Rational Inattention in Economic Choice

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Columbia University

Attentional and Perceptual Foundations of Economic Behavior
Inaugural Symposium
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
4. ‘State dependent stochastic choice’ data are great for testing models of inattention
5. 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
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
Attention is a Scarce Resource

- This is
  - Intuitively extremely plausible
  - Clear in empirical studies
  - Replicable in the laboratory
Attention is a Scarce Resource
Attention is a Scarce Resource

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Adding tax to the posted price reduces sales by about 8%.

Despite the fact people can accurately report tax rate if asked.
• Adding tax to the posted price reduces sales by about 8%
• Despite the fact people can accurately report tax rate if asked
• 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]
Attention is a Scarce Resource

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An Experimental Example

- 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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<thead>
<tr>
<th>Action</th>
<th>Payoff 49 red balls</th>
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<tr>
<td>a</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>b</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

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

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

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Attention and Incentives

- **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

- **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]
Attention and Incentives

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Attention and Incentives

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### Attention and Incentives

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<tbody>
<tr>
<td>a</td>
<td>×</td>
<td>0</td>
</tr>
<tr>
<td>b</td>
<td>0</td>
<td>x</td>
</tr>
</tbody>
</table>
### Experiment

<table>
<thead>
<tr>
<th>Decision Problem</th>
<th>$U(a, 1)$</th>
<th>$U(a, 2)$</th>
<th>$U(b, 1)$</th>
<th>$U(b, 2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>0</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>70</td>
<td>0</td>
<td>0</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>95</td>
<td>0</td>
<td>0</td>
<td>95</td>
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Attention and Incentives
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
In order to capture this behavior, we want a model that

- Recognizes attentional limits
- Allows attention to respond endogenously to incentives
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  • 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 Rational Inattention Model

- 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
The Rational Inattention Model

- The specifics of the process of information acquisition may be very complex.
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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 Rational Inattention Model

- 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

Objective states of the world

Nature

- G (1/6)
- M (1/2)
- B (1/3)
The Choice Problem

Objective states of the world

1/6

1/2

1/3

G

M

B

Subjective Signals

1

\gamma_1

\gamma_2

Nature

Information Structure
The Choice Problem

Objective states of the world

G
1/6

1/2

M

1/2

B
1/3

Subjective Signals

γ₁

1/2

γ₂

1/2

Nature

Information Structure
The Choice Problem

Objective states of the world
- G
- M
- B

Subjective Signals
- $\gamma_1$
- $\gamma_2$

Nature Information Structure Acts

1/6
1/2
1/3

1/2
1/2
1

H
L
State Dependent Stochastic Choice Data

- 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

What could we observe in this experiment?

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• ‘Standard’ choice data?
  • Which action is chosen in one repetition

Easy to collect in the lab
Possible outside?
An Experimental Example

- ‘Standard’ choice data?
  - Which action is chosen in one repetition
- Stochastic choice data
  - Probability of choosing each alternative

State dependant stochastic choice

Probability of choosing each action in each objective state of the world

Action

State = 49 red balls

\[ P(a | 49) \]

State = 51 red balls

\[ P(a | 51) \]

Easy to collect in the lab

Possible outside?
An Experimental Example

- ‘Standard’ choice data?
  - Which action is chosen in one repetition
- Stochastic choice data
  - Probability of choosing each alternative
- **State dependant** stochastic choice
  - Probability of choosing each action in each objective state of the world
An Experimental Example

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- Stochastic choice data
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- **State dependant** stochastic choice
  - Probability of choosing each action in each objective state of the world

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<th>Action</th>
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<tr>
<td>Prob choose $a$</td>
<td>$P(a</td>
<td>49)$</td>
</tr>
<tr>
<td>Prob choose $b$</td>
<td>$P(b</td>
<td>49)$</td>
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An Experimental Example

- ‘Standard’ choice data?
  - Which action is chosen in one repetition
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<td>$P(b</td>
<td>49)$</td>
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- Easy to collect in the lab
  - Possible outside?
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.
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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 \( \tilde{\gamma}^a \)
- Probability of signal \( \tilde{\gamma}^a \) in any state is the same as the probability of choosing action in that state

This is the ‘revealed information structure’
Recovering Information Structures

Objective states of the world

Subjective Signal

Observed Information Structure

Nature

Information Structure
• What if decision maker is not well behaved?
Same Action in Different States

Objective states of the world

Subjective Signal

Observed Information Structure

Nature

Information Structure

Garbling
Observing Information Structures

- 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
1. Attention is a Scarce Resource
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5. Theoretical Progress
6. Open Questions and Next Steps
• In recent papers we have used this insight to establish the testable implications of rational inattention
• Key question: what is the cost function?
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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
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Key question: what is the cost function?

We take two approaches:

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

- Example of a testable prediction from the ‘agonistic’ model
- No Improving Attention Cycles (NIAC)
- Guarantees the existence of a rationalizing cost function
Optimal Choice of Attention Strategy
Decision Problem 1

<table>
<thead>
<tr>
<th>Action</th>
<th>Payoff 49 red balls</th>
<th>Payoff 51 red balls</th>
</tr>
</thead>
<tbody>
<tr>
<td>a_1</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>b_1</td>
<td>0</td>
<td>10</td>
</tr>
</tbody>
</table>

Prior: \{0.5, 0.5\}

<table>
<thead>
<tr>
<th>Action</th>
<th>State = 49 red balls</th>
<th>State = 51 red balls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prob choose a</td>
<td>(\frac{3}{4})</td>
<td>(\frac{1}{4})</td>
</tr>
<tr>
<td>Prob choose b</td>
<td>(\frac{1}{4})</td>
<td>(\frac{3}{4})</td>
</tr>
</tbody>
</table>
### Optimal Choice of Attention Strategy

