Bounded Rationality Lecture 1

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Princeton - Behavioral Economics

Plan for this Part of Course

- Bounded Rationality (4 lectures)
- Reference dependence (3 lectures)
- Neuroeconomics (2 lectures)
- Temptation and Self control (3 lectures)

(Tentative) Plan for Bounded Rationality

1. Introduction, Costly information acquisition I: Models of Sequential Search and Satisficing
2. Costly Information acquisition II: Rational Inattention
3. Applications of costly information
4. Costly Thinking

What is Bounded Rationality?

- "Optimizing behavior with additional constraints"
- Costly information acquisition or processing
  - Stigler 1961, Sims 2002
- Bounded Memory
  - Wilson 2003, Rubinstein 1984
- Thinking/consideration costs
  - Bolton and Faure-Grimaud 2009, Ortoleva 2012

What is Bounded Rationality?

- Compare to other forms of behavioral economics
- Mess around with preferences
  - Loss Aversion
- Models which assume mistakes
  - Rabin and Vayanos 2010
- Potentially, both can be seen as ‘reduced form’ of bounded rationality

Advantages and Disadvantages of Bounded Rationality

- Advantage:
  - Can 'microfound' behavioral models - explain how behavioral phenomena can change with the environment
- Disadvantages:
  - What is correct constraint?
  - Regress issue

What Might We Want to Explain With Bounded Rationality

- Random Choice
- Status Quo Bias
- Failure to Choose the Best Option
- Salience/Framing Effects
- Too Much Choice
- Statistical Biases
- Compromise Effect

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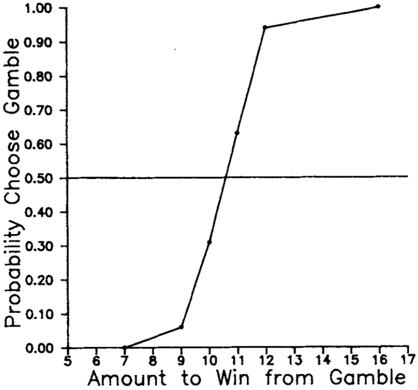
Random Choice (Mosteller and Nogee 1951)



- Gamble is $\frac{1}{3}$ probability win amount and $\frac{2}{3}$ loss of 5c
- Each bet offered 14 times

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Status Quo Bias/Inertia (Madrian and Shea 2001)

- Observe behavior of workers in firms that offer 401k savings plans
- Two types of plans
  - Opt In
  - Opt Out
- Average take up after 3-15 months of tenure
  - Opt In: 37%
  - Opt Out: 86%
- Effect reduces with tenure
- Also an effect on those not automatically enrolled

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Failure to Choose the Best Option (Caplin, Dean, Martin 2011)

4	2
3	13
20	11
15	8
8	10

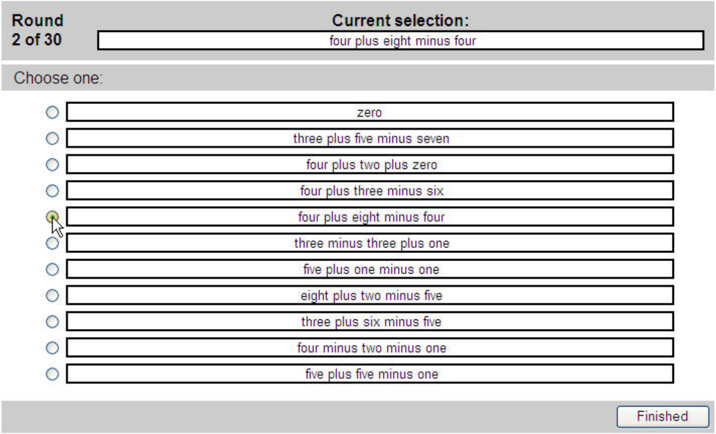
Failure to Choose the Best Option (Caplin, Dean, Martin 2011)

4+6+10-11-23+9	2+3+6-11-14+9+10
3+9-17-99+102-6+15	6+18-19-55+70
20-27+7-19+2+3-5	11+2-5+7-8-9+10
15-5-5+6+16+17-20-9	8+9+10-11+8+2+6-32
8+8+9-13-9-6+7	10-9+17-23+10+2+15

Choice Objects

- 6 treatments
  - 2 x complexity (3 and 7 operations)
  - 3 x choice set size (10, 20 and 40 options)
- No time limit

Size 10, Complexity 3



Size 20, Complexity 7

- ( ) zero
- ( ) seven minus four minus two minus four minus two plus eleven minus four
- ( ) six plus five minus eight plus two minus nine plus one plus four
- ( ) seven minus two minus four plus three plus four minus three minus three
- ( ) seven plus five minus two minus two minus three plus zero minus two
- ( ) six plus seven plus six minus two minus six minus eight plus four
- ( ) six plus two plus five minus four minus two minus seven plus three
- ( ) six minus four minus one minus one plus five plus three minus six
- (•) two plus six plus seven minus two minus four minus two plus zero
- ( ) two minus three minus five plus nine minus one plus five minus three
- ( ) three plus zero plus two plus zero plus one minus three minus one
- ( ) four plus three plus zero minus two plus three plus four minus ten
- ( ) seven plus two plus seven minus seven plus three minus two minus two
- ( ) three plus three minus two plus zero plus zero minus four plus five
- ( ) two minus two plus zero plus nine minus two minus one minus one
- ( ) three plus four minus three plus three minus four plus three minus four
- ( ) three plus five plus seven plus five minus two minus seven minus ten
- ( ) three plus six minus eight plus one plus two minus two plus zero
- ( ) three plus five plus zero plus four plus three minus four minus two
- ( ) eight minus one plus one minus four minus four minus five plus six
- ( ) four minus five plus four minus one minus four plus zero plus four

