Inference and Learning from Others
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- Complexity-based bounded rationality
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- Biased reasoning about self
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  - What effects of these errors?
Cursed Thinking:
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- People under-infer information from others’ behavior.
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  - ubiquitous imitation
  - overconfidently wrong social beliefs
Plugging my papers on inferring from others:
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- Eyster and Rabin (2005), *Econometrica*
- Eyster and Rabin (2010), *AEJ Theory*
- Eyster and Rabin (2012)
- Eyster, Rabin, and Vayanos (2013),
- **Eyster and Rabin (2013),**
- Eyster, Rabin, and Weizsacker (in progress)
- Gagnon-Bartsch and Rabin (in progress)
Extensive Imitation is Irrational and Harmful

Introduction

Today
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1 How Not to Cure Syphilis
Extensive Imitation is Irrational and Harmful

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1. How Not to Cure Syphilis
2. Rational Observational Learning
Extensive Imitation is Irrational and Harmful

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   - Behavioral implications
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Note: Today and virtually all on this topic → Erik Eyster
Rational-Herding Literature:
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- People infer from actions of those with similar tastes.
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Efficiency facts of rational-herding models:
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- Observing others always helps in expected terms.
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- Not of society (frequently) thinking it knows things it doesn’t.
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- High likelihood wrong herds only if those herds are unconfident.
- Rational-herding literature is about failure to aggregate information.
- Not of society (frequently) thinking it knows things it doesn’t.
- (Debated in literature: is even non-aggregation really likely?)
Extensive Imitation is Irrational and Harmful

Introduction

We think:
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- *Limits* to imitation perhaps bigger punchline than imitation itself.
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But:

- We are skeptical people so reluctant to imitate.
Extensive Imitation is Irrational and Harmful

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- Historical example: mercury
- Extended illustrative example
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  - redundancy neglect and mislearning

...
“A night with venus, and a lifetime with mercury”
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Late 15th to mid-20th century, syphilis wreaked havoc on the world.
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- Tens of millions had disease, millions died from it
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  - Many, especially military doctors with statistics, had their doubts
  - But continued to be widely used until penicillin
  - Partially superseded by the arsenic derivative salvarsan in 1909
  - (But standard practice was to combine salvarsan with mercury)
Why used so long?
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- Hard to prove, even now, that it was, on net, a bad idea.
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- *Not* arguing it was a dumb idea
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- If so, how could doctors get it wrong for over 400 years
- Even if not, doctors had such faith—but we still don’t know?

Note:

- *Not* arguing it was a dumb idea
- Asking why used for 450 years.
Paper: extended example, inspired by medical examples, of issues.
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- Trial and error of drugs.
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When most drugs false positives (and docs know this!),
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- Trial and error of drugs.
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When most drugs false positives (and docs know this!),

- the way rational herds self-correct: virtually guaranteed that bad drugs get abandoned by doctors with little personal evidence against who have observed massive number of doctors prescribing.
Extensive Imitation is Irrational and Harmful
A Night with Venus, a Lifetime with Mercury

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- Trial and error of drugs.
- Fully rational will eventually reject drugs that don’t work.
- Fure sure settle on effective drug
- But this requires extreme attention to redundancy.

When most drugs false positives (and docs know this!),

- the way rational herds self-correct: virtually guaranteed that bad drugs get abandoned by doctors with little personal evidence against who have observed massive number of doctors prescribing.
- And even mild redundancy neglect guarantees adoption of a bad drug.
Instead, now: extended example not in paper.
Instead, now: extended example not in paper.

- Mercury vs. this example vs. main model vs. Avery-Zemsky vs. dozens other examples ... all same.
Modification of the canonical two-state, two signal, two-restaurant model of social learning.
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- Two restaurants in town,
Modification of the canonical two-state, two signal, two-restaurant model of social learning.

- Two restaurants in town,
  - A and B, \( p(A \text{ good}, B \text{ bad}) = p(B \text{ good}, A \text{ bad}) = .5 \).
Modification of the canonical two-state, two signal, two-restaurant model of social learning.

- Two restaurants in town,
  - $A$ and $B$, $p(A \text{ good}, B \text{ bad}) = p(B \text{ good}, A \text{ bad}) = .5$.
  - Two states: $\omega_A \rightarrow A$ is good, $\omega_B \rightarrow B$ is good.

- Each of $\infty$ diners receives private signals $\in \{\alpha, \beta, \emptyset\}$
Modification of the canonical two-state, two signal, two-restaurant model of social learning.

- Two restaurants in town,
  - A and B, \( p(A \text{ good}, B \text{ bad}) = p(B \text{ good}, A \text{ bad}) = 0.5 \).
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- Each of \( \infty \) diners receives private signals \( \in \{ \alpha, \beta, \emptyset \} \)
- The signals are \textit{i.i.d.} conditional on the state,
Modification of the canonical two-state, two signal, two-restaurant model of social learning.

