# **State Pooling and Belief Polarization**

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Columbia University - Cognition and Decision Lab Meeting

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# **The Experiment**

- Laboratory experiment, about 1 hour
- Four tasks (tasks 3 and 4 are robustness checks)
- ▶ Do you think we should add other standardized tests at the end? E.g. risk preference elicitation [Eckel-Grossman], fluid intelligence [Raven matrices]. Ambuehl and Li (2018) add a questionnaire with demographic variables, psychological measures, and Cognitive Reflection Test

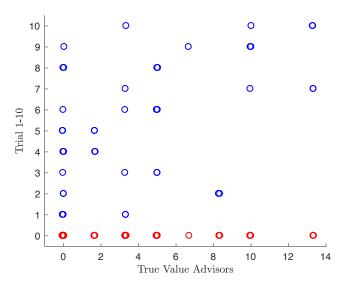
► Link to the demo

# Task 1

### Task 1 - WTP for Advisors

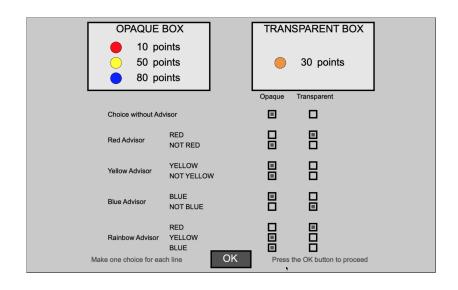
- Order of questions: signal-contingent actions first, WTP for hiring later (random order of the four advisors)
- Currently you are not reminded which action you chose in the first part
- We are changing only the payoffs of the yellow and gray ball. Any reason to change the red and blue as well?

## Task 1 - DGP

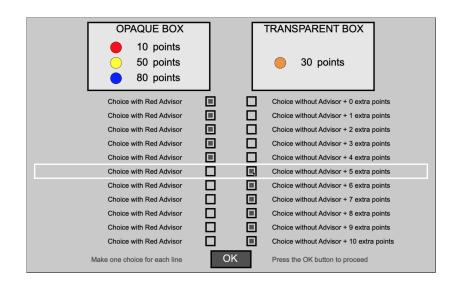


Value of the Advisors in each trial (blue) and across the task (red).

#### Task 1 - Choice screen



## Task 1 - Hiring screen

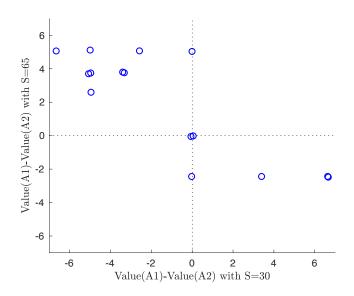


# Task 2

# Task 2 - Binary choice between Advisors

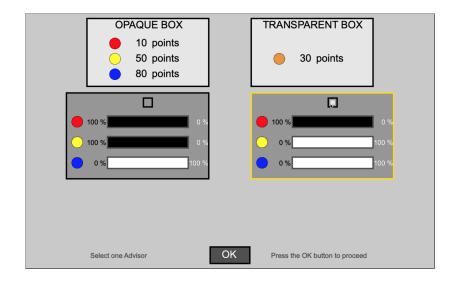
- ► In order to simplify the task we are using advisor probabilities as multiples of 25%
- ► Would it be clearer to use four cases (black/white balls) instead of the black/white bar?
- Currently black and white are randomized, so it is not immediate what action to take just by looking at the color [otherwise we should hint or explain the mechanism, it does not seem desirable]
- ▶ The opaque box has fixed values (10,50,80), the transparent box has only two possible values (30 or 65). Should I use two colors (orange and green) to indicate those two? Or keep the gray?

## Task 2 - DGP

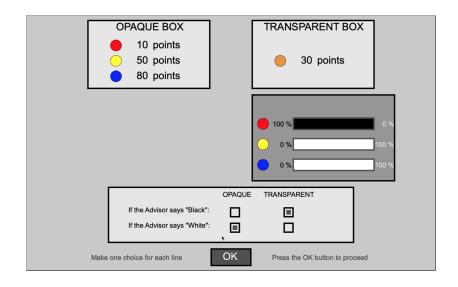


Value difference between Advisors when S=30 and S=65.