Finished

Results

Failure rates (%) (22 subjects, 657 choices)

Failure rate		
	Complexity	
Set size	3	7
10	7%	24%
20	22%	56%
40	29%	65%

Average Loss ($)		
	Complexity	
Set size	3	7
10	0.41	1.69
20	1.10	4.00
40	2.30	7.12

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- Random Choice
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Salience (Chetty, Looney and Kroft, 2009)

- Experiment in supermarket
- Posted prices usually exclude sales tax
- Post (in addition) prices including sales tax
- Reduced demand for these good by about 8%
- In same supermarket, archival data shows that, for alcohol, elasticity with respect to sales tax changes order of magnitude less that elasticity with respect to price changes

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Too Much Choice (Iyengar and Lepper 2000)

- Set up a display of jams in a local supermarket
- Two treatments:
  - Limited choice – 6 Jams
  - Extensive choice – 24 Jams
- Record what proportion of people stopped at each display
- And proportion of people bought jam conditional on stopping

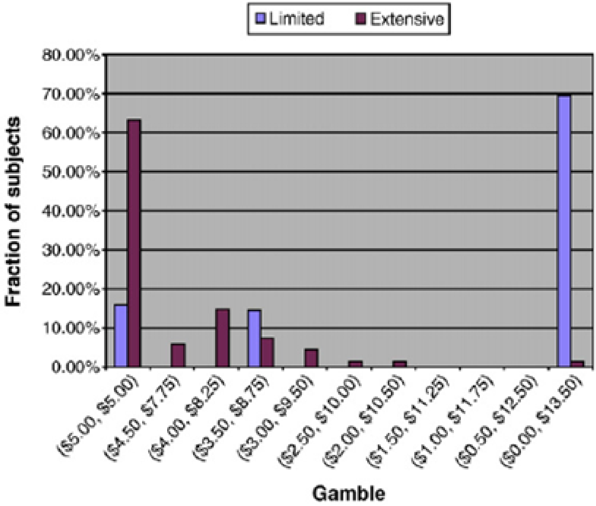
Too Much Choice (Iyengar and Lepper 2000)

- Slightly more people stopped to look at the display in the extensive choice treatment:
  - 60% Extensive choice treatment
  - 40% Limited choice treatment
- Far more people chose to buy jam, conditional on stopping, in the Limited choice treatment
  - 3% Extensive choice treatment
  - 31% Limited choice treatment

Too Much Choice and Simplicity Seeking (Iyengar and Kamenica 2010)

Gamble #	If heads	If tails
Extensive condition		
1	$5.00	$5.00
2	$4.50	$7.75
3	$4.00	$8.25
4	$3.50	$8.75
5	$3.00	$9.50
6	$2.50	$10.00
7	$2.00	$10.50
8	$1.50	$11.25
9	$1.00	$11.75
10	$0.50	$12.50
11	$0.00	$13.50
Limited condition		
1	$5.00	$5.00
2	$3.50	$8.75
3	$0.00	$13.50

Too Much Choice and Simplicity Seeking (Iyengar and Kamenica 2010)



Too Much Choice and Simplicity Seeking (Iyengar and Kamenica 2010)

Extensive condition

Gamble #	If ⚀	If ⚁	If ⚂	If ⚃	If ⚄	If ⚅
1	$0.00	$0.00	$0.00	$10.00	$10.00	$10.00
2	$1.50	$9.25	$8.75	$7.00	$0.75	$1.25
3	$4.25	$5.50	$9.75	$8.50	$0.00	$0.75
4	$1.00	$2.00	$6.75	$7.50	$5.75	$4.75
5	$5.50	$1.00	$0.75	$6.50	$7.50	$6.75
6	$0.00	$0.00	$8.75	$2.75	$9.75	$8.00
7	$9.75	$3.00	$7.00	$6.50	$0.50	$1.50
8	$9.50	$1.50	$1.50	$2.50	$3.25	$10.00
9	$5.50	$8.50	$3.25	$0.00	$8.50	$2.50
10	$9.25	$7.75	$3.75	$2.00	$3.25	$2.00
11	$1.25	$4.50	$8.50	$8.75	$4.50	$0.75

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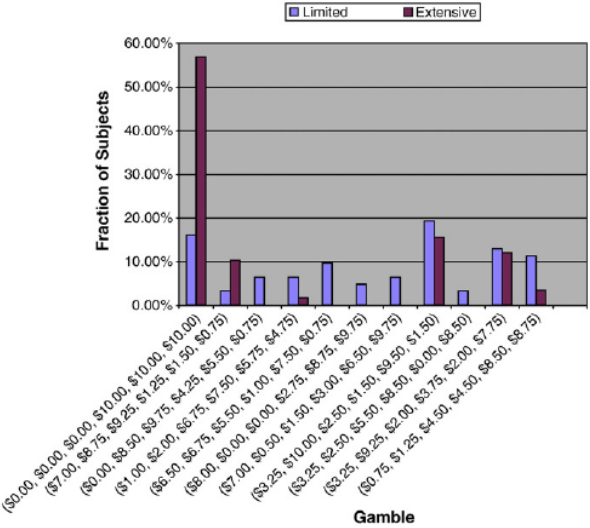

