## Rational Inattention in Economic Choice

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Attentional and Perceptual Foundations of Economic Behavior Inaugural Symposium

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- 1 Attention is a scarce resource in economic choice
- 2 Incentives affect the information that people gather
- 3 Models of 'rational inattention' capture the trade offs in attentional choice
- State dependent stochastic choice' data are great for testing models of inattention
- 6 We have made progress in understanding the behavioral implications of rational inattention
- 6 There are many open questions and much work still to be done

## Outline

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#### **1** Attention is a Scarce Resource

- 2 Attention and Incentives
- 3 Rational Inattention
- 4 State Dependent Stochastic Choice Data
- 5 Theoretical Progress
- 6 Open Questions and Next Steps

- Attention: Actively processing specific information in our environment
- Claim: Attention is a scarce resource in economic choice
  - People may not make use of all available information when making a choice

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#### • This is

- Intuitively extremely plausible
- Clear in empirical studies
- Replicable in the laboratory

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## Salience and Taxation: Chetty et al. [2009]

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## Salience and Taxation: Chetty et al. [2009]



- Adding tax to the posted price reduces sales by about 8%
- Despite the fact people can accurately report tax rate if asked

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- Changes in alcohol taxes included in posted prices have more effect than those applied at the register
  - Chetty et al. [2009]
- People fail to choose efficient plans in Medicare Part D
  - Abaluck and Gruber [2011]
- People make suboptimal choices in 401k retirement plans
  - Choi et al. [2011]
- Limited information search during internet purchases
  - De Los Santos et al. [2012]

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An Experimental Example

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- Subjects presented with 100 balls
- State is determined by the number of red balls
- Prior distribution of red balls known to subject

An Experimental Example

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Action	Payoff 49 red balls	Payoff 51 red balls		
а	10	0		
b	0	10		

- No time limit: trade off between effort and financial rewards
- Probability of choosing the correct action c. 70%

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- People display limited attention when making economic choices
- But will **adjust** what they pay attention to in response to perceived incentives

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#### • Example 1: Discrimination [Bartos et al. 2016]

- Sent housing applications to landlords and job applications to employers
- Randomized names to be traditionally white majority or Roma minority
- Tracked whether applicant's CV was viewed
- Roma CVs significantly more likely than 'White' CVs to be viewed in the housing case
- Not so in the employment case

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- Inflation is much more volatile in Iran than New Zealand, making it more important for firms to keep track of
- Firms have more precise inflation expectations in Iran than in New Zealand [Afrouzi 2017]

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#### • Example 2: Inflation forecasting

- Inflation is much more volatile in Iran than New Zealand, making it more important for firms to keep track of
- Firms have more precise inflation expectations in Iran than in New Zealand [Afrouzi 2017]
- Professional forecasters in Brazil make more accurate forecasts when taking part in a contest [Gaglianone et al. 2017]

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Action	Payoff 49 red balls	Payoff 51 red balls		
а	Х	0		
b	0	Х		

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Experiment						
Decision	Payoffs					
Problem	$U(a,1) \mid U(a,2) \parallel U(b,1) \mid U(b,2)$					
1	5	0	0	5		
2	40	0	0	40		
3	70	0	0	70		
4	95	0	0	95		



Incentive

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#### • In order to capture this behavior, we want a model that

- Recognizes attentional limits
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- In order to capture this behavior, we want a model that
  - Recognizes attentional limits
  - Allows attention to respond endogenously to incentives
- Rational inattention is one such model
- Attention allocation modelled as optimal choice
- Consumers choose information in order to maximize benefits net of costs
  - Benefits: better subsequent choices
  - Costs: cognitive resources, time costs, etc.

• The decision maker wants to learn about the state of the world

- Quality of a flight
- Price of an item
- Inflation rate
- Number of red balls on the screen
- Because they will subsequently have to choose an alternative
  - Buy a flight
  - Set prices of their own good
  - Make a forecast
  - Pick an experimental option
- Incentives to learn because the utility of different options depends on the state of the world
  - Different sets of options leads to different incentives

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• The specifics of the process of information acquisition may be very complex

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- The specifics of the process of information acquisition may be very complex
- Rational Inattention models the choice of information in an *abstract* way
- The decision maker chooses an *information structure* 
  - Set of signals to receive
  - Probability of receiving each signal in each state of the world

- The specifics of the process of information acquisition may be very complex
- Rational Inattention models the choice of information in an *abstract* way
- The decision maker chooses an information structure
  - Set of signals to receive
  - Probability of receiving each signal in each state of the world
- While this appears abstract
  - Specific information gathering strategies give rise to information structures
  - Can be thought of as a special case of this model










### The Choice Problem



### Outline

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#### State Dependent Stochastic Choice Data

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- What does the rational inattention model buy us?
  - What predictions can we make?
  - How can we test it?

