Caution in the Face of Complexity

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INTRODUCTION

Introduction

- Recent surge of interest on role of complexity in economic decisions
- Growing focus on cognitive explanations
- Most models: people treat complexity like Bayesians

$$\text{priors} + \text{noisy signals} \Rightarrow \text{Posteriors} \Rightarrow \text{Max. EU}$$

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- Evaluating options often cognitively complex
- Complexity leads to *internal ambiguity*
- Which may trigger cautious response
  - People undervalue complex options, in a way incompatible with beliefs + EU
  - Undervalue complex options in a way that is related to ambiguity aversion (even in problems with no objective ambiguity à la Ellsberg)
- In that case, complexity and cognitive uncertainty would interact with preference

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- value bets with specified probabilities (e.g. 50/50);

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- value bets with specified probabilities (e.g. 50/50);
- value ambiguous bets (à la Ellsberg);
- report confidence / cognitive uncertainty (CU) about chance of winning in main task.

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- value ambiguous bets (à la Ellsberg);
- report confidence / cognitive uncertainty (CU) about chance of winning in main task.

+ We reanalyzed data from Enke & Graeber (QJE 23).

(A) Belief-Updating Experiment

An updating problem

A bag contains:

- **30 Green** balls and **20 Purple** balls.
- **1/3** of the **Green** balls are marked with an **X**
- **1/2** of the **Purple** balls are marked with an **X**

A ball has been drawn from the bag. The computer informs you that this ball is **marked with an X**.

What is the chance the ball is Purple? Green?

Design

A bag contains:

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- Values (MPL) for bet that pays $30 if ball is Purple

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- Belief: how likely do you think the ball is purple? (later, using BSR)

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- Values (MPL) for complement bet, akin to paying $30 if ball is Green
- Belief: how likely do you think the ball is purple? (later, using BSR)
- Confidence/cognitive uncertainty (CU) about this belief

Design (Cont'd)

- We also elicit values (MPL) for lottery with 50% chance of winning $30

A bag contains **50 Purple** balls and **50 Green** balls.

A ball has been drawn from the bag.

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> A bag contains **50 Purple** balls and **50 Green** balls.
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> A ball has been drawn from the bag.

- And values (MPL) for ambiguous bet à la Ellsberg

> A bag contains **100** balls. Each ball is either **Purple** or **Green**. You are not told the exact number of **Purple** or **Green** balls. They could be all **Purple**, all **Green**, or any combination.

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  + 254 subjects in a 'Computational Control' (described later)

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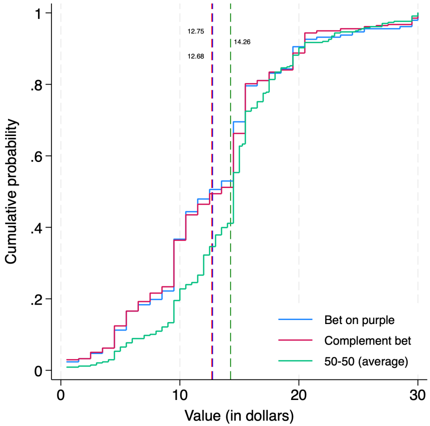
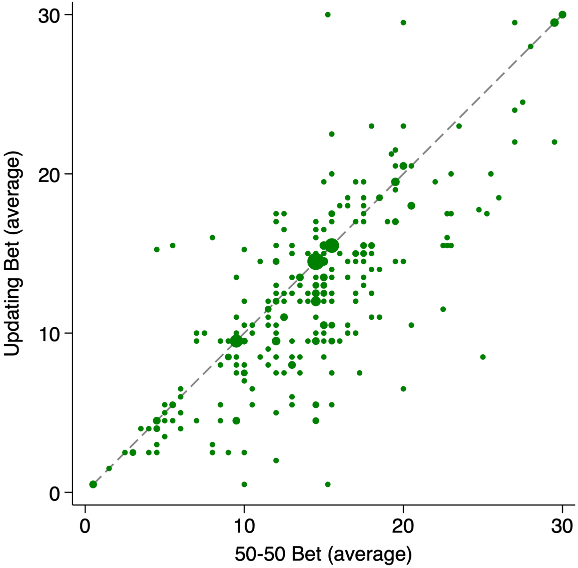
- Pre-registered experiment with 493 college-educated subjects (Prolific).
  + 254 subjects in a 'Computational Control' (described later)
- Show results here for subjects passing comprehension quiz ($\sim$ 70%)

