COMPLEXITY AND TIME (ENKE, GRAEBER AND OPREA, 2023)

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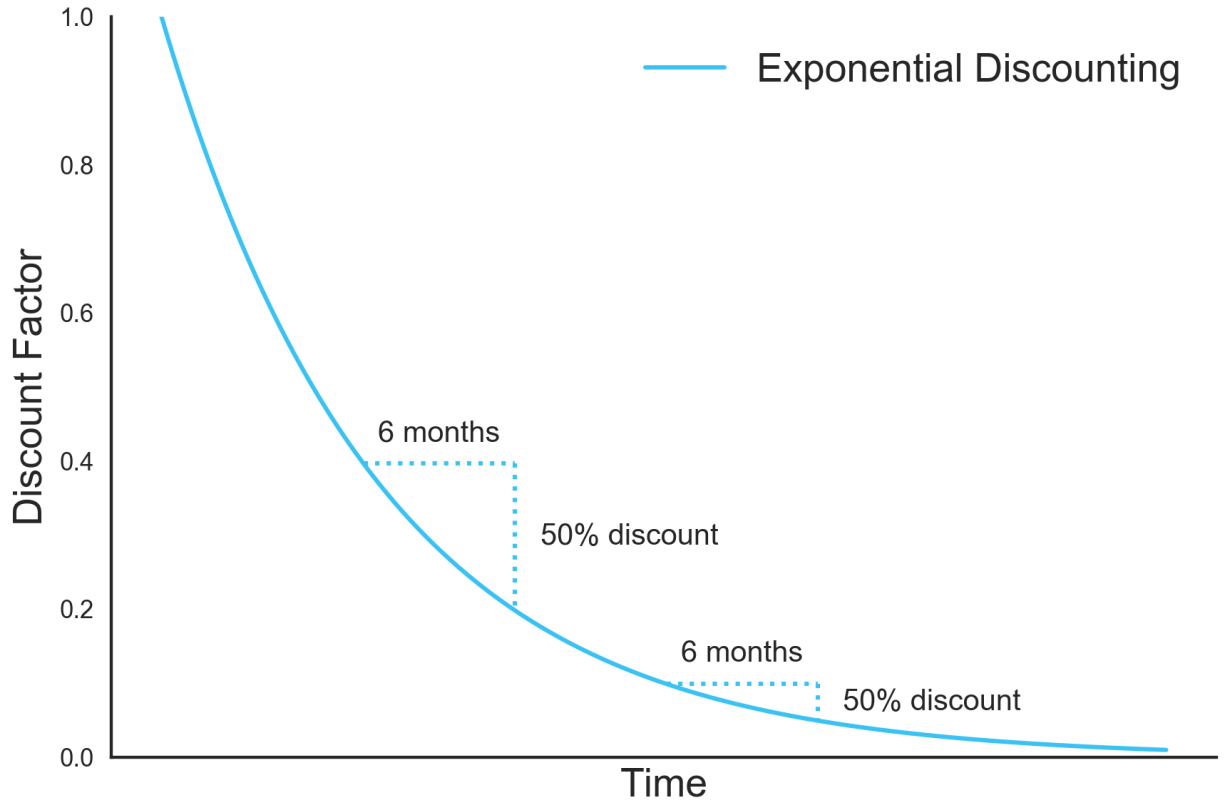
Motivation Hypothesis
Methods Results
Discussion

OUR ROADMAP

INTERTEMPORAL CHOICE: SMALLER SOONER VS LARGER LATER REWARDS

- Would you rather have $20 today or $50 in a year's time?
- Let's make the simplifying assumption that utility (u) = reward (R)
- Classical approach is exponential discounting, where the utility of rewards can be described as:
  - $u_{immediate} = R$
  - $u_{delayed} = R\delta^d$, where $\delta < 1$ is the discount factor and d is the length of the delay
- For a given δ, utility increases as R gets larger and decreases as d gets larger
- R and d are exogenous, while δ is specific to the individual, fixed, and estimated based on choices