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- Each of $\infty$ diners receives private signals $\in \{\alpha, \beta, \emptyset\}$
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  - $\alpha$ supports $\omega_A$. 

(Northwestern University) Extensive Imitation is Irrational and Harmful Dining Out
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(Northwestern University) Extensive Imitation October 2, 2013 13 / 47
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  - $\emptyset$ uninformative.
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- Each of \( \infty \) diners receives private signals \( \in \{\alpha, \beta, \emptyset\} \)

- The signals are \( i.i.d. \) conditional on the state,
  - \( \alpha \) supports \( \omega_A \),
  - \( \beta \) supports \( \omega_B \),
  - \( \emptyset \) uninformative.
For each Player $k$,

- $\Pr[s_k = \alpha|\omega_A] = \Pr[s_k = \beta|\omega_B] = 0.7(1 - \eta)$ and
For each Player $k$,

- $\Pr[s_k = \alpha | \omega_A] = \Pr[s_k = \beta | \omega_B] = 0.7(1 - \eta)$ and
- $\Pr[\emptyset | \omega_A] = \Pr[\emptyset | \omega_B] = \eta$. 
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- $\Pr[\emptyset | \omega_A] = \Pr[\emptyset | \omega_B] = \eta$.
- $\eta = 0$, canonical binary-signal information structure.
For each Player $k$,

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- When $\eta \to 1$, information is very rare.
For each Player $k$,

- $\Pr[s_k = \alpha | \omega_A] = \Pr[s_k = \beta | \omega_B] = .7(1 - \eta)$ and
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- $\eta = 0$, canonical binary-signal information structure.
- When $\eta \to 1$, information is very rare.
- (Lots results independent of $\eta$)
Each Player $k$ chooses among nine choices: she can dine in Restaurant A, dine in Restaurant B, or dine at home.
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- Goes to a restaurant if she thinks there is more than 60% chance it is good, and stays at home if that is not true at either restaurant.
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- Goes to a restaurant if she thinks there is more than 60% chance it is good, and stays at home if that is not true at either restaurant.

- Depending on confidence in restaurant’s quality, may go alone, or take one, two, or three of her relatives.
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- Superscripts for the number of people she takes:
Each Player $k$ chooses among nine choices: she can dine in Restaurant A, dine in Restaurant B, or dine at home.

- Goes to a restaurant if she thinks there is more than 60% chance it is good, and stays at home if that is not true at either restaurant.

- Depending on confidence in restaurant’s quality, may go alone, or take one, two, or three of her relatives.

- Superscripts for the number of people she takes:

  \[ p(\omega_A) \] [0,10),[10,20),[20,30),[30,40) [40,60] (60,70],(70,80],(80,90],(90,100]

  Choice \[ B^{+++}, B^{++}, B^+, B \] \[ H \] \[ A, A^+, A^{++}, A^{+++} \]
Three people choose restaurants each period,
Three people choose restaurants each period,

- Signal conditionally i.i.d. given state
Three people choose restaurants each period,

- Signal conditionally i.i.d. given state
- Each after observing
Three people choose restaurants each period,

- Signal conditionally i.i.d. given state
- Each after observing her own signal,
Three people choose restaurants each period,

- Signal conditionally i.i.d. given state
- Each after observing her own signal, and the full actions (three locations, and party size), in order,
Three people choose restaurants each period,

- Signal conditionally i.i.d. given state
- Each after observing her own signal, and the full actions (three locations, and party size), in order, taken in all previous periods.
What predictions does full rationality make?
What predictions does full rationality make?

- $\emptyset$ signal, observes nothing but $H \rightarrow$ stay home.
What predictions does full rationality make?

- Ø signal, observes nothing but $H \rightarrow$ stay home.
- $\alpha$ or $\beta$ signal, observes nothing but $H \rightarrow$ go to restaurant.
What predictions does full rationality make?

- ∅ signal, observes nothing but $H \rightarrow$ stay home.
- $\alpha$ or $\beta$ signal, observes nothing but $H \rightarrow$ go to restaurant.
- (alone, because beliefs exactly $0.7 \rightarrow$ alone).
What predictions does full rationality make?

- $\emptyset$ signal, observes nothing but $H \rightarrow$ stay home.
- $\alpha$ or $\beta$ signal, observes nothing but $H \rightarrow$ go to restaurant.
- (alone, because beliefs exactly $0.7 \rightarrow$ alone).

Suppose in period 2 observe exactly one $A$ in period 1.
What predictions does full rationality make?

- $\emptyset$ signal, observes nothing but $H \rightarrow$ stay home.
- $\alpha$ or $\beta$ signal, observes nothing but $H \rightarrow$ go to restaurant.
- (alone, because beliefs exactly $.7 \rightarrow$ alone).