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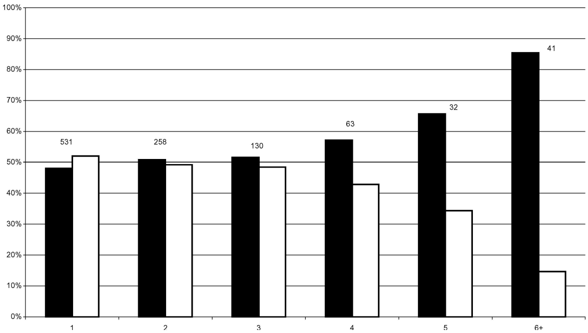
Gambler's Fallacy (Croson and Sundali 2005)

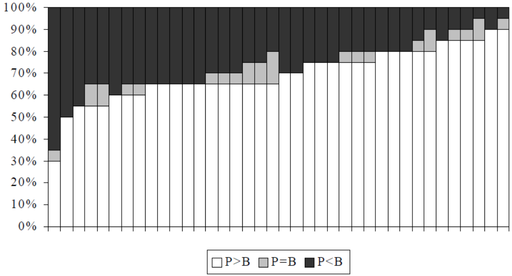


- Proportion of Gambler's Fallacy bets in casino gambling

Hot Hands Fallacy (Offerman and Sonnemans 2000)

- Two types of coin
  - ‘Fair’: Independent
  - ‘Unfair’: Repeat last outcome with probability 70%
- Prior distribution: 50/50
- Subjects observe 20 coin flips, then report probability of unfair coin

Gambler's Fallacy (Croson and Sundali 2005)



- For each subject, proportion that overestimate probability of unfair coin

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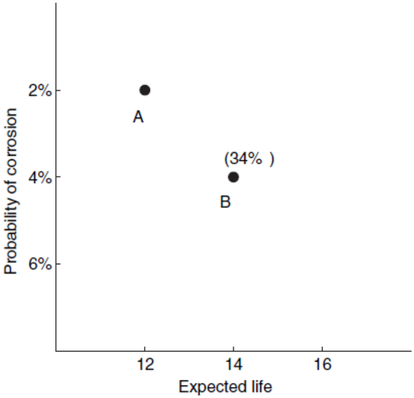
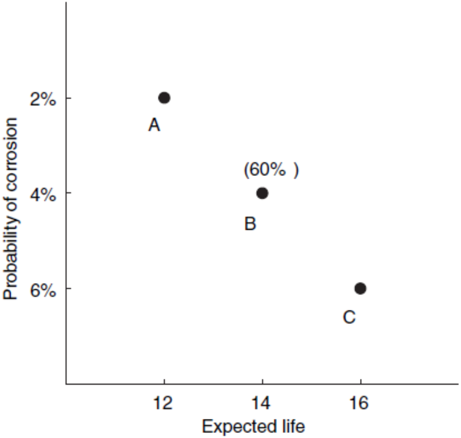
Compromise Effect (Simonsen 1989)



Compromise Effect (Simonsen 1989)



Satisficing as Optimal Stopping

- Satisficing model: Simon [1955]
- Very simple model:
  - Decision maker faced with a set of alternatives A
  - Searches through this set one by one
  - If they find alternative that is better than some threshold, stop search and choose that alternative
  - If all objects are searched, choose best alternative

Satisficing as Optimal Stopping

- Usually presented as a compelling description of a 'choice procedure'
- Can also be derived as optimal behavior as a simple sequential search model with search costs
- Primitives
  - A set A containing M items from a set X
  - A utility function u: $X \rightarrow \mathbb{R}$
  - A probability distribution f :decision maker's beliefs about the value of each option
  - A per object search cost k

The Stopping Problem

- At any point DM has two options

1. Stop searching, and choose the best alternative so far seen (search with recall)
2. Search another item and pay the cost k

- Solve by backwards induction
- Choice when there is 1 more object to search and current best alternative has utility $\bar{u}$

1. Stop searching: $\bar{u} - (M-1)k$
2. Search the final item:

$$\int_{-\infty}^{\bar{u}} \bar{u} f(u) du + \int_{\bar{u}}^{\infty} u f(u) du - Mk$$

- Stop searching if

$$\bar{u} - (M-1)k \leq \int_{-\infty}^{\bar{u}} \bar{u} f(u) du + \int_{\bar{u}}^{\infty} u f(u) du - Mk$$

- Implying

$$k \leq \int_{\bar{u}}^{\infty} (u - \bar{u}) f(u) du$$

- Cutoff strategy: search continues if $\bar{u} > u^*$ solving

$$k = \int_{u^*}^{\infty} (u - u^*) f(u) du \qquad (1)$$

- Now consider behavior when there are 2 items remaining
- $\bar{u} < u^*$ Search will continue
  - Search optimal if one object remaining
  - Can always operate continuation strategy of stopping after searching only one more option
- $\bar{u} > u^*$ search will stop
  - Not optimal to search one more item only
  - Search will stop next period, as $\bar{u} > u^*$

