is sufficient

2. divide by the inverse likelihood the action is taken

$$s_{a,o}(\mathbf{d}, P) = \frac{1}{\mathbf{d}_a} \bar{s}_o(P_a)$$

1. take a strictly proper scoring rule

Randomly taking any action is sufficient

2. divide by the inverse likelihood the action is taken

$$s_{a,o}(\mathbf{d}, P) = \frac{1}{\mathbf{d}_a} \bar{s}_o(P_a)$$

3. gives the same expected value as many strictly proper prediction markets

1. take a strictly proper scoring rule

$$\sum_{a,o} \mathbf{d}_a Q_{a,o} \left(\frac{1}{\mathbf{d}_a} \bar{s}_o(P_a) \right) = \sum_{a,o} Q_{a,o} \bar{s}_o(P_a)$$

Example

			Outcomes $\mathcal{O}$	
			Profit	Loss
Actions $\mathcal{A}$	80%	Springfield	$\frac{2}{3}$	$\frac{1}{3}$
	20%	Greenville	$\frac{2}{5}$	$\frac{3}{5}$

Example

	Outcomes $\mathcal{O}$	
	Profit	Loss
Actions $\mathcal{A}$		
Springfield	$\frac{2}{3}$	$\frac{1}{3}$
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expected score using log scoring rule for *two prediction markets*

$$(2/3 \log 2/3 + 1/3 \log 1/3)$$
$$+ (2/5 \log 2/5 + 3/5 \log 3/5)$$

Example

			Outcomes $\mathcal{O}$	
			Profit	Loss
Actions $\mathcal{A}$	80%	Springfield	$\frac{2}{3}$	$\frac{1}{3}$
	20%	Greenville	$\frac{2}{5}$	$\frac{3}{5}$

expected score using log scoring rule

$$.8(2/3 \log 2/3 + 1/3 \log 1/3)$$
$$+ .2(2/5 \log 2/5 + 3/5 \log 3/5)$$

Example

			Outcomes $\mathcal{O}$	
			Profit	Loss
Actions $\mathcal{A}$	80%	Springfield	$\frac{2}{3}$	$\frac{1}{3}$
	20%	Greenville	$\frac{2}{5}$	$\frac{3}{5}$

expected score using (**unbiased**) log scoring rule

$$.8/.8(2/3 \log 2/3 + 1/3 \log 1/3)$$
$$+ .2/.2(2/5 \log 2/5 + 3/5 \log 3/5)$$

Characterization

THEOREM 4.2 (STRICTLY PROPER PAIR CHARACTERIZATION). *A pair (d, s) is strictly proper if and only if d has full support and there exists a strictly convex function g such that*

$$s_{a,o}(\mathbf{d}, P) = g(P) - g^{\star}(P) : P + \frac{g^{\star}_{a,o}(P)}{\mathbf{d}_a} \tag{4}$$

Discuss: where does this leave us?

- Are these markets practical/credible?

With a single expert

Where the first prediction is also the last

Hypothetical

- I am a firm and I want to open a store in a city that maximizes my profit.
- I will open a store in whatever city you say.
- I will pay you 1% of my eventual profit.

Hypothetical

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Right-action rule (RAR)

Decision Markets With Good Incentives

Yiling Chen, Ian Kash, Mike Ruberry and Victor Shnayder
Harvard University

ASK PROFESSOR SCIENCE

Today's letter comes from T-Rex. "Oh no!" he writes, "I have to make a decision and am uncertain of the consequences!"

Since you need to predict the future, T-Rex, why not use a prediction market? They can predict the weather or who will be the next president!

That sounds good, but how does it work?

In a prediction market, a set of experts make a series of predictions over some set of outcomes, like whether it's sunny, cloudy or rainy on a particular day.

tomorrow's weather!	start	expert 1	expert 2	expert 3	...
sunny	33%	↑ 42%	↑ 65%	↓ 60%	...
cloudy	33%	↓ 30%	↓ 20%	= 20%	...
rainy	33%	↓ 28%	↓ 15%	↑ 20%	...