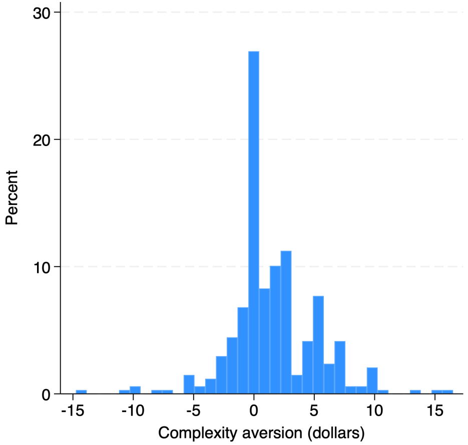
First Look at the Data



- ▶ Values for bet on purple and its complement are very similar.
- ▶ And $<$ Value distribution of 50/50 lottery (e.g., p-value 0.000 for test on averages)



30
20
10
0
Updating Bet (average)
0
10
20
30
50-50 Bet (average)



- Average **complexity aversion**:= 50/50-lottery value minus avg. value of updating bets
- Positive for 54% of subjects, zero for 27% and negative for 19%

Evidence Against Standard Approach

- Subjects hold posterior belief on state (**P**/**G**), and view bet as lottery
  Maximize expected utility, possibly using wrong probability distribution

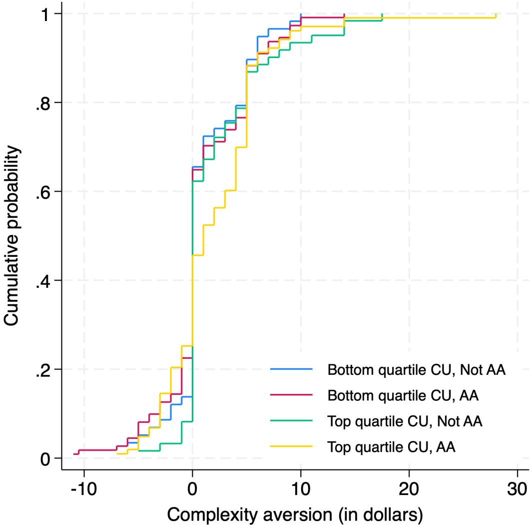
Observation

Average values for the bet and its complement must be more than the value of 50/50 lottery (unless subject risk-seeking).

Proof

Extends to probability weighting, if avg. weight $\geq 1/2$*, (e.g., convex weighting function)*

Ambiguity/CU Interaction Matters



Details

Table 1: Experiment A: The Role of Ambiguity and Cognitive Uncertainty

	Complexity Aversion	
	(1)	(2)
High Cognitive Uncertainty:		
Ambiguity Aversion	.38***	
	(.06)	
Low Cognitive Uncertainty:		
Ambiguity Aversion	.11*	
	(.06)	
Ambiguity Aversion		.09
		(.06)
CU		-.76
		(.60)
Ambiguity Aversion × CU		.43***
		(.11)
Constant	2.64***	2.65***
	(.61)	(.63)
Observations	676	676
Controls	Y	Y

Notes: Each updating bet is an observation, with robust standard errors clustered by subject in parentheses. * $p < .1$, *** $p < .01$. Both (1) and (2) are obtained from constrained regressions following the method explained above. Controls include beliefs about probabilities and a dummy for each updating task and, in model (1), a dummy for high CU.

Updating problem

A bag contains:

- **20** **Green** balls and **30** **Purple** balls.
- **1/2** of the **Green** balls are marked with an **X**
- **1/3** of the **Purple** balls are marked with an **X**

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Shouldn't complexity aversion decrease if reduce the task complexity?

Computational Control

There is a stock of **20** **Green** balls and **30** **Purple** balls available. A bag was constructed as follows:

- **1/2** of the **Green** balls were put in the bag
- **1/3** of the **Purple** balls were put in the bag

A ball has been drawn from the bag.