### State Dependent Stochastic Choice Data

- What does the rational inattention model buy us?
  - What predictions can we make?
  - How can we test it?
- Depends on the data you use
- Our work suggests (to us) a particularly useful type of data
- State Dependent Stochastic Choice data
  - Regularly used in psychology/psychometrics
  - Less commonly used in economics

### State Dependent Stochastic Choice

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Action	Payoff 49 red balls	Payoff 51 red balls
а	10	0
b	0	10

What could we observe in this experiment?

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- 'Standard' choice data?
  - Which action is chosen in one repetition

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Action	State = $49$ red balls	State = $51$ red balls
Prob choose <i>a</i>	P(a 49)	P(a 51)
Prob choose b	P(b 49)	P(b 51)

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- 'Standard' choice data?
  - Which action is chosen in one repetition
- Stochastic choice data
  - Probability of choosing each alternative
- State dependant stochastic choice
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Action	State = 49 red balls	State = $51$ red balls
Prob choose <i>a</i>	P(a 49)	P(a 51)
Prob choose b	P(b 49)	P(b 51)

- Easy to collect in the lab
  - Possible outside?

## Why State Dependent Stochastic Choice Data

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 Key observation: State dependent stochastic choice data tells us a lot about the information structure a decision maker has used

# Why State Dependent Stochastic Choice Data

- Key observation: State dependent stochastic choice data tells us a lot about the information structure a decision maker has used
- Assume that decision maker is 'well behaved'
  - Chooses each action in response to at most one signal
  - No mixed strategies one action per signal
- Information structure can be observed directly from state dependent stochastic choice
  - For each chosen action a there is an associated signal  $ar{\gamma}^a$
  - Probability of signal  $\bar{\gamma}^a$  in any state is the same as the probability of choosing action in that state
- This is the 'revealed information structure'

# **Recovering Information Structures**



## **Observing Information Structures**

• What if decision maker is not well behaved?

# Same Action in Different States



# Mixing



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- What if decision maker is not well behaved?
- Can still construct the revealed information structure, but may not be the same as the 'true' information structure
- But we can put a lower bound on the amount of information gathered
  - Choices cannot be more informative about the state than the information structure
- Turns out that this is still very useful
- Allows us to identify necessary and sufficient conditions for various classes of model

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### **Theoretical Progress**

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- In recent papers we have used this insight to establish the testable implications of rational inattention
- Key question: what is the cost function?

## **Theoretical Progress**

- In recent papers we have used this insight to establish the testable implications of rational inattention
- Key question: what is the cost function?
- We take two approaches
  - In each case provide a complete axiomatic characterization
- 1 Agnostic: Make no assumption about costs
  - Caplin and Dean [2015]
  - Pros: results do not depend on assumptions on the cost function
  - Cons: weak predictions (?), hard to use

# Theoretical Progress

- In recent papers we have used this insight to establish the testable implications of rational inattention
- Key question: what is the cost function?
- We take two approaches
  - In each case provide a complete axiomatic characterization
- **1** Agnostic: Make no assumption about costs
  - Caplin and Dean [2015]
  - Pros: results do not depend on assumptions on the cost function
  - Cons: weak predictions (?), hard to use
- **2** Specific: Assume a specific functional form for costs
  - Based on Shannon mutual information between signal and states
    - Sims [2003]
    - Caplin, Dean and Leahy [2016, 2017]
  - Pros: relatively easy to use
  - Cons: might be the wrong cost function

#### **Testable Implications**

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- Example of a testable prediction from the 'agonistic' model
- No Improving Attention Cycles (NIAC)
- Guarantees the existence of a rationalizing cost function

Decision Problem 1

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Action	Payoff 49 red balls	Payoff 51 red balls
$a^1$	10	0
$\mathbf{b}^1$	0	10

Prior: {0.5, 0.5}

Action	State = 49 red balls	State = $51$ red balls
Prob choose <i>a</i>	$\frac{3}{4}$	$\frac{1}{4}$
Prob choose b	$\frac{1}{4}$	$\frac{3}{4}$

**Decision Problem 2** 

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Action	Payoff 49 red balls	Payoff 51 red balls
$a^2$	20	0
$\mathbf{b}^2$	0	20

Prior: {0.5, 0.5}

Action	State = 49 red balls	State = $51$ red balls
Prob choose a	$\frac{2}{3}$	$\frac{1}{3}$
Prob choose b	$\frac{1}{3}$	$\frac{2}{3}$

G(A, π) is the gross value of using information structure π in decision problem A

G	$\bar{\pi}^1$	$\bar{\pi}^2$
$\left\{ a^{1},b^{1} ight\}$	$7\frac{1}{2}$	$6\frac{2}{3}$
$\{a^2, b^2\}$	15	$13\frac{1}{3}$

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•  $G(A, \pi)$  is the gross value of using information structure  $\pi$  in decision problem A

G	$\bar{\pi}^1$	$\bar{\pi}^2$
$\left\{ {{a^1},{b^1}}  ight\}$	$7\frac{1}{2}$	$6\frac{2}{3}$
$\{a^2, b^2\}$	15	$13\frac{1}{3}$