Suppose in period 2 observe exactly one $A$ in period 1.

- What do as a function of your signal?
What predictions does full rationality make?

- ∅ signal, observes nothing but $H \rightarrow$ stay home.
- $\alpha$ or $\beta$ signal, observes nothing but $H \rightarrow$ go to restaurant.
- (alone, because beliefs exactly .7 $\rightarrow$ alone).

Suppose in period 2 observe exactly one $A$ in period 1.

- What do as a function of your signal?
- You will realize that the three signals in period 1 were $\{\alpha, \emptyset, \emptyset\}$. 
What predictions does full rationality make?

- $\emptyset$ signal, observes nothing but $H \rightarrow$ stay home.
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Suppose in period 2 observe exactly one $A$ in period 1.

- What do as a function of your signal?
- You will realize that the three signals in period 1 were $\{\alpha, \emptyset, \emptyset\}$.
- $\beta \rightarrow H$. 
What predictions does full rationality make?

- $\emptyset$ signal, observes nothing but $H \rightarrow \text{stay home.}$
- $\alpha$ or $\beta$ signal, observes nothing but $H \rightarrow \text{go to restaurant.}$
- (alone, because beliefs exactly $.7 \rightarrow \text{alone}$).

Suppose in period 2 observe exactly one $A$ in period 1.

- What do as a function of your signal?
- You will realize that the three signals in period 1 were $\{\alpha, \emptyset, \emptyset\}$.
  - $\beta \rightarrow H$
  - $\emptyset \rightarrow A$.  

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What predictions does full rationality make?

- $\emptyset$ signal, observes nothing but $H \rightarrow$ stay home.
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Suppose in period 2 observe exactly one $A$ in period 1.

- What do as a function of your signal?
- You will realize that the three signals in period 1 were $\{\alpha, \emptyset, \emptyset\}$.
  - $\beta \rightarrow H$.
  - $\emptyset \rightarrow A$.
  - $\alpha \rightarrow A^{++}$
### Extensive Imitation is Irrational and Harmful

**Dining Out**

<table>
<thead>
<tr>
<th>actions</th>
<th>response</th>
</tr>
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<tbody>
<tr>
<td>Period 1:</td>
<td>{A, H, H}</td>
</tr>
<tr>
<td>Period 2:</td>
<td>{A, A, A}</td>
</tr>
</tbody>
</table>

Key logic: guys in period 2 did not get any additional information. (If did, would not have gone alone.) Period 3: rationally realize no new information in Period-2 followers.
| Period 1: | $\{A, H, H\}$ |
| Period 2: | $\{A, A, A\}$ |
| Period 3: | $\beta \rightarrow H$, $\emptyset \rightarrow A$, $\alpha \rightarrow A^{++}$ |
### Extensive Imitation is Irrational and Harmful

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<td></td>
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<td>{α, ∅, ∅}</td>
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<tr>
<td>Period 2</td>
<td>{A, A, A}</td>
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<td>{∅, ∅, ∅}</td>
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Period 3:

\[ \beta \rightarrow H, \varnothing \rightarrow A, \alpha \rightarrow A^{++} \]

- Key logic: guys in period 2 did not get any additional information.
### Extensive Imitation is Irrational and Harmful

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<tr>
<td>Period 3:</td>
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Extensive Imitation is Irrational and Harmful

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<td>Period 3:</td>
<td>{A, A, A}</td>
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<tr>
<td>Period 4:</td>
<td>{A, A, A}</td>
<td></td>
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<tr>
<td>Period 5:</td>
<td>{A, A, A}</td>
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Understanding redundancy information in actions: hard. But it matters a lot.
# Extensive Imitation is Irrational and Harmful

## Dining Out

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<tr>
<td>Period 5:</td>
<td>{A, A, A}</td>
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<tr>
<td>Period 6:</td>
<td>(\beta \rightarrow H, \emptyset \rightarrow A, \alpha \rightarrow A^{++})</td>
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### Extensive Imitation is Irrational and Harmful

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<table>
<thead>
<tr>
<th>Period</th>
<th>Actions ${A, H, H}$</th>
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<th>Signals ${\emptyset, \emptyset, \emptyset}$</th>
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<tr>
<td>Period 2:</td>
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- Understanding redundancy information in actions: hard.
### Extensive Imitation is Irrational and Harmful

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**Period 6:** \( β \rightarrow H, ∅ \rightarrow A, α \rightarrow A^{++} \)

- Understanding redundancy information in actions: hard.
- But it matters a lot.
Herding without sufficiently increased enthusiasm is a bad sign:

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<td>{\emptyset, \emptyset, \beta}</td>
</tr>
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<td>{∅, ∅, β}</td>
</tr>
<tr>
<td>Period 3:</td>
<td>β → B, ∅ → H, α → A</td>
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3 A, 3 H → ω_A, ω_B equally likely!
Herding without sufficiently increased enthusiasm is a bad sign:

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</tr>
<tr>
<td>Period 2: {A, A, H}</td>
<td>{∅, ∅, β}</td>
<td></td>
</tr>
<tr>
<td>Period 3: [β \rightarrow B, ∅ \rightarrow H, α \rightarrow A]</td>
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<td></td>
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</table>

3 \(A, 3H \rightarrow ω_A, ω_B\) equally likely!