Reduce conceptual complexity of updating bets – **don't have to figure out Bayes' rule** – while preserving the computational steps

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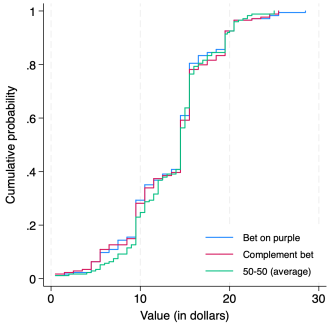
Control otherwise same as Main

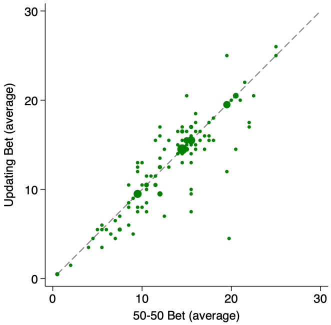
Pre-registered, 254 subjects on Prolific

Computational Control (Results)



- Almost no effect: Mean CA: 0.33, Median CA: 0

Computational Control (Results)



- Almost no effect: Mean CA: 0.33, Median CA: 0
- **Source of complexity is mostly conceptual, not computational**

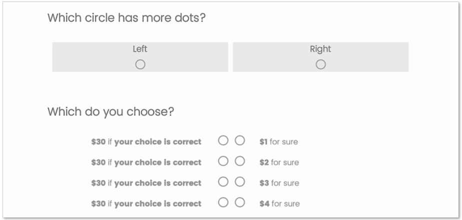
(B) Perception Experiment

Design

Builds on standard perception task, **widely used** in cognitive science:

- Which circle has more dots? (subjects told whether left/right has more drawn at random). Each circle appears for a moment, in random order:

- Four perceptual tasks, two nearly impossible (our focus)
- Unlike standard task, we also ask for valuation (after circles disappear):



Which circle has more dots?

Left ○ Right ○

Which do you choose?

$30 if **your choice is correct**	○ ○	**$1** for sure
$30 if **your choice is correct**	○ ○	**$2** for sure
$30 if **your choice is correct**	○ ○	**$3** for sure
$30 if **your choice is correct**	○ ○	**$4** for sure

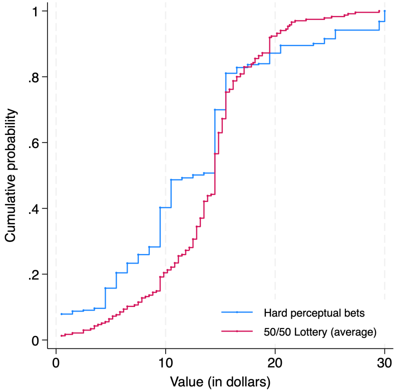
+ Value Ellsberg bet & lotteries with 30/50/70 chance of winning, confidence chose correctly

Why an interesting addition to first experiment?

- Also a belief updating/information processing task, but with low cognitive load (pure perception, no numbers!) and using skill honed through evolutionary adaptation
- Typical setup for cognitive-noise and rational-inattention (RI) models within economics
  - Under RI, **ex-ante** aversion to complexity (avoid processing cost), but beliefs are set (Bayes' rule) and **no** aversion to complexity **after** seeing the stimulus.
  - Here: check for aversion to complexity **after** people have confronted the stimulus
- In Bayesian Experiment, must deal with possibility of inference mistakes, but here, absolute reference benchmark in standard model (information can't lower value below a coin toss)
- Some other design differences (but also pre-registered, with 498 college-educated Prolific subjects, and still focus on the $\approx 70\%$ passing comprehension quiz))

Value of Perception Bet vs. Lottery

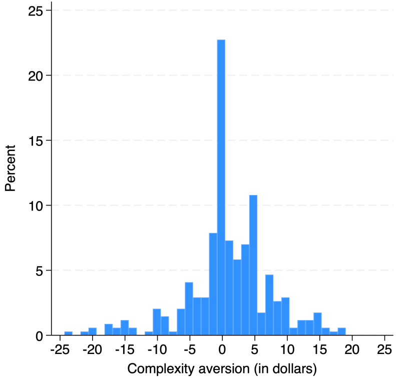
Low-confidence subjects



- Again hard bets valued below 50/50 lottery! $p = 0.0015$ & 0.0113 (Signed-Rank Test)
- Contradicts standard model (information cannot lower value; NIAS of Caplin et al.)