# **Task 2 - Hiring screen**



#### Task 2 - Choice screen

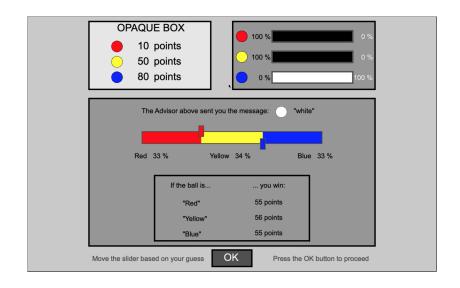


# Task 3

# Task 3 - Eliciting belief over 3 states

We are using quadratic score, that is NOT strategyproof [you can get up to a 4% higher EV by using small deviations]. Better ideas?

### Task 3 - Belief elicitation

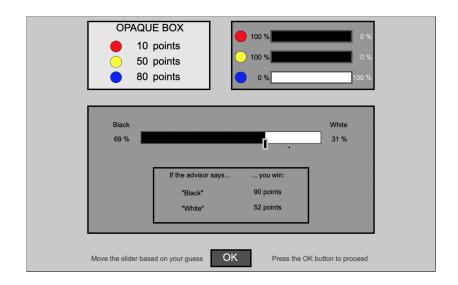


# Task 4

# Task 4 - Eliciting belief over 2 messages

- ► This part seems solid
- ► Should we put this easy task first, and the more difficult one with 3 states later?

#### Task 4 - Belief elicitation



## **Previous Presentation**

- Motivating Example
- Research Question
- Related Literature
- State Pooling Model
- Laboratory Experiment

# MOTIVATING EXAMPLE

### Setting

- Alice and Bob face a choice: go to the Theater or stay Home
  - ► Theater: uncertainty about the quality of the movie [state *s*]
  - ► Home: "safe" choice [status quo]

	Theater	Home	
S	$v_i^T(s)$	$v_A^H(s)$	$v_B^H(s)$
bad	0	0.45	0.55
medium	0.5	0.45	0.55
good	1	0.45	0.55

► Assume uniform prior  $p_s = \frac{1}{3}$  and risk neutrality

- ► Alice and Bob have the same beliefs over *s* and *EV*(Theater)
  - $\triangleright$  *EV*(Theater) = 0.5
- Alice and Bob make different choices
  - A chooses Theater as 0.5 = EV(Theater) > EV(Home) = 0.45
  - ▶ B chooses Home as 0.5 = EV(Theater) < EV(Home) = 0.55

	Theater	Home	
S	$v_i^T(s)$	$v_A^H(s)$	$v_B^H(s)$
bad	0	0.45	0.55
medium	0.5	0.45	0.55
good	1	0.45	0.55

- Same problem as before, but now A and B can collect "some" information about the movie quality
- ▶ Note that we have 2 actions (T/H) and 3 states (b/m/g)
  - ► For Alice it is *sufficient* to know if the movie is b or (m/g)

	Theater	Home	
S	$v_i^T(s)$	$v_A^H(s)$	$v_B^H(s)$
bad	0	0.45	0.55
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- Same problem as before, but now A and B can collect "some" information about the movie quality
- ▶ Note that we have 2 actions (T/H) and 3 states (b/m/g)
  - ► For Bob it is *sufficient* to know if the movie is (b/m) or g

	Theater	Home	
S	$v_i^T(s)$	$v_A^H(s)$	$v_B^H(s)$
bad	0	0.45	0.55
medium	0.5	0.45	0.55
good	1	0.45	0.55

- If the movie is good (bad) they agree about the action Theater (Home)
- But they do not agree about the expected quality of the movie
  - Good movie:  $EV_A(T|g) = 0.75 < EV_B(T|g) = 1$
  - ▶ Bad movie:  $EV_A(T|b) = 0 < EV_B(T|b) = 0.25$
- ▶ If the movie is medium they still disagree about the action
- But they also disagree about the expected quality of the movie
  - ► Alice chooses Theater:  $EV_A(T|m) = 0.75$
  - ▶ Bob chooses Home:  $EV_B(T|m) = 0.25$

#### **Summary**

- Alice and Bob have the same prior beliefs
- ► The introduction of **endogenous information collection** created disagreement about movie quality
- ➤ **State pooling**: agents avoid redundant information when the action space is smaller than the state space
- ▶ **Belief polarization**: posterior beliefs are more distant (extreme) than prior beliefs

#### **Puzzle**

- Society today is more polarized (McCarty et al. 2006)
- ► Information is more easily accessible (lower cost)
- ▶ If a "true state" exists, beliefs should converge, right?
- Not necessarily true if information collection is endogenous

Research Question

## **Research Question**

# Can endogenous information acquisition provide an explanation for belief polarization?

Broad question that includes prior heterogeneity, update heterogeneity, confirmatory/contradictory strategies, etc.