Optimal Stopping

- Optimal stopping strategy is satisficing:
- Find u^* that solves

$$k = \int_{u^*}^{\infty} (u - u^*) f(u) du$$

- Continue searching until find an object with $u > u^*$, then stop
- Predictions about how reservation level changes with environment
    - u^* decreasing in k
    - increasing in variance of f (for well behaved distributions)
    - Unaffected by the size of the choice set
- Comes from optimization, not reduced form satisficing model

Testing Satisficing: The Problem

- Satisficing models difficult to test using choice data alone
  - If search order is fixed, prediction is just WARP
  - If it can vary, any behavior can be explained
- Two ways out:
  - Make more assumptions
  - Enrich data set
- Consider the latter:- **Choice Process Data**
  - Campbell (1978)
  - Caplin and Dean (2010)
  - Caplin, Dean and Martin (2011)

Characterizing the Satisficing Model

- Two main assumptions

1. Search is **alternative-based**
   - DM searches through items in choice set sequentially
   - Completely understands each item before moving on to the next
2. Stopping is due to a **fixed reservation rule**
   - Subjects have a fixed reservation utility level
   - Stop searching if and only if find an item with utility above that level

Choice Process Data

- In order to test predictions of our model we introduce 'choice process' data
- Records how choice changes with contemplation time
  - $C(A)$: Standard choice data - choice from set A
  - $C_A(t)$: Choice process data - choice made from set A after contemplation time t

Notation

- X : Finite grand choice set
- $\mathcal{X}$: Non-empty subsets of X
- $Z \in \{Z_t\}_t^\infty$: Sequences of elements of $\mathcal{X}$
- $\mathcal{Z}$ set of sequences Z
- $\mathcal{Z}_A \subset \mathcal{Z}$: set of sequences s.t. $Z_t \subset A \in \mathcal{X}$

Definition

A Choice Process Data Set (X, C) comprises of:

- finite set X
- choice function $C : \mathcal{X} \rightarrow \mathcal{Z}$

such that $C(A) \in \mathcal{Z}_A \; \forall \; A \in \mathcal{X}$

- $C_A(t)$: choice made from set A after contemplation time t

Alternative-Based Search (ABS)

- DM has a fixed utility function
- Searches sequentially through the available options,
- Always chooses the best alternative of those searched
- May not search the entire choice set
- 'Standard' model of information search within economics
  - Stigler [1960]
  - McCall [1970]
- (We will consider other forms of information acquisition next lecture)

- DM is equipped with a utility function

$$u : X \rightarrow \mathbb{R}$$

- and a search correspondence

$$S : \mathcal{X} \rightarrow \mathcal{Z}$$

  with $S_A(t) \subseteq S_A(t+s)$
- Such that the DM always chooses best option of those searched

$$C_A(t) = \arg\max_{x \in S_A(t)} u(x)$$

Revealed Preference and ABS

- Finally choosing x over y does *not* imply (strict) revealed preference
  - DM may not know that y was available
- Replacing y with x *does* imply (strict) revealed preference
  - DM must know that y is available, as previously chose it
  - Now chooses x, so must prefer x over y
- Choosing x and y at the same time reveals indifference
- Use $\succ^{ABS}$ to indicate ABS strict revealed preference
- Use $\sim^{ABS}$ to indicate revealed indifference

- Choice process data will have an ABS representation if and only if $\succ^{ABS}$ and $\sim^{ABS}$ can be represented by a utility function u

$$\begin{aligned} x &\succ^{ABS} y \Rightarrow u(x) > u(y) \\ x &\sim^{ABS} y \Rightarrow u(x) = u(y) \end{aligned}$$

- Necessary and sufficient conditions for utility representation well known:
  - Let $\succeq^{ABS} = \succ^{ABS} \cup \sim^{ABS}$
  - Then if

$$x_1 \succeq^{ABS} x_2, ..., x_{n-1} \succeq^{ABS} x_n \succeq^{ABS} x_1$$

  - then there is no k such that $x_k \succ^{ABS} x_{k+1}$
- We call this condition **Only Weak Cycles**

Theorem 1

Theorem

Choice process data admits an ABS representation if and only if $\succ^{ABS}$ and $\sim^{ABS}$ satisfy Only Weak Cycles

Satisficing

- Choice process data admits an **satisficing representation** if we can find
  - An ABS representation (u, S)
  - A reservation level ρ
- Such that search stops if and only if an above reservation object is found
  - If the highest utility object in $S_A(t)$ is above ρ, search stops
  - If it is below ρ, then search continues
- Implies complete search of sets comprising only of below-reservation objects

Revealed Preference and Satisficing

- Final choice can now contain revealed preference information
  - If final choice is **below-reservation** utility
- How do we know if an object is below reservation?
- If they are **non-terminal**: Search continues after that object has been chosen

Directly and Indirectly Non-Terminal Sets

- Directly Non-Terminal: $x \in X^N$ if
  - $x \in C_A(t)$
  - $C_A(t) \neq C_A(t+s)$
- Indirectly Non Terminal: $x \in X^I$ if
  - for some $y \in X^N$
  - $x, y \in A$ and $y \in \lim_{t \to \infty} C_A(t)$
- Let $X^{IN} = X^I \cup X^N$

Add New Revealed Preference Information

- If
  - one of x,$y \in A$ is in X^{IN}
  - x is finally chosen from some set A when y is not,
- then, $x \succ^{S} y$
  - If x is is in X^{IN}, then A must have been fully searched, and so x must be preferred to y
  - If y is in X^{IN}, then either x is below reservation level, in which case the set is fully searched, or x is above reservation utility
- Let $\succ = \succ^{S} \cup \succ^{ABS}$