- Do we get that?
Extensive Imitation is Irrational and Harmful

Dining Out

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### Actions and Response

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### Extensive Imitation is Irrational and Harmful

#### Dining Out

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</tr>
<tr>
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<td></td>
<td>( {\emptyset, \beta, \beta} )</td>
</tr>
<tr>
<td>Period 3:</td>
<td>( \beta \to B^{++}, \emptyset \to B, \alpha \to H )</td>
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You shouldn’t go to \(A\) even if get \(\alpha\)!
## Extensive Imitation is Irrational and Harmful

### Dining Out

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<tr>
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<tbody>
<tr>
<td>Period 2:</td>
<td>{H, H, H}</td>
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**Go to B no matter what!**

(Northwestern University)
Extensive Imitation is Irrational and Harmful

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<td>Period 1: {A, H, H}</td>
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Go to B no matter what!
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<td>${\beta, \beta, \beta}$</td>
</tr>
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<td>Period 3: $\beta \rightarrow B^{+++}$, $\emptyset \rightarrow B^{++}$, $\alpha \rightarrow B$</td>
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<td>{β, β, β}</td>
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<td>Period 3:</td>
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Go to \(B\) no matter what!

\(\Rightarrow\)
### Extensive Imitation is Irrational and Harmful

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<tr>
<td>2</td>
<td>{A^{++}, A, A}</td>
<td></td>
</tr>
<tr>
<td>3</td>
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*Northwestern University*
Extensive Imitation is Irrational and Harmful

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<tr>
<td>5</td>
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Will a β signal help stop the herd?
### Actions and Response

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<tr>
<td>Period 4</td>
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<tr>
<td>Period 5</td>
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<tr>
<td>Period 6</td>
<td></td>
<td>β → H, ∅ → A, α → A^{++}</td>
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Will a β signal help stop the herd?
### Extensive Imitation is Irrational and Harmful

#### Dining Out

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<tbody>
<tr>
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<tr>
<td>6</td>
<td>$\beta \to H$, $\emptyset \to A$, $\alpha \to A^{++}$</td>
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<td></td>
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</table>
Extensive Imitation is Irrational and Harmful

Dining Out

| Period 1: | Actions: \{A, H, H\} | Response: \{\alpha, \emptyset, \emptyset\} | Signals: \{\alpha, \emptyset, \emptyset\} |
| Period 2: | Actions: \{A^{++}, A, A\} | Response: \{\alpha, \emptyset, \emptyset\} | Signals: \{\alpha, \emptyset, \emptyset\} |
| Period 3: | Actions: \{A^{++}, A^{++}, A\} | Response: \{\emptyset, \emptyset, \beta\} | Signals: \{\emptyset, \emptyset, \beta\} |
| Period 4: | Actions: \{A^{++}, A^{++}, A\} | Response: \{\alpha, \alpha, \emptyset\} | Signals: \{\alpha, \alpha, \emptyset\} |
| Period 5: | Actions: \{A^{++}, A^{++}, A^{++}\} | Response: \{\beta, \beta, \beta\} | Signals: \{\beta, \beta, \beta\} |
| Period 6: | \beta \rightarrow H, \emptyset \rightarrow A, \alpha \rightarrow A^{++} |

Will a \beta signal help stop the herd?

\(\n\)
Dining Out

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<tbody>
<tr>
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Extensive Imitation is Irrational and Harmful

Dining Out

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<tr>
<td>Period 3:</td>
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### Extensive Imitation is Irrational and Harmful

**Dining Out**

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- Enough.
Extensive Imitation is Irrational and Harmful

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- Enough.

- Things fare more complicated if
### Extensive Imitation is Irrational and Harmful

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- Enough.

- Things fare more complicated if don’t observe order
### Extensive Imitation is Irrational and Harmful

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<td>{\beta, \beta, \beta}</td>
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<tr>
<td>Period 3:</td>
<td></td>
<td>(\beta \rightarrow B, \emptyset \rightarrow H, \alpha \rightarrow A)</td>
<td></td>
</tr>
</tbody>
</table>

- Enough.

- Things fare more complicated if don’t observe order don’t observe all

---

(Northwestern University) Extensive Imitation October 2, 2013 25 / 47
Extensive Imitation is Irrational and Harmful

Dining Out

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- Enough.

- Things fare more complicated if don’t observe order don’t observe all heterogenous preferences
Extensive Imitation is Irrational and Harmful
Dining Out

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- Enough.