#### How do DMs evaluate and choose information sources?

Test whether agents:

- Seek information based on the impact on their action
- ▶ Ignore information without instrumental value (state pooling)



RELATED LITERATURE

#### **Related Literature**

- Polarization is widely studied phenomenon
- ► Information and belief polarization: McCarty, Poole and Rosenthal (2006), Boxell, Gentzkow and Shapiro (2017)
- ► Explanations for polarization based on **exogenous** information and/or exogenously imposed biases: Rabin, Schrag (1999); Fryer, Harms, Jackson (2017), Wilson (2014), Lord, Ross, Lepper (1979) [confirmation bias], Ortoleva and Snowberg (2015) [overconfidence and correlation neglect], Klayman and Ha (1987), Nickerson (1998) [positive test strategy]
- ➤ Confirmation bias and **rational inattention**: Su (2014), Nimark and Sundaresan (2018), Dixit and Weibull (2007) [prior heterogeneity]



# **Experimental Literature**

### 1. Ambuehl and Li (2018) Design AL18

- Systematic analysis of belief updating and demand for info.
- Compression effect: subjective valuation of useful information underreacts to increased informativeness
- Biases mainly due to non-standard belief updating rather than risk preferences

### 2. Charness, Oprea, Yuksel (2018) Design COY 18

- Study how people choose between biased information sources
- ► Evidence of confirmation-seeking rule
- Mistakes driven by errors in reasoning about informativeness

#### 3. Vast experimental literature about belief updating

- Heterogeneity in belief updating: El-Gamal and Grether 1995, Fehr-Duda and Epper 2012, Augenblick and Rabin 2015, Buser et al 2016, Antoniou et al 2017.
- Biases in demand for information: Eli and Rao 2011, Mobius et al 2011, Bursks et al 2013, Oster et al 2013, Sicherman et al 2015

# "SIMPLIFIED"

# STATE POOLING MODEL

## Model

- Simplified RI model (Matveenko and Novak)
- ► Stage 1: collect information, Stage 2: choose an action
- ▶ N > 2 possible states of the world  $s \in \{1, ..., N\}$
- ▶ Binary action  $a \in \{1, 2\}$
- Risky action ("stock/reform"), safe action ("bond/status quo")
- Risky action
  - ▶ value  $v_s$ , where  $s \in 1, ..., N$
  - $\triangleright$   $v_i < v_j$  for i < j
- Safe action
  - ▶ value *B* independent from *s*
  - Assumption:  $v_1 < B < v_N$

## Model

- ▶  $p_s$  correct prior belief state s realized, with  $\sum_{s=1}^{n} p_s = 1$
- Stage 1: collect information
  - ▶ Choose one "advisor"  $(\pi_e, c_e) \in \{(\pi_e, c_e)\}_e$  [experiment-cost]
  - ▶ Pay the cost  $c_e$  to observe the experiment  $\pi_e$
- Observe signal realization and update beliefs
- Stage 2: choose one action
  - ▶ Choose action  $a \in \{1, 2\}$
  - ► Safe action (return B) and risky action (return  $v_s$ )

# Model - 3 states, 2 signal realizations

- ► The experiment  $\pi_e$  can generate only two signals  $\sigma \in \{1, 2\}$  and is defined by the triplet  $\pi(\sigma = 1|s)$
- ▶ The instrumental value of a signal structure  $\pi_e$  is

$$U(\pi_e) = \underbrace{\sum_{\sigma} v^*(\{p(s|\sigma)\}_s)\pi(\sigma)}_{\text{EV with } \pi_e} - \underbrace{v^*(\{p(s)\}_s)}_{\text{EV w/o } \pi_e}$$

where  $v^*$  is the expected value of the optimal action (conditional on available information)