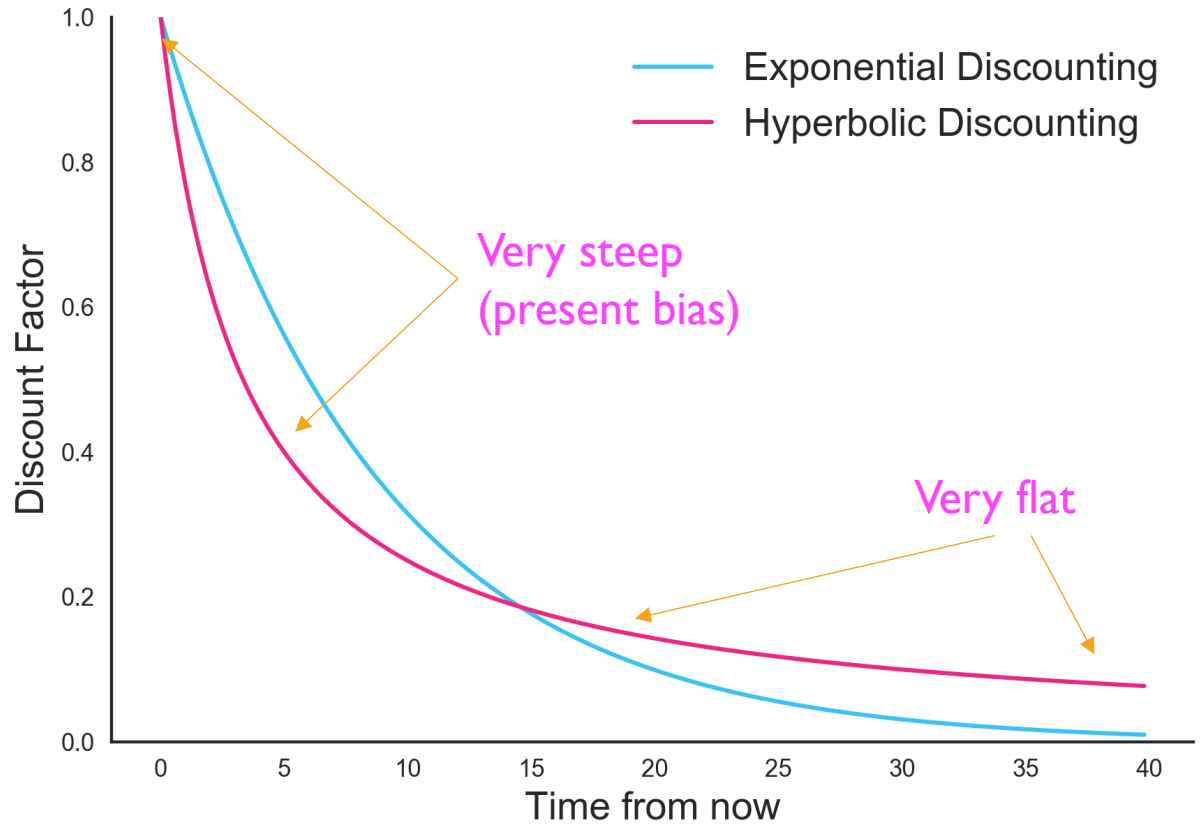
EXPONENTIAL DISCOUNTING IS PROPORTIONATE



EXPERIMENTS SHOW PEOPLE TEND TO DISCOUNT HYPERBOLICALLY

- Classical: $u_{delayed} = R\delta^d$, where $\delta < 1$ is the discount factor and d is the length of the delay
- Behavioural: $u_{delayed} = \beta R\delta^d$, where $\beta < 1$ is an additional term capturing "present bias"
- As present bias does not depend on the delay, it leads to larger discounting over near time horizons (short-run impatience) and smaller discounting over far time horizons (long-run patience)
- Like δ, β is specific to the individual, fixed, and estimated based on choices

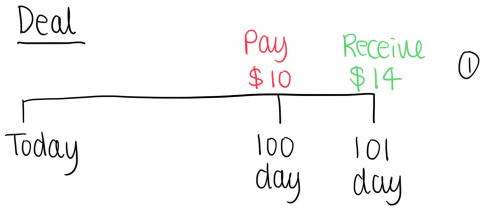
HYPERBOLIC DISCOUNTING IS DISPROPORTIONATE



HYPERBOLIC DISCOUNTING MATTERS BECAUSE IT IS EXPLOITABLE

- There are two key reasons why exponential discounting is considered rational: it leads to consistent choices, and as such it cannot be exploited
- Hyperbolic is inconsistent, e.g. someone may prefer:

- Which means they could be exploited by a contract where:
  - Scenario 2 is offered today
  - Scenario 1 is offered in 100 days time



IS HYPERBOLIC DISCOUNTING SIMPLY A RESULT OF PREFERENCES?

- Do people genuinely prefer hyperbolic discounting over exponential discounting?
  - But how can one explain the exploitation loop?

- Are preferences non-stationary and does δ change over time?
  1. For a given d, people may use different δ depending on the date of the sooner reward
     - Test: check for **front-end delay effects.** Are choices consistent between, e.g.:
       - Prefer \$10 today or \$15 tomorrow?
       - Prefer \$10 in 50 days or \$15 in 51 days?
       - People tend to exhibit front-end delay effects and these are considered to measure 'true' present bias
  2. Rather than constant δ for a given period, δ may change over the length of an interval
     - Test: check for **subadditivity**. Are choices transitive between, e.g.:
       - δ in a single choice between rewards at (t_1, t_3)
       - Joint δ in a pair of choices between rewards at (t_1, t_2) and (t_2, t_3)
       - People tend to discount the total interval (t_1, t_3) by less than the joint decisions of (t_1, t_2) and (t_2, t_3)

OR IS COMPLEXITY A FACTOR IN HYPERBOLIC DISCOUNTING?

- Do people know their own δ?
- Can people easily reason recursively to discount future rewards by δ with each iteration?
  - Can they do so accurately?
- Do people resort to simpler, easier heuristics if the cost of information processing (read: computation) for rationality is too high?