- Things fare more complicated if don’t observe order don’t observe all heterogenous preferences
  - But nothing makes the severe limits to imitation go away
Same setting (same signals, players per period, etc.) but:
Extensive Imitation is Irrational and Harmful

Dining Out

Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
Extensive Imitation is Irrational and Harmful

Dining Out

Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
Extensive Imitation is Irrational and Harmful

Dining Out

Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
  - If see \{H, H, H, H, H, H\}, then believe
Extensive Imitation is Irrational and Harmful

Dining Out

Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
  - If see \( \{H, H, H, H, H, H\} \), then believe \( .5 \)
Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
  - If see \{H, H, H, H, H, H\}, then believe .5
  - If see \{A, H, H, H, H, H\}, then believe
Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
  - If see \( \{H, H, H, H, H, H\} \), then believe .5
  - If see \( \{A, H, H, H, H, H\} \), then believe .7
Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
  - If see \( \{H, H, H, H, H, H\} \), then believe .5
  - If see \( \{A, H, H, H, H, H\} \), then believe .7
  - If see \( \{A, A, H, H, H, H\} \), then believe
Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
  - If see \( \{H, H, H, H, H, H\} \), then believe \( .5 \)
  - If see \( \{A, H, H, H, H, H\} \), then believe \( .7 \)
  - If see \( \{A, A, H, H, H, H\} \), then believe \( .84 \)
Dining Out

Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
  - If see $\{H, H, H, H, H, H\}$, then believe $0.5$
  - If see $\{A, H, H, H, H, H\}$, then believe $0.7$
  - If see $\{A, A, H, H, H, H\}$, then believe $0.84$
  - If see $\{A, A, A, H, H, H\}$, then believe
Extensive Imitation is Irrational and Harmful

Dining Out

Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
  - If see \( \{H, H, H, H, H, H\} \), then believe .5
  - If see \( \{A, H, H, H, H, H\} \), then believe .7
  - If see \( \{A, A, H, H, H, H\} \), then believe .84
  - If see \( \{A, A, A, H, H, H\} \), then believe .5

(Example combines Callender-Horner and Eyster-Rabin intuitions)

One old and one new example:
Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
  - If see \(\{H, H, H, H, H, H\}\), then believe \(0.5\)
  - If see \(\{A, H, H, H, H, H\}\), then believe \(0.7\)
  - If see \(\{A, A, H, H, H, H\}\), then believe \(0.84\)
  - If see \(\{A, A, A, H, H, H\}\), then believe \(0.5\)
  - If see \(\{A, A, A, A, H, H\}\), then believe

(Example combines Callender-Horner and Eyster-Rabin intuitions)
Same setting (same signals, players per period, etc.) but:

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  - If see \( \{A, H, H, H, H, H\} \), then believe 0.7
  - If see \( \{A, A, H, H, H, H\} \), then believe 0.84
  - If see \( \{A, A, A, H, H, H\} \), then believe 0.5
  - If see \( \{A, A, A, A, H, H\} \), then believe 0.7
Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**

In period 3,

- If see \( \{ H, H, H, H, H, H \} \), then believe 0.5
- If see \( \{ A, H, H, H, H, H \} \), then believe 0.7
- If see \( \{ A, A, H, H, H, H \} \), then believe 0.84
- If see \( \{ A, A, A, H, H, H \} \), then believe 0.5
- If see \( \{ A, A, A, A, H, H \} \), then believe 0.7
- If see \( \{ A, A, A, A, A, H \} \), then believe
Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**

In period 3,

- If see \(\{H, H, H, H, H, H\}\), then believe \(.5\)
- If see \(\{A, H, H, H, H, H\}\), then believe \(.7\)
- If see \(\{A, A, H, H, H, H\}\), then believe \(.84\)
- If see \(\{A, A, A, H, H, H\}\), then believe \(.5\)
- If see \(\{A, A, A, A, H, H\}\), then believe \(.7\)
- If see \(\{A, A, A, A, A, H\}\), then believe \(.3\)
Same setting (same signals, players per period, etc.) but:

- Cannot observe order of play.
- **Signals rare**
- In period 3,
  - If see \( \{H, H, H, H, H, H\} \), then believe \( .5 \)
  - If see \( \{A, H, H, H, H, H\} \), then believe \( .7 \)
  - If see \( \{A, A, H, H, H, H\} \), then believe \( .84 \)
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(Example combines Callender-Horner and Eyster-Rabin intuitions)
Same setting (same signals, players per period, etc.) but:

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  - If see \(\{H, H, H, H, H, H\}\), then believe \(0.5\)
  
  - If see \(\{A, H, H, H, H, H\}\), then believe \(0.7\)
  
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(Example combines Callender-Horner and Eyster-Rabin intuitions)

One old and one new example:
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**Anti-imitation!**