- Stage 1: collect information
  - A rational agent chooses the signal structure

$$e^* = \operatorname{argmax}_e U(\pi_e) - c_e$$

# Model - 3 states, 2 signal realizations

▶ The instrumental value of a signal structure  $\pi_e$  is

$$U(\pi_e) = \underbrace{\sum_{\sigma} v^*(p(s|\sigma))\pi(\sigma)}_{\text{EV with } \pi_e} - \underbrace{v^*(p(s))}_{\text{EV w/o } \pi_e}$$

- We can simplify further the calculation of the value
- ► Irrelevant experiments have  $a^*(\emptyset) = a^*(\sigma = 1) = a^*(\sigma = 2)$

$$U(\pi_e)=0$$

► Relevant experiments have wlog  $a^*(\emptyset) = a^*(\sigma = 1) \neq a^*(\sigma = 2)$ 

$$U(\pi_e) = Pr(\sigma = 2) \cdot \left( E[v(a^*(\sigma = 2)) | \sigma = 2] - E[v(a^*(\sigma = 1)) | \sigma = 2] \right)$$

# **Simplified Environments**

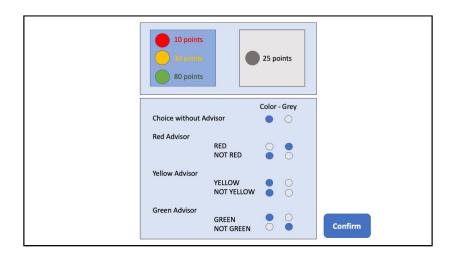
- ► Consider only pairs of advisors  $\{(\pi_1, c_1), (\pi_2, c_2)\}$
- In our experiment we focus on two simple cases:
- $ightharpoonup c_1 = c_2 = 0$  both signal structures are free
  - ▶ The DM selects the most informative advisor
- ▶  $c_1 > c_2 = 0$  only one signal structure is costly, but  $\pi_2(\sigma = 1|s) = 1$ , i.e. the free signal is not informative
  - ▶ The DM selects the informative advisor only if  $U(\pi_1) \ge c_1$

LABORATORY EXPERIMENT

# **Laboratory Experiment**

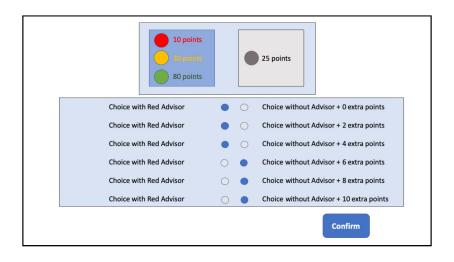
- How do agents evaluate and choose information sources?
- Stage 1: choose or "hire" an advisor
- Observe signal realization
- Stage 2: select an action [risky/safe]
- We want to collect separately
  - Action (conditional on posterior beliefs)
  - WTP for advisor / preferences over advisors
  - Posterior beliefs [guessing task]
- Deviations from optimality can enhance or reduce the effect predicted by the state pooling model
- A controlled lab setting allows to analyze individually all the components of the decision process

### Task 1 - Colorblind Advisor Game - Action choice



Signal realization contingent choices - Collect actions  $a_i(\sigma)$ .

# Task 1 - Colorblind Advisor Game - Hiring screen



Signal structure value elicitation - Collect subjective  $U_i(\pi)$ .

### Task 1 - Colorblind Advisor Game

### We can test:

- 1. whether agents choose optimally in the binary choice stage, conditional on the available information
- 2. how they evaluate the additional information represented by the signal
- whether the status quo affects choice and signal valuation (if subjects' reaction is qualitatively and quantitatively coherent with the optimal one)

### Theoretical predictions:

- choose the lottery with the highest expected value
- ▶ the highest price paid in order to receive the signal is  $U(\pi_e)$  (instrumental value)

# Task 2 - Imprecise Advisor Game

Are the results robust to noisy signal structures?