Experts attempt to correct past predictions, and are scored by how well they improve the accuracy of the market using strictly proper scoring rules, like the logarithmic scoring rule. These rules mean experts expect to maximize their score by predicting what they really believe! If we let outcomes be a set O and an expert believes q, then for any other prediction p

$$\sum_{o \in O} q_o \log(q_o) > \sum_{o \in O} q_o \log(p_o).$$

And experts are paid for improving the market's accuracy, so they get the difference of their and the last expert's score. Expert 2, for example, expects to be paid

$$\sum_{o \in O} q_o [\log(p_o^2) - \log(p_o^1)].$$

terror stomping

This is great, I'll just run a prediction market to decide what to do. Tell me, oh market, what is more awesome, ballooning or terror stomping?

But wait, T-Rex! That's not how prediction markets work. A prediction market requires you actually observe what you ask people to predict, and you can't go both ballooning and terror stomping, you can only pick one. Look at this example:

ballooning

		current	beliefs	profitable lie
terror stomping	awesome?	30%	60%	60%
ballooning	awesome?	80%	80%	40%

Since you pick the more awesome action, only that market will be scored. When you pick ballooning an expert with the above beliefs will make no money if they're honest, but if they convince you to pick terror stomping you'll reward them!

But that's the less awesome option!

Exactly, but you'll never know that! Experts have an incentive to be accurate, not to help you get what you want.

Damn, experts!

Instead, you need to run a decision market. Running two prediction markets means you have to do both things, but a decision market knows you can only do one. It reviews the market and assigns a probability to each action, then uses a decision scoring rule to normalize experts' scores.

Prediction Market	**Probability Action Taken**	**Expected Score**
terror stomping	1	$\log(p_b)$
ballooning	1	$\log(p_s)$

Decision Market	**Probability Action Taken**	**Expected Score**
terror stomping	d_s	$\frac{1}{d_s} d_s \log(p_s) = \log(p_s)$
ballooning	$d_b = 1 - d_s$	$\frac{1}{d_b} d_b \log(p_b) = \log(p_b)$

Great! So experts' expected scores are the same as in a set of prediction markets. Finally a way to make decisions! But wait, this means I might have to take an un-awesome action because those probabilities must be positive! And according to this paper* every myopic incentive compatible decision market has this problem! Oh darn! Terror stomping again!

*Decision Markets With Good Incentives, available at http://people.seas.harvard.edu/~mruberry/

supported by NSF grant CCF-0915016

HARVARD School of Engineering and Applied Sciences

Research is fun (aside)

Ryan North ryanqnorth@gmail.com via seas.harvard.edu
to Mike

Dude this is awesome. I love it! I rate this poster: 100% supercanon.

Ryan
www.qwantz.com

Research is fun (aside) (part 2)

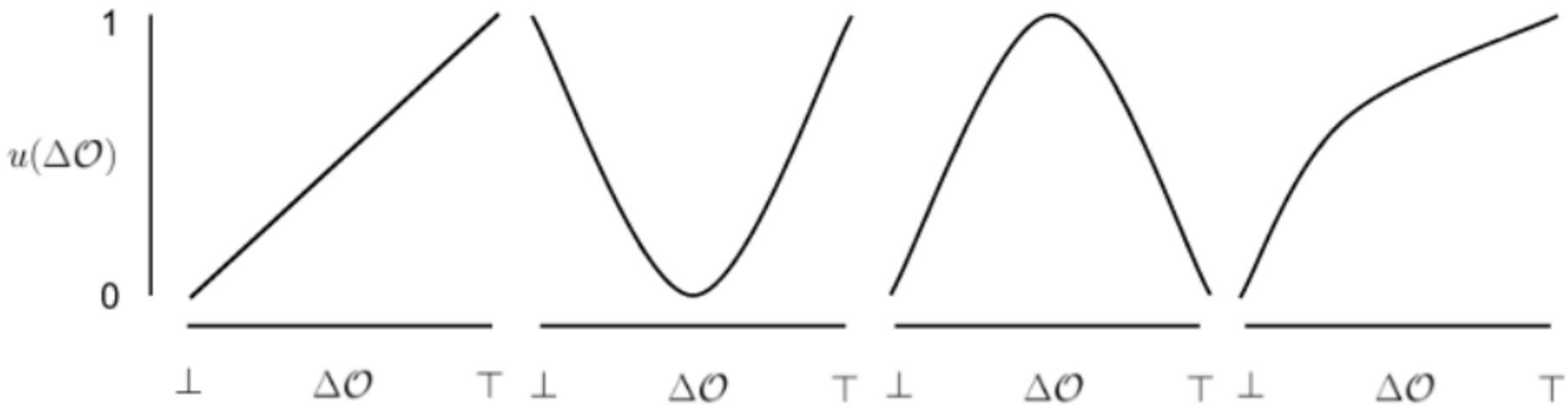
Ryan North ryanqnorth@gmail.com via seas.harvard.edu
to Mike