(ESDU)
Harder to see:
Harder to see:

- Rational observational learning in this case:
Harder to see:

- Rational observational learning in this case:
  - Eventually will herd on \(B^{+++}\) or \(A^{+++}\).
Harder to see:

- Rational observational learning in this case:
  - Eventually will herd on $\{B^{+++}\}$ or $\{A^{+++}\}$.
  - More than 95% of time $\rightarrow$ right restaurant.
Harder to see:

- Rational observational learning in this case:
  - Eventually will herd on \( \{B^{+++}\} \) or \( \{A^{+++}\} \).
  - More than 95% of time $\rightarrow$ right restaurant.
  - Intuition: any lesser certainty, contrary signal will moderate behavior.
Harder to see:

- Rational observational learning in this case:
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  - More than 95% of time → right restaurant.
  - Intuition: any lesser certainty, contrary signal will moderate behavior.

- When signals rare:
Harder to see:

- Rational observational learning in this case:
  - Eventually will herd on \( B^{+++} \) or \( A^{+++} \).
  - More than 95% of time \( \rightarrow \) right restaurant.
  - Intuition: any lesser certainty, contrary signal will moderate behavior.

- When signals rare:
  - Roughly 30% of time herd starts in wrong direction,
Extensive Imitation is Irrational and Harmful

Dining Out

Harder to see:

- Rational observational learning in this case:
  - Eventually will herd on \( B^{+++} \) or \( A^{+++} \).
  - More than 95% of time → right restaurant.
  - Intuition: any lesser certainty, contrary signal will moderate behavior.

- **When signals rare:**
  - Roughly 30% of time herd starts in wrong direction,
  - stays wrong < 5% time.
Harder to see:

- **Rational observational learning in this case:**
  - Eventually will herd on \( \{B^{+++}\} \) or \( \{A^{+++}\} \).
  - More than 95% of time → right restaurant.
  - Intuition: any lesser certainty, contrary signal will moderate behavior.

- **When signals rare:**
  - Roughly 30% of time herd starts in wrong direction,
  - stays wrong < 5% time.
  - → > 25% of time: herd in wrong direction followed by reversal...
Harder to see:

- **Rational observational learning in this case:**
  - Eventually will herd on \( \{B^{+++}\} \) or \( \{A^{+++}\} \).
  - More than 95% of time → right restaurant.
  - Intuition: any lesser certainty, contrary signal will moderate behavior.

- **When signals rare:**
  - Roughly 30% of time herd starts in wrong direction,
  - stays wrong < 5% time.
  - \( \rightarrow > 25\% \) of time: herd in wrong direction followed by reversal...
  - somebody observing at least 50 people going to one restaurant and none to other decides stay home based on opposite signal.
Harder to see:

- **Rational observational learning in this case:**
  - Eventually will herd on \( \{B^{+++}\} \) or \( \{A^{+++}\} \).
  - More than 95% of time → right restaurant.
  - Intuition: any lesser certainty, contrary signal will moderate behavior.

- **When signals rare:**
  - Roughly 30% of time herd starts in wrong direction,
  - stays wrong < 5% time.
  - → > 25% of time: herd in wrong direction followed by reversal...
  - somebody observing at least 50 people going to one restaurant and none to other decides stay home based on opposite signal.
When signals are rare,
When signals are rare,

- Tommy:
When signals are rare,

- Tommy:
  - less than 5% chance society converges to wrong restaurant,
When signals are rare,

- **Tommy:**
  - less than 5% chance society converges to wrong restaurant,
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**Now:** formal, continuous framework
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Now: formal, continuous framework

- Lots of structure ... simple results
- Two possible states, $\omega \in \{0, 1\}$, *ex ante* equally likely
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Players \(\{1, 2, \ldots\}\) receive private signal
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Extensive Imitation is Irrational and Harmful
Impartial Inference and the Limits of Imitation

- \( F_k^{(0)} \) and \( F_k^{(1)} \) mutually absolutely continuous
  - no signal reveals the state with certainty;
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- $\mathcal{N} = \{\{1, 2, \ldots\}, \{D(1), D(2), \ldots\}\}$ is observation structure
Player $k$ chooses action $\alpha_k \in [0, 1]$ to maximize $E\{- (\alpha_k - \omega)^2\}$
given her information, $l_k$:

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Extensive Imitation is Irrational and Harmful
Impartial Inference and the Limits of Imitation

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Central definition:

**Definition**

The quadruple of distinct players \((i, j, k, l)\) in \(N\) forms a diamond if

\[ i \in ID(j) \cap ID(k), \; j \notin ID(k), \; k \notin ID(j), \; \text{and} \; \{j, k\} \subseteq D(l) \]
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- Player $i$ observed by $j$ and $k$, and $j$ and $k$ observed by $l$, and $j$ and $k$ don’t observe each other.
- Canonical single-file models of Banerjee (1992) and Bikchandani, Hirshleifer, and Welch (1992) do not include diamonds
We wish to abstract from difficulties that arise when players can partially but not fully infer their predecessors’ signals.
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Look at diamonds that are “shields”: $j$ and $k$ don’t observe each other, but do observe $i$. $l$ observes $j$, $k$, and $i$. 
Extensive Imitation is Irrational and Harmful

Impartial Inference and the Limits of Imitation

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- Look at diamonds that are “shields”: $j$ and $k$ don’t observe each other, but do observe $i$. $l$ observes $j$, $k$, and $i$.