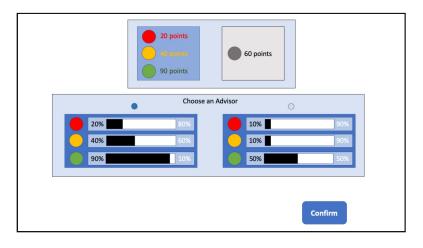
### We can test:

- if agents choose signal structures that are more informative in instrumental way
- 2. if agents correctly update own beliefs
- 3. if agents correctly estimate the probability of each realization

$$EV_e = E[v(\sigma)|\sigma = 0] \cdot P(\sigma = 0) + E[v(\sigma)|\sigma = 1] \cdot P(\sigma = 1)$$

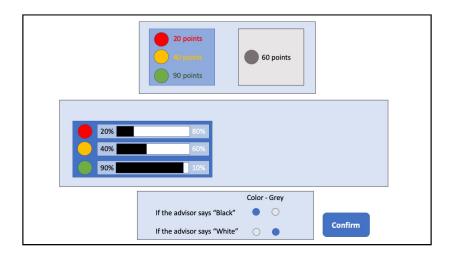
The EV given a signal structure e is a function of the strategy  $v(\sigma)$  conditional on signal realization  $\sigma$ . We record separately subjective estimates of  $P(s|\sigma)$  and  $P(\sigma = 0)$ 

# Task 2 - Imprecise Advisor Game - Advisor choice



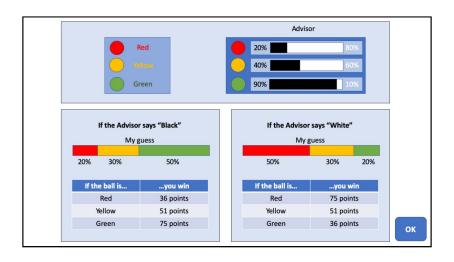
Binary advisor choice - Collect preference over  $\pi_e$  (c = 0).

# Task 2 - Imprecise Advisor Game - Action choice



Signal realization contingent choice - Collect actions  $a_i(\sigma)$ .

### **Task 3 - Color Prediction Game**



Posterior beliefs elicitation (exogenous signal structure) - Collect  $\hat{p}_i(s|\sigma)$ .

# **Task 4 - Message Prediction Game**



Signal probability elicitation (exogenous signal structure) - Collect  $\hat{p}_i(\sigma)$ .

## Tasks 2-4 - Advisor Choice and Control Tasks

We are mostly interested in Task 2 (advisor choice), but we need 3 and 4 (guessing tasks) for robustness.

Choose pairs of signal structures  $\{\pi_1, \pi_2\}$  such that:

- they have the same information about the states (Shannon entropy reduction)
- 2.  $\pi_1$  should be chosen if  $B < \overline{B}$
- 3.  $\pi_2$  should be chosen if  $B > \overline{B}$

The same pair appears in two separate trials, with different status quo *B*.

# Summary

Motivation: Empirical evidence of belief polarization

# Information valuation $\downarrow\downarrow$ Endogenous information acquisition $\downarrow\downarrow$ Belief polarization

- ► RI model with N=3 states and binary action choice
- State pooling depends on status quo (safe action's value)
- Sharp predictions about optimal information acquisition
- Alternative hypothesis include confirmatory strategy, biased updating, preference for non-instrumental information
- ▶ Lab experiment to test separately the model's **assumptions**

List of Potential Confounding Factors

# **State Pooling and Belief Polarization**

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# **Appendix Slides**

Appendix A - The Model

► Appendix A

Appendix B - Related Literature

► Appendix B

**Appendix C - Confounding Factors** 

► Appendix C

# APPENDIX A - THE MODEL

# Full Model (Matveenko and Novak)

- ▶ DM is rationally inattentive (Sims, 2003, 2006)
  - Information costly Shannon cost
  - $\triangleright$   $\lambda$  marginal cost of information
  - $\kappa(P, G)$  expected reduction in entropy
  - ightharpoonup G(v) prior distribution
  - ▶ P(i|v) probability of choosing action i conditional on v

Main result: possible "wrong direction" updating of beliefs dependent on respective position of prior beliefs and safe option. It leads to polarization (more extreme posterior beliefs).