Value of Perception Bet vs. Lottery

Low-confidence subjects



- Complexity aversion negative for 33.2%, zero for 14.3%, strictly positive for 52.5%.
- $1.02 on avg., with large variation: among those strictly CA, $5.36 (avg.) and $4.67 (med.)

Details

Table 2: Experiment B: The Role of Ambiguity

	Complexity Aversion	
	(1)	(2)
High Uncertainty:		
Ambiguity Aversion	.58***	
	(.09)	
Low Uncertainty:		
Ambiguity Aversion	.22*	
	(.13)	
Ambiguity Aversion		.09
		(.20)
Uncertainty	9.01***	6.66***
	(2.51)	(2.26)
Ambiguity Aversion × Uncertainty		.77**
		(.38)
Constant	-5.23***	-4.89***
	(1.01)	(1.09)
Observations	684	684
Controls	Y	Y

Notes: Each perceptual bet is an observation, with robust standard errors clustered by subject in parentheses. * $p < .1$, ** $p < .05$, *** $p < .01$. Both (1) and (2) are obtained from constrained regressions, as explained earlier. Controls include a dummy for which hard perceptual task the observation corresponds to, and in model (1), a dummy for high uncertainty.

(C) Compound-Lottery Experiment

Main Treatment

- Measure value of compound lotteries, regular lotteries & ambiguous bet
- Also: belief of chances in compound + confidence
- For compound bets, include 'trivial' compound to help benchmark. Compare:

> There are **2 decks**. Each contains **50** cards:
>
> - In deck 1: **20%** of cards are **Purple** and **80%** are **Green**
> - In deck 2: **80%** of cards are **Purple** and **20%** are **Green**
>
> The computer **selects one of the two decks at random**, shuffles the selected deck and then draws a card.

'non-trivial'

vs.

> There are **2 decks**. Each contains **50** cards:
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> - In deck 1: **50%** of cards are **Purple** and **50%** are **Green**
> - In deck 2: **50%** of cards are **Purple** and **50%** are **Green**
>
> The computer **selects one of the two decks at random**, shuffles the selected deck and then draws a card.

'trivial'

- Also have Graphical framing instead of Percents (smaller numbers + pictures)

Is compounding complex for conceptual, or computational, reasons?

There are **2 decks**. Each contains **50** cards:

- In deck 1: **20%** of cards are **Purple** and **80%** are **Green**
- In deck 2: **80%** of cards are **Purple** and **20%** are **Green**

The computer **selects one of the two decks at random**, shuffles the selected deck and then draws a card.

One-Stage Control

Is compounding complex for conceptual, or computational, reasons?

There are **2 decks**. Each contains **50** cards:

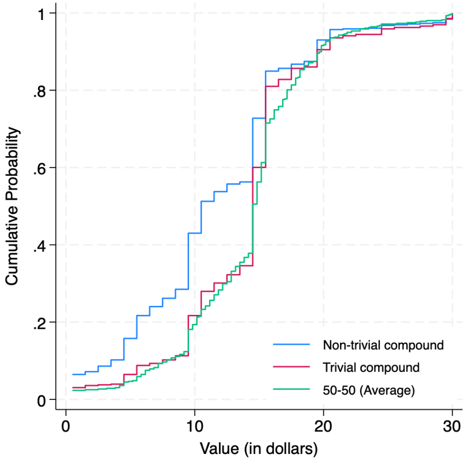
- In deck 1: **20%** of cards are **Purple** and **80%** are **Green**
- In deck 2: **80%** of cards are **Purple** and **20%** are **Green**

The computer **combines the two decks together**, shuffles, and then draws a card.