**Definition**

$k$ imitates $j$ if $a_k(a_j, a^k_j; s_k)$ is weakly increasing (but not constant) in $a_j$.

**Definition**

$k$ anti-imitates $j$ if $a_k(a_j, a^k_j; s_k)$ weakly decreasing (not constant) in $a_j$. 

(Note: Northwestern University)
• $k$ anti-imitates $j$ if $k$’s action moves in the opposite direction as $j$’s—holding everyone else’s action fixed
Extensive Imitation is Irrational and Harmful

Impartial Inference and the Limits of Imitation

- $k$ anti-imitates $j$ if $k$’s action moves in the opposite direction as $j$’s—holding everyone else’s action fixed
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Extensive Imitation is Irrational and Harmful
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**Proposition**

_Assume the observation structure \( \mathcal{N} \) generates impartial inference. Then some player anti-imitates another if and only if \( \mathcal{N} \) contains a shield._
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Proposition

Assume the observation structure $\mathcal{N}$ generates impartial inference. Then some player anti-imitates another if and only if $\mathcal{N}$ contains a shield

Proposition 1 shows that any impartial-inference setting that contains a shield includes at least one player who anti-imitates another
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**Proposition**

*Assume the observation structure $\mathcal{N}'$ generates impartial inference. Then some player anti-imitates another if and only if $\mathcal{N}$ contains a shield.*

• Proposition 1 shows that any impartial-inference setting that contains a shield includes at least one player who anti-imitates another
• Proof does some accounting based on simple single-shield correlation-subtraction intuition.
In settings where rational people do not anti-imitate, they do not do very much imitation
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- More generally: if no player anti-imitates, then no player imitates two predecessors who both observe an earlier, common predecessor
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- Single-file: each person imitates only her immediate predecessor
- More generally: if no player anti-imitates, then no player imitates two predecessors who both observe an earlier, common predecessor
- But sharing no common observation excludes virtually all social learners (except at the beginning) in almost all settings of interest
Rational social learning also may lead some players to form beliefs on the opposite side of their priors than all their information.
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**Definition**

Player $k$’s action $a_k$ is *contrarian* given signal $s_k$ and history $a_{k-1}$ iff $a_k \neq 0$ and $\text{sgn}(a_k) = -\text{sgn}(s_k) = -\text{sgn}(a_j)$ for every $j \in D(k)$. 
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**Proposition**

Assume $\mathcal{N}$ generates impartial inference.

1. If some player’s action is contrarian, then $\mathcal{N}$ contains a shield.
2. If $\mathcal{N}$ contains a shield and players’ private signals are drawn from the density $f(\omega)$ that is everywhere positive on $[s, \bar{s}]$, then with positive probability some player’s action is contrarian.
To illustrate our model, consider: $n$ players move in each *round*,

\[
A_t = \sum_{k=1}^{n} a_k t, \text{ the sum of round-} t \text{ actions,}
\]
\[
S_t = \sum_{k=1}^{n} s_k t, \text{ the sum of round-} t \text{ signals}
\]

Then:

\[
A_t = S_t + n t \sum_{i=1}^{n} \left( \frac{1}{i} \right)^{1} \left( \frac{n}{i} \right)^{1} A_t^i \]
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Then:

$$A_t = S_t + n \sum_{i=1}^{t-1} (-1)^{i-1} (n-1)^{i-1} A_{t-i}$$
When $n = 1$, $A_t = S_t + A_{t-1}$
- Players imitate only their immediate predecessors, do not anti-imitate
Extensive Imitation is Irrational and Harmful

Impartial Inference and the Limits of Imitation

- When $n = 1$, $A_t = S_t + A_{t-1}$
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- When $n = 2$, players imitate and anti-imitate alternating rounds with coefficients of constant magnitude:
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- When $n = 3$, the coefficients on past actions grow exponentially:
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When $n = 3$, the coefficients on past actions grow exponentially:

$$A_t = S_t + 3 \sum_{i=1}^{t-1} (-1)^{i-1} 2^{i-1} A_{t-i},$$

Leading to
Extensive Imitation is Irrational and Harmful
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  - Leading to
    - $A_1 = S_1$, $A_2 = S_2 + 3A_1$
    - $A_3 = S_3 + 3A_2 - 6A_1$
    - $A_4 = S_4 + 3S_3 - 6A_2 + 12A_1$
What happens if people do not anti-imitate, and imitate more broadly than predicted by full rationality?
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- Broad class of rules with minimal restrictions on use own signal:
Extensive Imitation is Irrational and Harmful

Redundancy Neglect

What happens if people do not anti-imitate, and imitate more broadly than predicted by full rationality?