Theorem 2

Theorem

Choice process data admits an satisficing representation if and only if $\succ$ *and* $\sim^{ABS}$ *satisfy Only Weak Cycles*

Experimental Design

- Experimental design has two aims
  - Identify choice ‘mistakes’
  - Test satisficing model as an explanation for these mistakes
- Two design challenges
  - Find a set of choice objects for which ‘choice quality’ is obvious and subjects do not always choose best option
  - Find a way of eliciting ‘choice process data’
- We first test for 'mistakes' in a standard choice task...
- ... then add choice process data in same environment

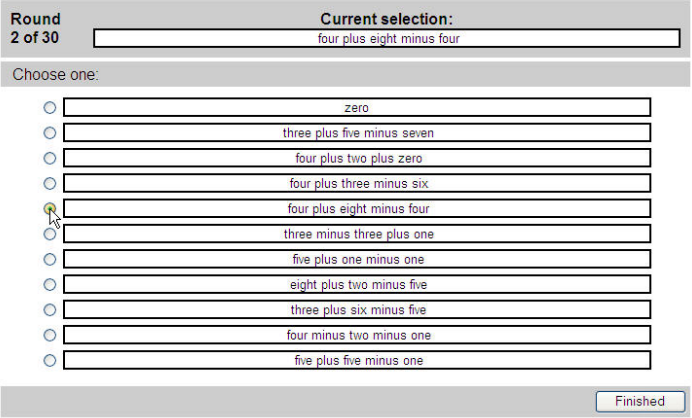
Choice Objects

- Subjects choose between ‘sums’

four plus eight minus four

- Value of option is the value of the sum
- 'Full information’ ranking obvious, but uncovering value takes effort
- 6 treatments
  - 2 x complexity (3 and 7 operations)
  - 3 x choice set size (10, 20 and 40 options)
- No time limit

Size 10, Complexity 3



Size 20, Complexity 7

- zero
- seven minus four minus two minus four minus two plus eleven minus four
- six plus five minus eight plus two minus nine plus one plus four
- seven minus two minus four plus three plus four minus three minus three
- seven plus five minus two minus two minus three plus zero minus two
- six plus seven plus six minus two minus six minus eight plus four
- six plus two plus five minus four minus two minus seven plus three
- six minus four minus one minus one plus five plus three minus six
- (selected) two plus six plus seven minus two minus four minus two plus zero
- two minus three minus five plus nine minus one plus five minus three
- three plus zero plus two plus zero plus one minus three minus one
- four plus three plus zero minus two plus three plus four minus ten
- seven plus two plus seven minus seven plus three minus two minus two
- three plus three minus two plus zero plus zero minus four plus five
- two minus two plus zero plus nine minus two minus one minus one
- three plus four minus three plus three minus four plus three minus four
- three plus five plus seven plus five minus two minus seven minus ten
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- three plus five plus zero plus four plus three minus four minus two
- eight minus one plus one minus four minus four minus five plus six
- four minus five plus four minus one minus four plus zero plus four

Finished

Failure rates (%) (22 subjects, 657 choices)

Failure rate

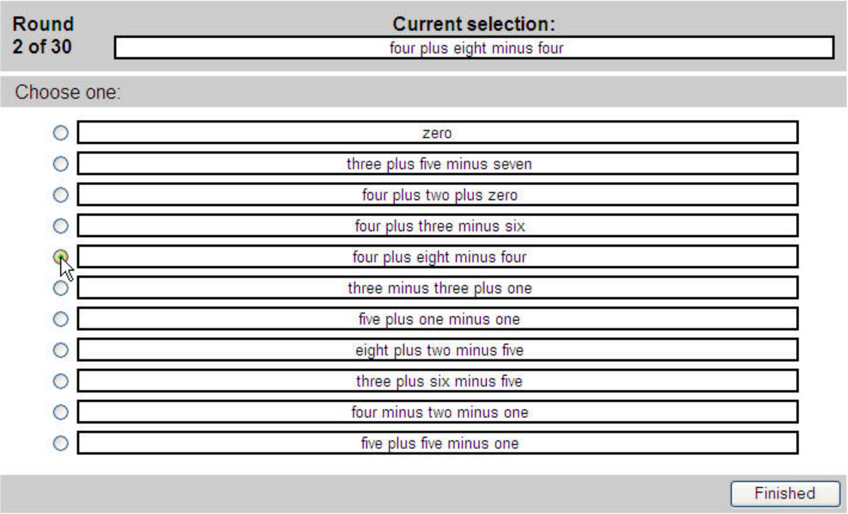
	Complexity	
Set size	3	7
10	7%	24%
20	22%	56%
40	29%	65%

Average Loss ($)		
	Complexity	
Set size	3	7
10	0.41	1.69
20	1.10	4.00
40	2.30	7.12

Eliciting Choice Process Data

1. Allow subjects to select any alternative at any time
    - Can change selection as often as they like
2. Choice will be recorded at a random time between 0 and 120 seconds unknown to subject
    - Incentivizes subjects to always keep selected current best alternative
    - Treat the sequence of selections as choice process data
3. Round can end in two ways
    - After 120 seconds has elapsed
    - When subject presses the 'finish' button
    - We discard any rounds in which subjects do not press 'finish'