Also I think I accidentally made a decision market a while back! It's the Regret Index and lets people rate how much they regretted something, so that you can check that out before you decide to do it:

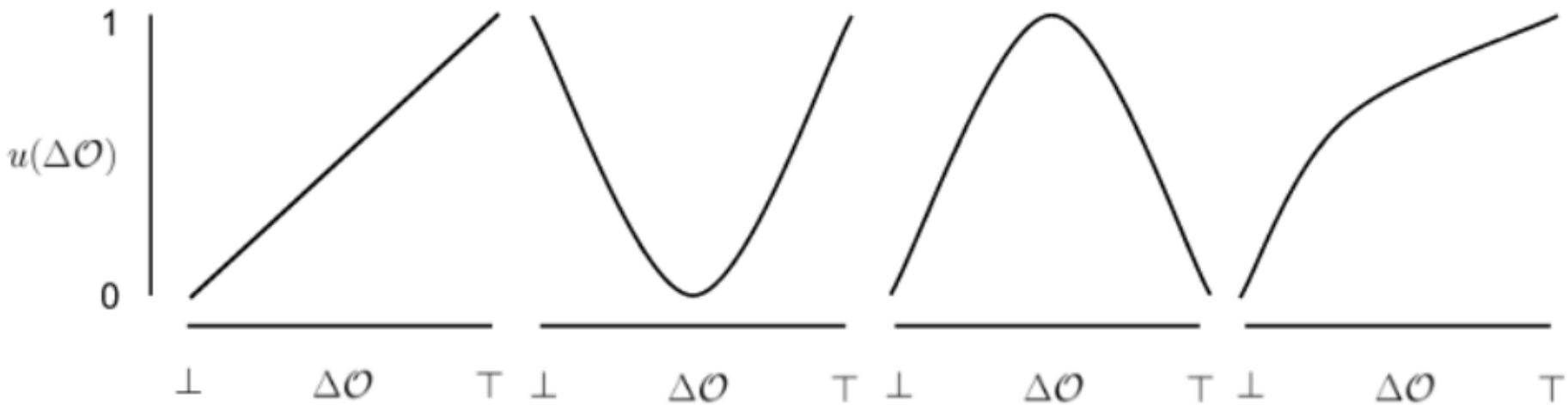
http://qwantz.com/regret/

Top regrets include "that your housemate is taking like a billion years to get out of the bathtub, and you really have to pee". That kinda gives you an idea of the kind of site it turned into, I guess?

Preferences



Preferences



Previously we didn't have to talk about preferences, but it turns out only some preferences have right-action rules!

Preferences

Definition 5.4 (*(Strictly) Convexible*). A function f is (strictly) convexible if there exists a (strictly) convex function g such that if $f(x) > f(y)$ then $g(x) > g(y)$.

Preferences

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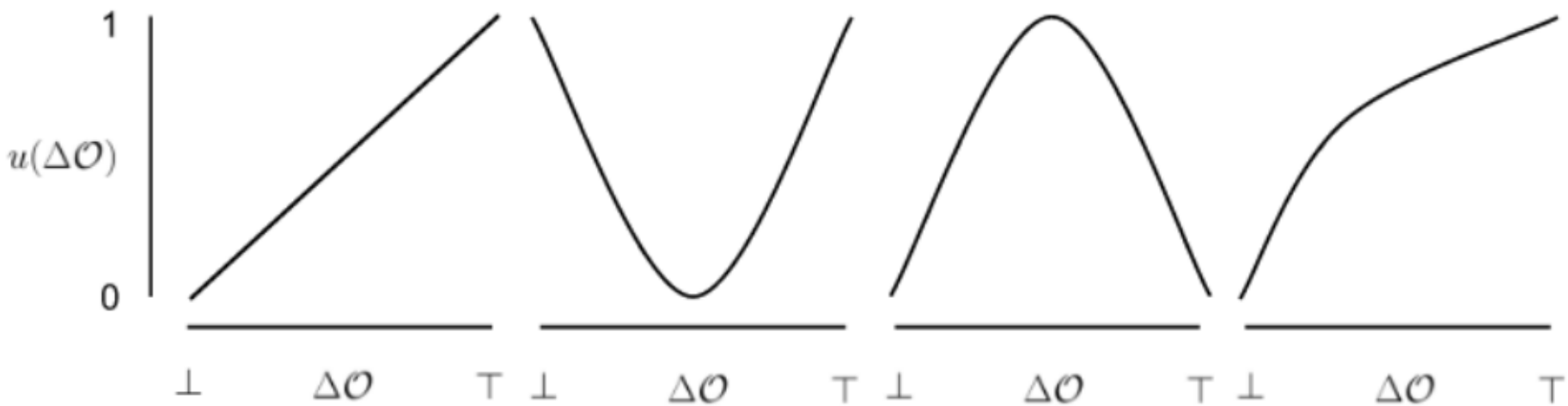