# Agent's problem

Denote:  $\mathbf{v} = (v_1, \dots, v_n)$ ,  $G(\mathbf{v})$  - prior joint distribution Find an information strategy maximizing:

$$\max_{P(i|v)} \left\{ \sum_{i=1}^{2} \int_{\mathbf{v}} v_{i} P(i|\mathbf{v}) G(d\mathbf{v}) - \lambda \kappa(P, G) \right\},\,$$

where

$$\kappa(P,G) = -\sum_{i=1}^{2} P_i^0 \ln P_i^0 + \int_{\mathbf{v}} \left( \sum_{i=1}^{2} P(i|\mathbf{v}) \ln P(i|\mathbf{v}) \right) G(d\mathbf{v}).$$

P(i|v) is the conditional on the realized value of v, the probability of choosing option i and

$$P_i^0 = \int_{\mathcal{U}} P(i|\mathbf{v})G(d\mathbf{v}), i = 1, 2$$

where  $P_i^0$  is the unconditional probability of option i to be chosen.

# Lemma 1 (Matějka, McKay, 2015)

Conditional on the realized state of the world  $s^*$  probability of choosing risky option is

$$P(\text{picking risky}|\text{state is }s^*) = \frac{P_1^0 e^{\frac{v_s}{\lambda}}}{P_1^0 e^{\frac{v_s^*}{\lambda}} + (1 - P_1^0)e^{\frac{R}{\lambda}}}$$

of choosing safe option is:

$$P(\text{picking safe}|\text{state is } s^*) = \frac{(1 - P_1^0)e^{\frac{R}{\lambda}}}{P_1^0 e^{\frac{v_s^*}{\lambda}} + (1 - P_1^0)e^{\frac{R}{\lambda}}}$$

here  $P_1^0$  is unconditional probability of choosing risky option.

### **Beliefs**

Agent's prior expected value of the risky option is:

$$\mathbb{E}v = \sum_{s=1}^{n} v_s g_s$$

we **fix the state** of the nature: it is  $s^*$ 

Observer sees agent's updated belief about the average of v:

$$\mathbb{E}_{i}[\mathbb{E}(v|i)|s^{*}] = P(i = 1|s^{*})\mathbb{E}(v|\text{picking option 1}) + (1 - P(i = 1|s^{*}))\mathbb{E}(v|\text{picking option 2})$$

where for option  $i \in \{1, 2\}$ 

$$\mathbb{E}(v|\text{picking option i}) = \sum_{i=1}^{n} v_i P(\text{state is j}|\text{picking option i})$$

### **Beliefs**

### **Theorem**

Expected posterior value of the risky option for a rationally inattentive decision maker is

$$\mathbb{E}_{i}[\mathbb{E}(v|i)|s^{*}] = \sum_{i=1}^{n} v_{i}g_{i}\frac{\alpha_{s^{*}}e^{\frac{v_{i}}{\lambda}} + (1-\alpha_{s^{*}})e^{\frac{R}{\lambda}}}{P_{1}^{0}e^{\frac{v_{i}}{\lambda}} + (1-P_{1}^{0})e^{\frac{R}{\lambda}}}$$
(1)

where

$$\alpha_{s^*} = \frac{P_1^0 e^{\frac{v_{s^*}}{\lambda}}}{P_1^0 e^{\frac{v_{s^*}}{\lambda}} + (1 - P_1^0) e^{\frac{R}{\lambda}}}$$

# Updating of beliefs

We are interested in

$$\Delta = \mathbb{E}_i[\mathbb{E}(v|i)|s^*] - \mathbb{E}v$$

### **Theorem**

The sign of  $\Delta$  is the same as the sign of  $(v_{s^*} - R)$ .

### Proof.

Straightforward and we use:

### Lemma 2

Relations  $\alpha_{s^*} \geqslant P_1^0$  under  $P_1^0 > 0$  are equivalent to  $v_{s^*} \geqslant R$ 

# Example 3 states, 2 actions

- 3 possible states of the world indexed by s
- 2 options/actions indexed by a
  - ▶ Option 1 Risky with values:  $v_1 < v_2 < v_3$
  - ▶ Option 2 Safe option with value *R* in all states
- ▶ Prior belief about the states:  $g_1, g_2, g_3$
- Marginal cost of information: λ

**Assumption 1:** to rule out uninteresting cases

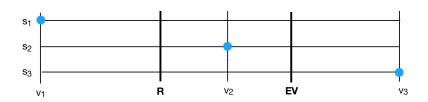
$$v_1 < R < v_3$$

# Updating in "wrong" direction

We are interested when the conditional expectation moves in the "wrong" direction

**Example** for  $s^* = 1$  the expectation "should" go down, so the agent is biased when

$$\mathbb{E}_a[\mathbb{E}(v|a)|s^*] > \mathbb{E}v > 0$$



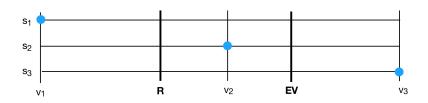
# Updating in "wrong" direction

Let's denote 
$$\Delta = \mathbb{E}_a[\mathbb{E}(v|a)|s^*] - \mathbb{E}v$$
.