Stage 1: Selection



Stage 2: Choice Recorded

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Choice Recorded

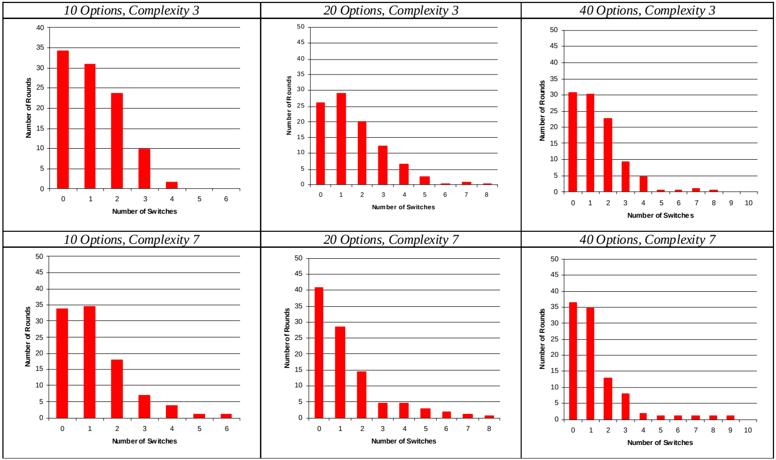
In this round, your choice was recorded after **9** seconds. At that time, you had selected:

four plus four minus six

Next

Do We Get Richer Data from Choice Process Methodology?

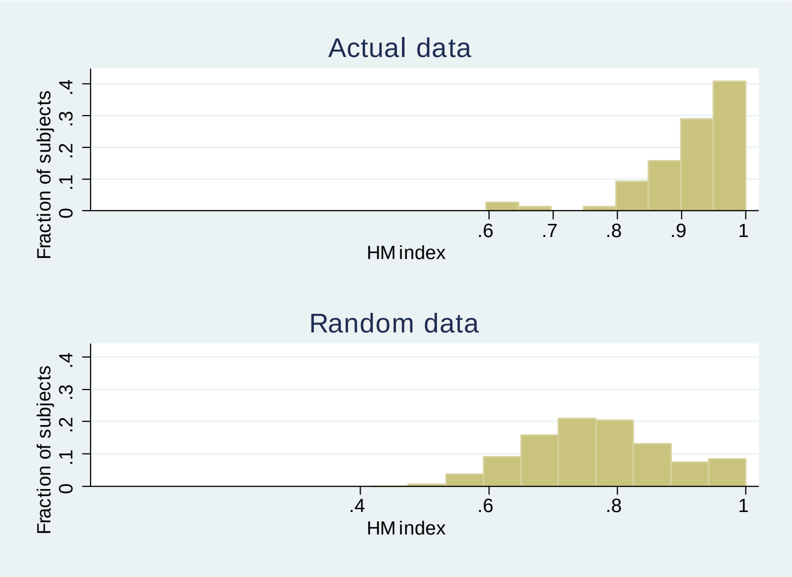
978 Rounds, 76 Subjects



Testing ABS

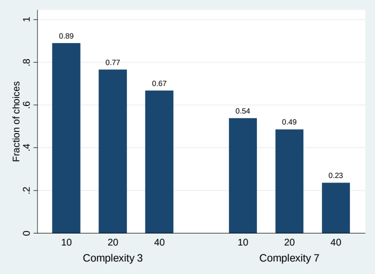
- Choice process data has ABS representation if $\succ^{ABS}$is *consistent*
- Assume that more money is preferred to less
- Implies subjects must always switch to higher-valued objects **(Condition 1)**
- Calculate Houtman-Maks index for Condition 1
    - Largest subset of choice data that is consistent with condition

Houtman-Maks Measure for ABS

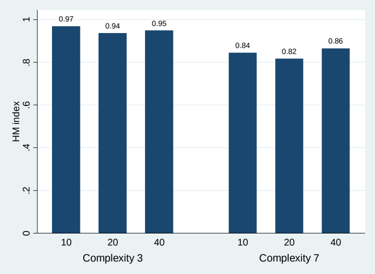


Traditional vs ABS Revealed Preference

Traditional

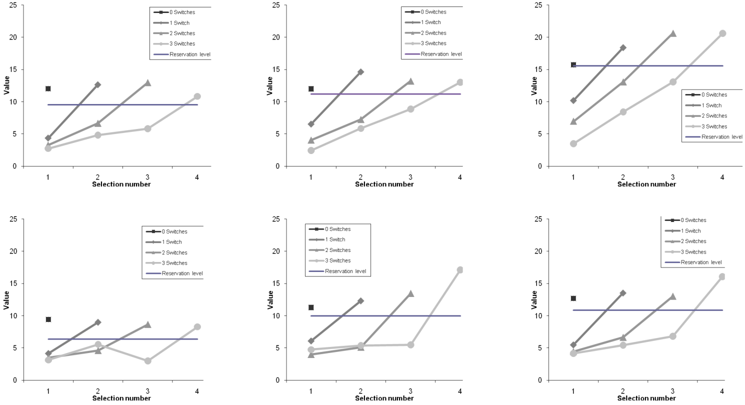


ABS



Satisficing Behavior

10 20 40



3

7

Estimating Reservation Levels

- Choice process data allows observation of subjects
  - Stopping search
  - Continuing to search
- Allows us to estimate reservation levels
- Assume that reservation level is calculated with some noise at each switch
- Can estimate reservation levels for each treatment using maximum likelihood