Preferences

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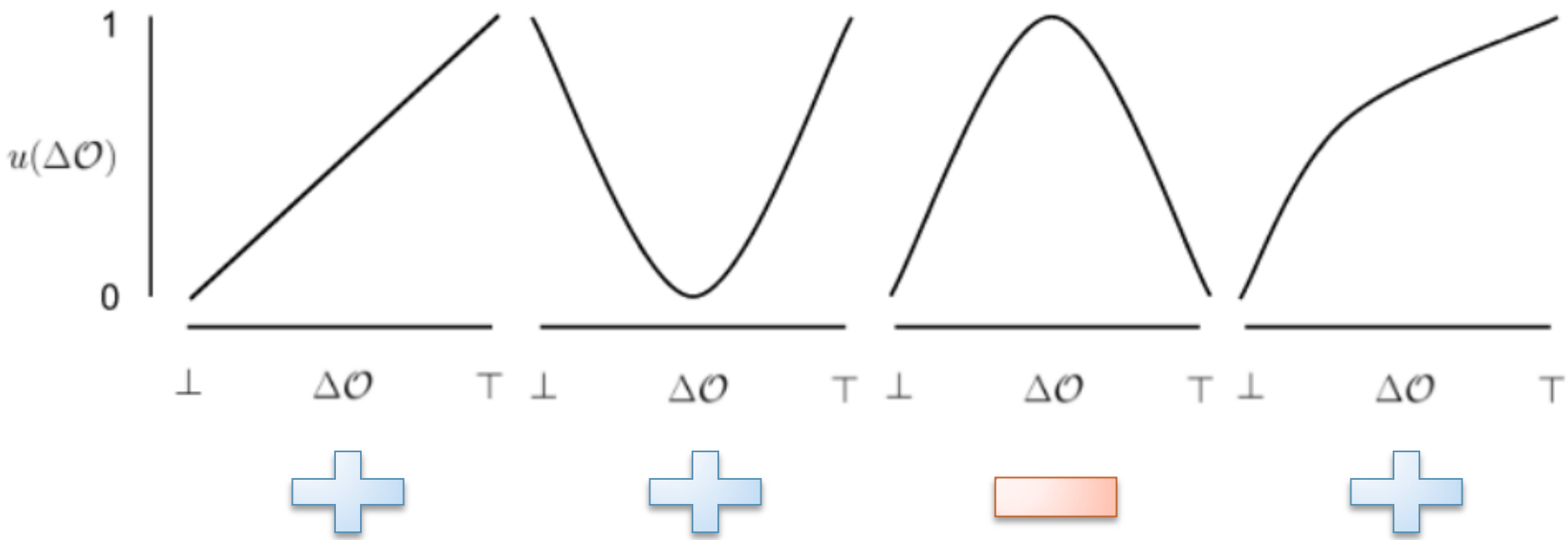

Preferences

THEOREM 5.5 (RIGHT-ACTION RULE CHARACTERIZATION). *If the decision maker is considering at least two actions, a utility function u has a right-action rule if and only if u is convexible.*

Discuss: single expert v. market

- Sometimes one or the other?

Discuss: where do we go from here?

- the undiscovere'd country (?)

Conclusion

- Decision markets are part of an emerging interest in “markets that do things”
- This started as a 286r project
  - Think **big** about your project!