• Cost function must satisfy

$$\begin{array}{rcl} G(\{a^1,b^1\},\pi^1)-K(\pi^1) & \geq & G(\{a^1,b^1\},\pi^2)-K(\pi^2) \\ G(\{a^2,b^2\},\pi^2)-K(\pi^2) & \geq & G(\{a^2,b^2\},\pi^1)-K(\pi^1) \end{array}$$

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• Which implies

$$\frac{5}{6} = G(\{a^1, b^1\}, \pi^1) - G(\{a^1, b^1\}, \pi^2) \ge K(\pi^1) - K(\pi^2) \ge G(\{a^2, b^2\}, \pi^1) - G(\{a^2, b^2\}, \pi^2) = 1\frac{2}{3}$$

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• Surplus must be maximized by observed assignments

$$\begin{split} & G(\{\mathbf{a}^1, \mathbf{b}^1\}, \pi^1) + G(\{\mathbf{a}^2, \mathbf{b}^2\}, \pi^2) \\ \geq & G(\{\mathbf{a}^1, \mathbf{b}^1\}, \pi^2) + G(\{\mathbf{a}^2, \mathbf{b}^2\}, \pi^1) \end{split}$$

• This has to be true if decision maker is rationally inattentive **regardless** of cost function

#### **Testable Implications**

- Example of a testable prediction from the Shannon model
  - Costs based on Shannon mutual information
- Invariance Under Compression
- Identifies Shannon within the broader class of 'posterior separable' models

#### Invariance Under Compression - An Example

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• Consider decision problem (*i*)

	$\omega_1$	$\omega_2$
Prior Probability	0.5	0.5
Payoff Action A	10	0
Payoff Action B	0	10

#### Invariance Under Compression - An Example

• Consider decision problem (*i*)

	$\omega_1$	$\omega_2$
Prior Probability	0.5	0.5
Payoff Action A	10	0
Payoff Action B	0	10

• And now decision problem (ii) which splits  $\omega_2$ 

State	$\omega_1$	$\omega_2$	$\omega_3$
Prior Probability	0.5	0.2	0.3
Payoff Action A	10	0	0
Payoff Action B	0	10	10

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- How should behavior change between the two decision problems?
- In principle, many things could happen
  - Could be harder to learn about two states that one, so less accurate in (ii) than (i)
  - Could be easier to learn about two states that one, so more accurate in (ii) than (i)

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- In principle, many things could happen
  - Could be harder to learn about two states that one, so less accurate in (ii) than (i)
  - Could be easier to learn about two states that one, so more accurate in (ii) than (i)

• Shannon model says that behavior should not change

• 
$$P_i(\mathbf{a}|\omega_2) = P_{ii}(\mathbf{a}|\omega_2) = P_{ii}(\mathbf{a}|\omega_3)$$

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- 2 Attention and Incentives
- **3** Rational Inattention
- 4 State Dependent Stochastic Choice Data
- **5** Theoretical Progress
- **6** Open Questions and Next Steps

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- What are the appropriate costs for inattention
  - Can we develop a parsimonious usable model which is fit for purpose?
- Can models of inattention be used to 'microfound' and unify other behavioral phenomena
  - Reference dependence [Woodford 2012]

# What are the Open Questions

- How does rational inattention compare to other models of attention
  - Salience [Bordalo, Gennaioli, and Shleifer, 2012]
  - Focussing [Koszegi and Szeidl, 2013]
  - Relative thinking [Bushong et al 2015]

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- For which economic problems is this really important?
  - All of them?
  - Expectations in macroeconomic models?
  - Mechanism design?



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- How does information gathering change with incentives?
- Simplest possible design: two states and two acts
- Change the value of choosing the correct act

### Expansion:

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Experiment 2				
Decision	Payoffs			
Problem	U(a,1)	<i>U</i> ( <i>a</i> , 2)	U(b,1)	U(b,2)
1	5	0	0	5
2	40	0	0	40
3	70	0	0	70
4	95	0	0	95

- States equally likely
- Increase the value of making the correct choice
  - Payment in probability points
- 52 subjects



#### 1 Are people rationally inattentive?

- NIAC: choose information optimally relative to some cost function
- 2 What do information costs look like?
- **3** Do they look like Shannon Costs?
  - ILR: implies an 'expansion path' for information

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- NIAC: Ensures data is rationalizable according to some cost function
- Requires that surplus cannot be increased by reassigning information structures to decision problems

# Testing NIAC

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- In this experiment: Proportion of correct choices **weakly increasing** with incentives
- From the aggregate data



Incentive

# Recovering Costs - Individual Level



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## Shannon Mutual Information Costs

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• Observation of choice accuracy for x = 2 pins down  $\lambda$ 

### Shannon Mutual Information Costs



• Implies expansion path for all other values of x

## Aggregate Data



#### Incentive v Accuracy with Predicted Expansion Path

 In aggregate, subjects respond less slowly than Shannon predicts

#### Individual Level Data

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- Predicted vs Actual behavior in DP 4 given behavior in DP 1
- 44% of subjects adjust significantly more slowly than Shannon
- 19% significantly more quickly