Estimated Reservation Levels

	Complexity			
Set size	3		7	
10	9.54	(0.20)	6.36	(0.13)
20	11.18	(0.12)	9.95	(0.10)
40	15.54	(0.11)	10.84	(0.10)

Estimating Reservation Levels

- Increase with 'Cost of Search'
  - In line with model predictions
- Increase with size of choice set
  - In violation of model predictions

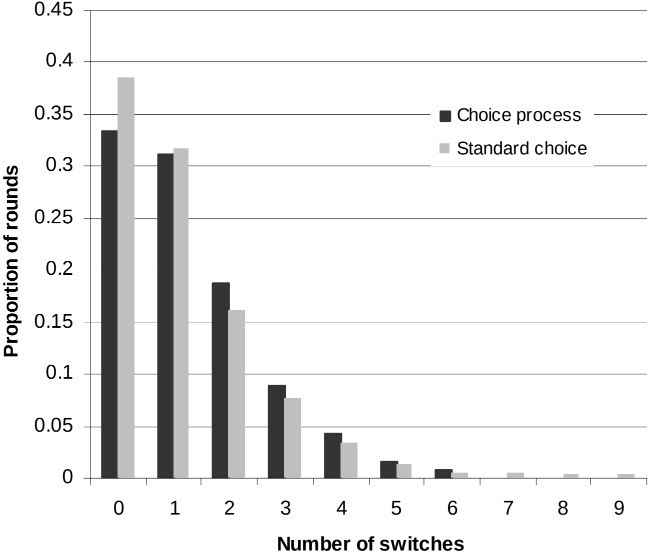
HM Indices for Estimated Reservation Levels

	Complexity	
Set size	3	7
10	0.90	0.81
20	0.87	0.78
40	0.82	0.78

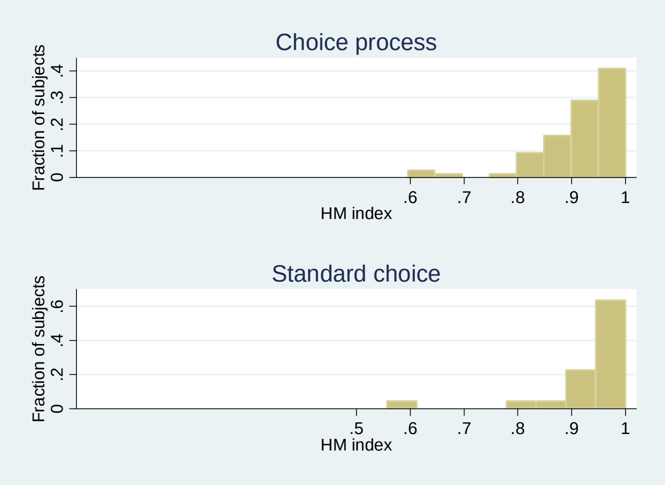
Does Choice Process Elicitation Change Behavior?

- In 'standard choice' experiment subjects could make intermediate selections
- Were not incentivized to do so, but did so anyway
- Can use this to explore the effect of choice process elicitation

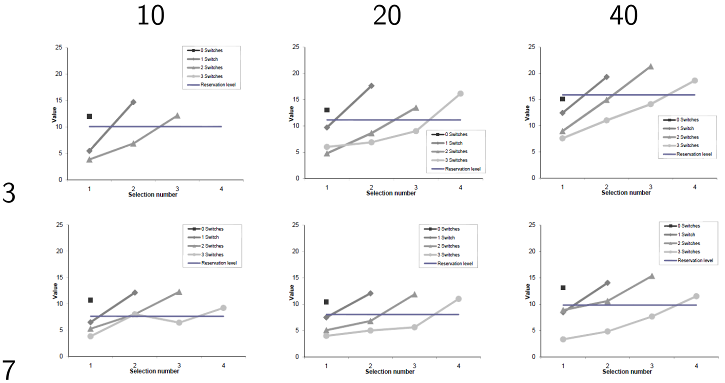
Question 1: Does Choice Process Elicitation Change Behavior?



Does Standard Choice Experiment Also Have Sequential Search?



Satisficing Behavior in Standard Choice Environment



How Does Choice Process Elicitation Change Incentives?

- Frame as an optimal stopping problem (within ABS framework)
- Assume
  - Fixed cost of search
  - Value of objects drawn from a fixed distribution
- Can formulate optimal strategy

Differences in Optimal Strategy

- **Fixed** reservation optimal in standard choice but **declining** reservation optimal in choice process
  - No good evidence for declining reservation level in either case
- Choice process environment should also always have lower reservation levels that standard choice
  - Weak evidence for this