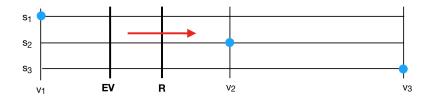
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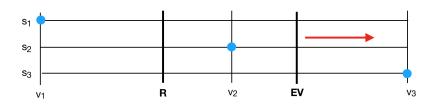
$$(\mathbb{E}v - v_{s^*}) \cdot \Delta > 0$$

then the agent is updating belief in the wrong direction



# Result





► Back to Model slides

# Appendix B - Literature

### **Information and Belief Polarization**

- Polarization is an ubiquitous phenomenon
- Mixed evidence of how information contributes to polarization
  - Politicians and voters more polarized despite increased availability of information
     McCarty, Poole and Rosenthal (2006)
  - Greater Internet use is not associated with faster growth in political polarization among US demographic groups Boxell, Gentzkow and Shapiro (2017)



# **Multiple Explanations for Polarization**

### 1. Confirmation bias

- Misreading ambiguous signals: Rabin, Schrag (1999); Fryer, Harms, Jackson (2017)
- ► Limited memory: Wilson (2014)
- Experiments: Lord, Ross, Lepper (1979)

### 2. Overconfidence and correlation neglect

Ortoleva and Snowberg (2015)

### 3. Positive test strategy

Klayman and Ha (1987), Nickerson (1998)

Results mostly based on exogeneous information and/or exogeneously imposed biases.



### **Confirmation Bias and Rational Inattention**

### 1. Su (2014)

- Gaussian signal + quadratic loss function
- Attention proportional to observation window
- Results: conformism in learning

### 2. Nimark and Sundaresan (2018)

- Mainly focus on polarization persistence
- Agent pays more attention to the states which are more likely

### 3. Dixit and Weibull (2007) - not RI

- Learning about policy in place (signal bimodal)
- Agents agree on loss function, disagree on probabilities of states
- Status quo vs. new reform Divergence of opinions



# **Experimental Literature**

### Ambuehl and Li (2018)

- Systematic analysis of belief updating and demand for information
- Compression effect: subjective valuation of useful information underreacts to increased informativeness
- Biases mainly due to non-standard belief updating rather than risk preferences

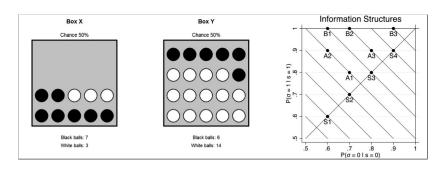
### 2. Charness, Oprea, and Yuksel (2018)

- Study how people choose between biased information sources
- Evidence of confirmation-seeking rule
- Mistakes are driven by errors in reasoning about informativeness



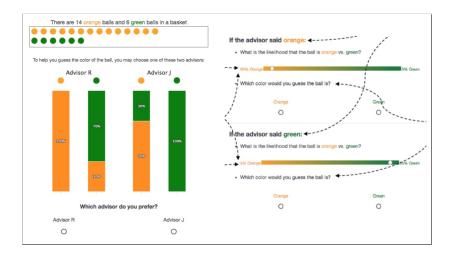
# Ambuehl and Li (2018)

- Prediction game
- Information valuation task
- Belief updating task
- Eliciting signal probabilities
- Gradual information task





# Charness, Oprea, and Yuksel (2018)



# APPENDIX C CONFOUNDING FACTORS

# Who killed RI in the lab? A list of usual suspects

- Risk attitude
- Noise/randomness
- Inertia
- Status quo effect
- Wrong updating (base-rate neglect, conservatism)
- Updating strength affected by irrelevant variables
- Confirmatory strategy (positive test)
- Preference over non-instrumental information
- Signal avoidance (ostrich effect)
- Biased information cost/value function (compression)