Design

- 994 subjects (Prolific, pre-registered, college-educated)
  - 397 in Percents framing (two-stage)
  - 397 in Graphical framing (two-stage)
  - 200 in One-Stage mirror treatment
- Approx. 70% passed comprehension quiz

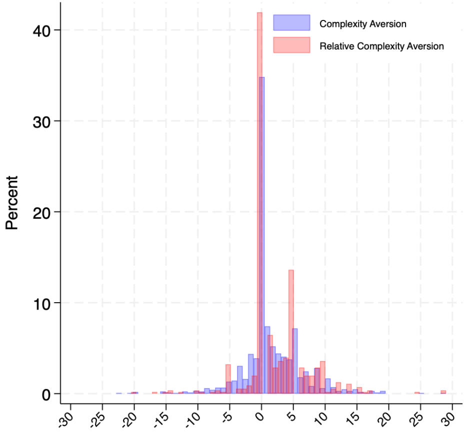
Results for Compound Bets



Non-Trivial Compound bet is significantly undervalued, on average, by $2.56
Complexity aversion strictly negative for 16%, zero for 21%, and strictly positive for 63%.

Can also capture changes in value due to complexity, holding constant number stages:

$$\text{Relative CA} = \text{Value Trivial Compound -Value Non-Trivial Compound}$$



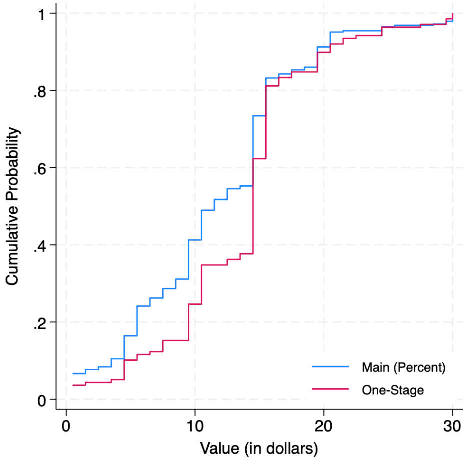
Relative CA similar to CA, with an average of $2.37.

Table 3: Experiment C: The Role of Ambiguity and Cognitive Uncertainty

	Complexity Aversion (Trivial and non-Trivial)		Complexity Aversion (non-Trivial only)		Relative Complexity Aversion (non-Trivial only)	
	(1)	(2)	(3)	(4)	(5)	(6)
High Cognitive Uncertainty:						
Ambiguity Aversion	.39***		.60***		.53***	
	(.05)		(.08)		(.09)	
Low Cognitive Uncertainty:						
Ambiguity Aversion	.21***		.35***		.26***	
	(.06)		(.08)		(.07)	
Ambiguity Aversion		.20***		.40***		.31***
		(.05)		(.08)		(.06)
CU		-.89		-.37		-1.12
		(.61)		(.74)		(1.05)
Ambiguity Aversion × CU		.32***		.26*		.60***
		(.12)		(.15)		(.20)
Constant	2.54***	2.91***	2.18***	2.60***	3.04**	3.08***
	(.60)	(.62)	(.75)	(.75)	(1.26)	(1.27)
Observations	1116	1116	558	558	558	558
Controls	Y	Y	Y	Y	Y	Y

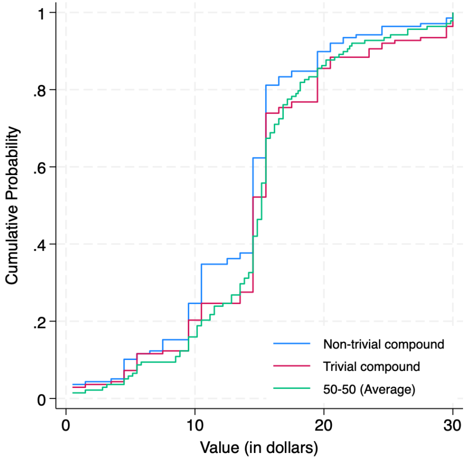
Notes: Robust standard errors in parentheses, clustered by subject in models (1) and (2), where each subject appears in two observations. * $p < .1$, ** $p < .05$, *** $p < .01$. (1)-(4) are obtained from constrained regressions. In (5)-(6), CU refers to relative cognitive uncertainty. Controls include beliefs and a dummy for each compound lottery; in model (1), (3), (5), also a dummy for high CU.