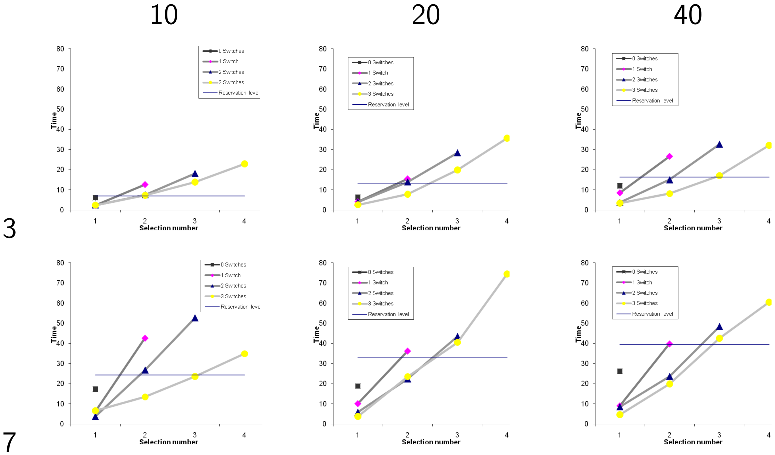
Estimated Reservation Levels

		Complexity	
Set size		3	7
10	Choice process	10.17	6.34
	Standard choice	*10.05*	*8.41*
20	Choice process	11.22	8.92
	Standard choice	*11.73*	*8.39*
40	Choice process	15.15	10.07
	Standard choice	*16.38*	*10.39*

Alternative Models

- Reservation stopping time
- Complete search with calculation errors

Reservation Stopping Time?



Complete Search with Calculation Errors

- An alternative explanation for suboptimal choice
- Subjects look at all objects, but make calculation errors
- Estimate logistic random error model of choices
  - Scale factor allowed to vary between treatment
- Select scale factor to maximize likelihood of observed choices

- Extremely large errors needed to explain mistakes

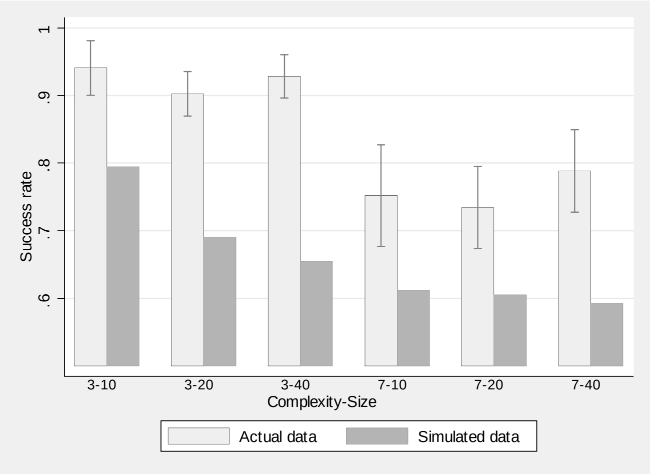
Estimated standard deviations

	Complexity	
Set size	3	7
10	1.90	3.34
20	2.48	4.75
40	3.57	6.50

- Still underpredict magnitude of losses

Failure Rate			
		Complexity	
10	Actual choices	11.38	46.53
	Simulated choices	*8.35*	*32.47*
20	Actual choices	26.03	58.72
	Simulated choices	*20.13*	*37.81*
40	Actual choices	37.95	80.86
	Simulated choices	*25.26*	*44.39*

- But overpredict violations of ABS



Estimating Reservation Levels

- Incomplete information search provides a good explanation for suboptimal choice in this environment
- Subjects behave in line with satisficing model
  - Search sequentially through choice set
  - Stop searching when finding object above reservation utility
- Environmental factors change behavior, but within satisficing framework

Related Literature

- Previous studies have used eye tracking/mouselab to examine process of information search
  - Payne, Bettman and Johnson [1993]
  - Gabaix, Laibson, Moloche and Weinberg [2006]
  - Reutskaja, Pulst-Korenberg, Nagel, Camerer and Rangel.[2008]
- Modelled choice data with consideration sets and ordered search
  - Rubinstein and Salant [2006]
  - Manzini and Mariotti [2007]
  - Masatlioglu and Nakajima [2008]

Table 1: Magnitude of Mistakes, Experiment 1				
Set Size		***Complexity***		***Total***
		3	7	
10	**Failure Rate (%)**	**6.78**	**23.61**	**16.03**
	Average Loss ($)	0.41	1.69	1.11
	Average Loss (%)	3.44	13.66	9.05
	Observations	*59*	*72*	*131*
20	**Failure Rate (%)**	**21.97**	**56.06**	**39.02**
	Average Loss ($)	1.10	4.00	2.55
	Average Loss (%)	7.07	24.70	15.89
	Observations	*132*	*132*	*264*
40	**Failure Rate (%)**	**28.79**	**65.38**	**46.95**
	Average Loss ($)	2.30	7.12	4.69
	Average Loss (%)	10.49	33.25	21.79
	Observations	*132*	*130*	*262*
Total	**Failure Rate (%)**	**21.98**	**52.69**	**37.60**
	Average Loss ($)	1.46	4.72	3.12
	Average Loss (%)	7.81	25.65	16.88
	Observations	*323*	*334*	*657*

Absolute Loss				
Set Size		***Complexity***		***Total***
		3	7	
10	**Choice Process**	**0.42**	**3.69**	**1.90**
	Normal Choice	*0.41*	*1.69*	*1.11*
20	**Choice Process**	**1.63**	**4.51**	**2.88**
	Normal Choice	*1.10*	*4.00*	*2.55*
40	**Choice Process**	**2.26**	**8.30**	**5.00**
	Normal Choice	*2.30*	*7.12*	*4.69*
Total	**Choice Process**	**1.58**	**5.73**	**3.43**
	Normal Choice	*1.46*	*4.72*	*3.12*

Number of Observations - Choice Process				
Set Size		***Complexity***		***Total***
		3	7	
10		123	101	224
20		225	172	397
40		195	162	357
Total		543	435	978