- Broad class of rules with minimal restrictions on use own signal:

**Definition**

Social learning is *strictly and boundedly increasing in private signals* if

1. (strictly increasing) for each Player $t$, and each $a^{t-1} \in \mathbb{R}^{t-1}$,

   $\hat{s}^t > s^t \Rightarrow a_t(a^{t-1}, \hat{s}_t) > a_t(a^{t-1}, s_t)$

2. (boundedly increasing) there exists $K \in \mathbb{R}_{++}$ such that for each Player $t$, each $a^{t-1} \in \mathbb{R}^{t-1}$, and each $s^t, \hat{s}^t \in \mathbb{R}$,

   \[ |a_t(a^{t-1}, \hat{s}_t) - a_t(a^{t-1}, s_t)| \leq K |\hat{s}_t - s_t| \]
Excludes: people ignore or put arbitrarily high weight on own signals
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- Excludes: people ignore or put arbitrarily high weight on own signals
- Encompasses many forms of non-Bayesian belief updating, including cases where people overconfidently overweight their own signal
Extensive Imitation is Irrational and Harmful

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- Excludes: people ignore or put arbitrarily high weight on own signals
- Encompasses many forms of non-Bayesian belief updating, including cases where people overconfidently overweight their own signal
- Main assumption: people under-attend to redundancy in predecessors’ actions:

Players use social-learning rules that neglect redundancy if there exist an integer $N$ and a constant $c > 0$ with the property that for each Player $t \geq N + 1$, each $a_t \neq N + 1$, each $s_t \neq a_t$, and each $z_0 > z_0$, we have:

$$a_t(a_t \neq N + 1, z_0, z_0, \ldots, z_0, \{z\}_N) a_t(a_t \neq N + 1, z, z, \ldots, z) \leq (1 + c)(z_0 - z_0).$$
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$$a_t(a^{t-N-1}, z', z', \ldots, z', s_t) - a_t(a^{t-N-1}, z, z, \ldots, z, s_t) \geq (1 + c)(z' - z)$$

\[N\text{ times}\] \hspace{1cm} \[N\text{ times}\]
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But generally this will not be the case—redundancy neglect embodies the error of reading more than one conditionally independent piece of information into recent predecessors’ actions
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But generally this will not be the case—redundancy neglect embodies the error of reading more than one conditionally independent piece of information into recent predecessors’ actions

RN is joint assumption about observation structure and imitation
E.g., if Player \( t \)'s two immediate predecessors choose actions based solely on their private signals \((a_{t-1} = s_{t-1}, a_{t-2} = s_{t-2})\);

if both raised their action from some \( z \) to \( z' \), then Player \( t \), if observing both, would increase her action by \( 2(z' - z) \)

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RN is joint assumption about observation structure and imitation

- encompasses all sorts of combinations of assumptions about whom people observe and whom they imitate
Also allows people to under-infer from their predecessors, as in partially-cursed equilibrium (Eyster and Rabin (2005)), so long as they neglect redundancy:
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- someone can treat all predecessors’ actions as half as informative as they are at the same time as she mistakenly imitates many predecessors instead of just one.
Also allows people to under-infer from their predecessors, as in partially-cursed equilibrium (Eyster and Rabin (2005)), so long as they neglect redundancy:

someone can treat all predecessors’ actions as half as informative as they are at the same time as she mistakenly imitates many predecessors instead of just one.

The condition is, intuitively, that the sum total of influence from underweighting individuals and overcounting predecessors is greater than the influence of one person, correctly interpreted.
Proposition

Suppose players social-learning rules are strictly and boundedly increasing in private signals as well as neglect redundancy, and that no player anti-imitates any other. Then, with positive probability, society converges to the action that corresponds to certain beliefs in the wrong state.
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- Redundancy neglect and the absence of anti-imitation do not merely prevent society from learning
- but instead cause it to mislearn
- redundancy-neglecting doctors can converge with near certainty to a bad medicine ... and believe it works with near certainty
When players move single-file and observe all predecessors, BRTNI players (Eyster and Rabin, 2010), who interpret each predecessor’s action as her private signal, satisfy redundancy neglect with $c = N - 1$ for each $N$ and mislearn with positive probability.
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Reminder: results do not depend upon details of our environment
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When observed recent actors provide independent information, they should all be imitated
Reminder: results do not depend upon details of our environment

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But when those recent players themselves imitate earlier actions, those earlier actions should be subtracted