Mirror Treatment (Pseudo-Compound Bets)



Value of non-trivial bet clearly increases, alongside a reduction in CU (from 42% to 23%).

Mirror Treatment (Pseudo-Compound Bets)



Some CA still there ($1.4 versus $2.5)! Two stages accounts for ≈ 44% of compound aversion.

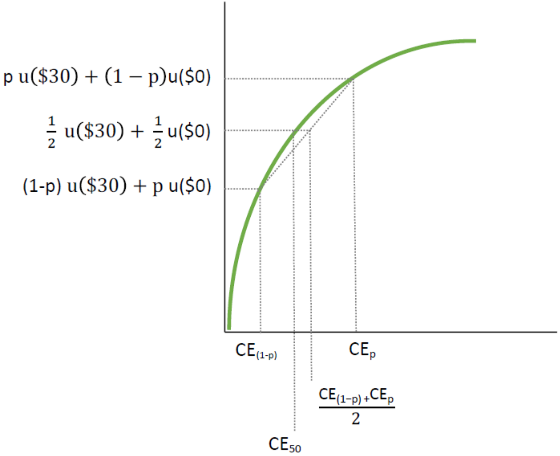
Takeaways

- Show complexity affects valuations: lower when subjects are uncertain
- Correlated with Ellsberg's ambiguity, but in problems with no objective uncertainty. Preferences still matter.
- Shown in variety of contexts, with added insights in each:
  - Bayesian Updating: idea of a posterior probability might not make sense (contrary to large literature on non-bayesian updating)
  - Perception: value may decrease with opportunity to get information
  - Compound Lottery: instead of viewing Ellsberg as compound in disguise, perhaps compound aversion reflects internal-ambiguity aversion due to conceptual (two rounds) and computational complexity.
- Ongoing, separate project: games

THANK YOU!

Proof

Back



p u($30) + (1 − p)u($0)
$\frac{1}{2}$ u($30) + $\frac{1}{2}$ u($0)
(1-p) u($30) + p u($0)
$CE_{(1-p)}$
CE_p
$\frac{CE_{(1-p)} + CE_p}{2}$
CE_{50}

Regression testing

Bayesian · Perception · Compound

Denote by

- U: Updating bet (or complement bet) value
- L: 50/50 lottery value
- E: Ellsberg bet value

Imagine regressing complexity aversion ($\mathrm{CA} = \mathrm{L} - \mathrm{U}$) on ambiguity aversion ($\mathrm{AA} = \mathrm{L} - \mathrm{E}$):

$$\mathrm{CA} = \alpha + \beta \mathrm{AA} + \vec{\gamma} \cdot \textit{controls} + \textit{error}.$$

To avoid spurious correlation, don't want L on both sides

Denote by

- U: Updating bet (or complement bet) value
- L: 50/50 lotteries average value
- E: Ellsberg bet value of the Ellsberg Bet

Note that

$$\underbrace{\mathrm{L}-\mathrm{U}}_{\mathrm{CA}} = \alpha + \beta \underbrace{(\mathrm{L}-\mathrm{E})}_{\mathrm{AA}} + \vec{\gamma} \cdot \textit{controls} + \textit{error}.$$

is equivalent to

$$\mathrm{U} = -\alpha + (1-\beta)\mathrm{L} + \beta\mathrm{E} - \vec{\gamma} \cdot \textit{controls} - \textit{error}.$$

Denote by

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is equivalent to

$$\mathrm{U} = -\alpha + (1-\beta)\mathrm{L} + \beta\mathrm{E} - \vec{\gamma}\cdot \textit{controls} - \textit{error}.$$

Now can use *constrained regression*! And extend to include desired interactions with CU, etc.

Relative CU

Compound

- Consider model:

$$\text{Relative CA} = \text{Value Trivial Compound -Value Non-Trivial Compound}$$
$$= \text{constant} + \alpha\text{AA} + \beta\text{Relative CU} + \gamma\text{Relative CU * AA} + \vec{\delta} \cdot \text{controls},$$

where

$$\text{Relative CU} = \text{CU in Non-Trivial Compound} - \text{CU in Trivial Compound}$$