**Decision Problem 2**

<table>
<thead>
<tr>
<th>Action</th>
<th>Payoff 49 red balls</th>
<th>Payoff 51 red balls</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a^2$</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>$b^2$</td>
<td>0</td>
<td>20</td>
</tr>
</tbody>
</table>

Prior: \{0.5, 0.5\}

<table>
<thead>
<tr>
<th>Action</th>
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<tbody>
<tr>
<td>Prob choose $a$</td>
<td>$\frac{2}{3}$</td>
<td>$\frac{1}{3}$</td>
</tr>
<tr>
<td>Prob choose $b$</td>
<td>$\frac{1}{3}$</td>
<td>$\frac{2}{3}$</td>
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</table>
Optimal Choice of Attention Strategy

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

<table>
<thead>
<tr>
<th>$G$</th>
<th>$\pi_1^1$</th>
<th>$\pi_2^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>${a^1, b^1}$</td>
<td>$7\frac{1}{2}$</td>
<td>$6\frac{2}{3}$</td>
</tr>
<tr>
<td>${a^2, b^2}$</td>
<td>$15$</td>
<td>$13\frac{1}{3}$</td>
</tr>
</tbody>
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Optimal Choice of Attention Strategy

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

<table>
<thead>
<tr>
<th></th>
<th>$\bar{\pi}^1$</th>
<th>$\bar{\pi}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>${a^1, b^1}$</td>
<td>7 $\frac{1}{2}$</td>
<td>6 $\frac{2}{3}$</td>
</tr>
<tr>
<td>${a^2, b^2}$</td>
<td>15</td>
<td>13 $\frac{1}{3}$</td>
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</tbody>
</table>

- Cost function must satisfy

$$G(\{a^1, b^1\}, \pi^1) - K(\pi^1) \geq G(\{a^1, b^1\}, \pi^2) - K(\pi^2)$$
$$G(\{a^2, b^2\}, \pi^2) - K(\pi^2) \geq G(\{a^2, b^2\}, \pi^1) - K(\pi^1)$$
Optimal Choice of Attention Strategy

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

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\[
G(\{a^1, b^1\}, \pi^1) - K(\pi^1) \geq G(\{a^1, b^1\}, \pi^2) - K(\pi^2) \\
G(\{a^2, b^2\}, \pi^2) - K(\pi^2) \geq G(\{a^2, b^2\}, \pi^1) - K(\pi^1)
\]

- Which implies

\[
\frac{5}{6} = G(\{a^1, b^1\}, \pi^1) - G(\{a^1, b^1\}, \pi^2) \geq K(\pi^1) - K(\pi^2) \geq G(\{a^2, b^2\}, \pi^1) - G(\{a^2, b^2\}, \pi^2) = 1\frac{2}{3}
\]
• Surplus must be maximized by observed assignments

\[ G(\{a^1, b^1\}, \pi^1) + G(\{a^2, b^2\}, \pi^2) \]

\[ \geq G(\{a^1, b^1\}, \pi^2) + G(\{a^2, b^2\}, \pi^1) \]

• 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
Consider decision problem (i)

<table>
<thead>
<tr>
<th></th>
<th>$\omega_1$</th>
<th>$\omega_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prior Probability</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Payoff Action A</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Payoff Action B</td>
<td>0</td>
<td>10</td>
</tr>
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</table>
Invariance Under Compression - An Example

- Consider decision problem \((i)\)

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</tr>
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<td>0</td>
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</table>

- And now decision problem \((ii)\) which splits \(\omega_2\)

<table>
<thead>
<tr>
<th>State</th>
<th>(\omega_1)</th>
<th>(\omega_2)</th>
<th>(\omega_3)</th>
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Invariance Under Compression - An Example

- 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)
Invariance Under Compression - An Example

• 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 \((i)\)

• Shannon model says that behavior should not change
  • \(P_i(a|\omega_2) = P_{ii}(a|\omega_2) = P_{ii}(a|\omega_3)\)
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What are the Open Questions

- Now we know what rationally inattentive behavior looks like, when is it appropriate model of behavior?
What are the Open Questions

- Now we know what rationally inattentive behavior looks like, when is it appropriate model of behavior?
- What are the appropriate costs for inattention
  - Can we develop a parsimonious usable model which is fit for purpose?
Now we know what rationally inattentive behavior looks like, when is it appropriate model of behavior?

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]
- How does instrumental demand for information relate to other motivators?
  - Curiosity/fear
  - Preference for early resolution of uncertainty
- 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
## Experiment 2

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<thead>
<tr>
<th>Decision Problem</th>
<th>Payoffs</th>
<th></th>
<th></th>
<th></th>
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<td>$U(a, 1)$</td>
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<td>$U(b, 1)$</td>
<td>$U(b, 2)$</td>
</tr>
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<tr>
<td>4</td>
<td>95</td>
<td>0</td>
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</table>

- 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
• NIAC: Ensures data is rationalizable according to some cost function
• Requires that surplus cannot be increased by reassigning information structures to decision problems
• In this experiment: Proportion of correct choices weakly increasing with incentives
• From the aggregate data
Recovering Costs - Individual Level

High Fixed Cost, Low Marginal Cost

Low Fixed Cost

High Fixed Cost, High Marginal Cost
Observation of choice accuracy for $x = 2$ pins down $\lambda$
Shannon Mutual Information Costs

- Implies expansion path for all other values of $x$
In aggregate, subjects respond less slowly than Shannon predicts.
Individual Level Data

- 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