THE KEY PROBLEM: SEPARATING PREFERENCES FROM COMPLEXITY

- How do you know for sure that a person's choice would've been different if they were presented with a simpler/more complex set of alternatives?

- Their solution: development of atemporal mirrors

ATEMPORAL MIRRORS: DISCOUNTING WITHOUT TEMPORAL PREFERENCES

	Option A	Option B
1	$42.00 in 12 months	$2.00 now
2	$42.00 in 12 months	$4.00 now
3	$42.00 in 12 months	$6.00 now
4	$42.00 in 12 months	$8.00 now
5	$42.00 in 12 months	$10.00 now
6	$42.00 in 12 months	$12.00 now
7	$42.00 in 12 months	$14.00 now
8	$42.00 in 12 months	$16.00 now
9	$42.00 in 12 months	$18.00 now
10	$42.00 in 12 months	$20.00 now
11	$42.00 in 12 months	$22.00 now
12	$42.00 in 12 months	$24.00 now
13	$42.00 in 12 months	$26.00 now
14	$42.00 in 12 months	$28.00 now
15	$42.00 in 12 months	$30.00 now
16	$42.00 in 12 months	$32.00 now
17	$42.00 in 12 months	$34.00 now
18	$42.00 in 12 months	$36.00 now
19	$42.00 in 12 months	$38.00 now
20	$42.00 in 12 months	$40.00 now
21	$42.00 in 12 months	$42.00 now

a) *Delay* treatment

	Option A	Option B
1	$42.00 shrunk 12 times	$2.00
2	$42.00 shrunk 12 times	$4.00
3	$42.00 shrunk 12 times	$6.00
4	$42.00 shrunk 12 times	$8.00
5	$42.00 shrunk 12 times	$10.00
6	$42.00 shrunk 12 times	$12.00
7	$42.00 shrunk 12 times	$14.00
8	$42.00 shrunk 12 times	$16.00
9	$42.00 shrunk 12 times	$18.00
10	$42.00 shrunk 12 times	$20.00
11	$42.00 shrunk 12 times	$22.00
12	$42.00 shrunk 12 times	$24.00
13	$42.00 shrunk 12 times	$26.00
14	$42.00 shrunk 12 times	$28.00
15	$42.00 shrunk 12 times	$30.00
16	$42.00 shrunk 12 times	$32.00
17	$42.00 shrunk 12 times	$34.00
18	$42.00 shrunk 12 times	$36.00
19	$42.00 shrunk 12 times	$38.00
20	$42.00 shrunk 12 times	$40.00
21	$42.00 shrunk 12 times	$42.00

b) *Mirror* treatment

KEY IDEA: WITHOUT A DELAY THERE CAN BE NO CHANGE IN TIME PREFERENCES

- By framing immediate payoffs in the same way as distant payoffs, and inducing the same kind of calculation in both, one can separate time preferences from complexity effects
- As the mirror treatment involves no delay, there cannot be any effect of time preferences in choices
- By removing time preferences one can solely estimate the effect of complexity and choices can be assessed objectively

TEST: DO ATEMPORAL MIRRORS INDUCE HYPERBOLIC DISCOUNTING

- H1: do atemporal mirrors induce hyperbolic discounting and present bias?
  - If so, evidence that complexity drives present bias
- H2: is there a correlation b/w the switching point in the mirror and delay treatments?
  - If so, evidence that complexity drives present bias
- H3: does lower confidence and/or greater choice inconsistency predict hyperbolic discounting?
  - If so, evidence that complexity drives present bias
- H4: does higher task difficulty lead to lower confidence and/or greater choice inconsistency?
  - If so, evidence that complexity drives present bias
- H5: can the front-end delay effect or subadditivity anomalies be replicated in the mirror treatment?

EXP 1: ATEMPORAL MIRRORS

- Exp 1 (Mirror): Delay treatment vs mirror treatment
- 36 trials, evenly split b/w delay and mirror, order of treatments randomised
- N=500, participants paid $6 plus a 20% chance of being paid out one choice at random, from one trial, in cash

EXP 2: CONFIDENCE AND CONSISTENCY

- Exp 2 (Delay-M): elicit confidence estimates after each trial, check for degree of consistency
  - Measure of confidence: Enke and Graeber's Cognitive Uncertainty. "From 0% to 100%, how certain are you that your true value is between x and y"? Ranges from 0 (no confidence) to 1 (certain)
  - Measure of consistency: how often did the participant make the same choice on duplicate trials
- 12 trials (2 of which are duplicate trials), all delay treatment
- n = 645, participants paid a flat $4.5 as it wasn't feasible to pay participants according to their choices for multi-year delays
- Exp 2.1: Task difficulty and confidence/consistency
  - A subset of participants (n=300) had either payoffs or dates expressed as an equation rather than a number
  - E.g. instead of $40, $(4*8/2)+(8*9/2)-12
  - E.g. instead of in 1 year, in (6*2/3-3) years AND (3*6/2-9) months AND (5*4/2-10) days

EXP 3: INCENTIVE-COMPATIBLE CONFIDENCE AND CONSISTENCY

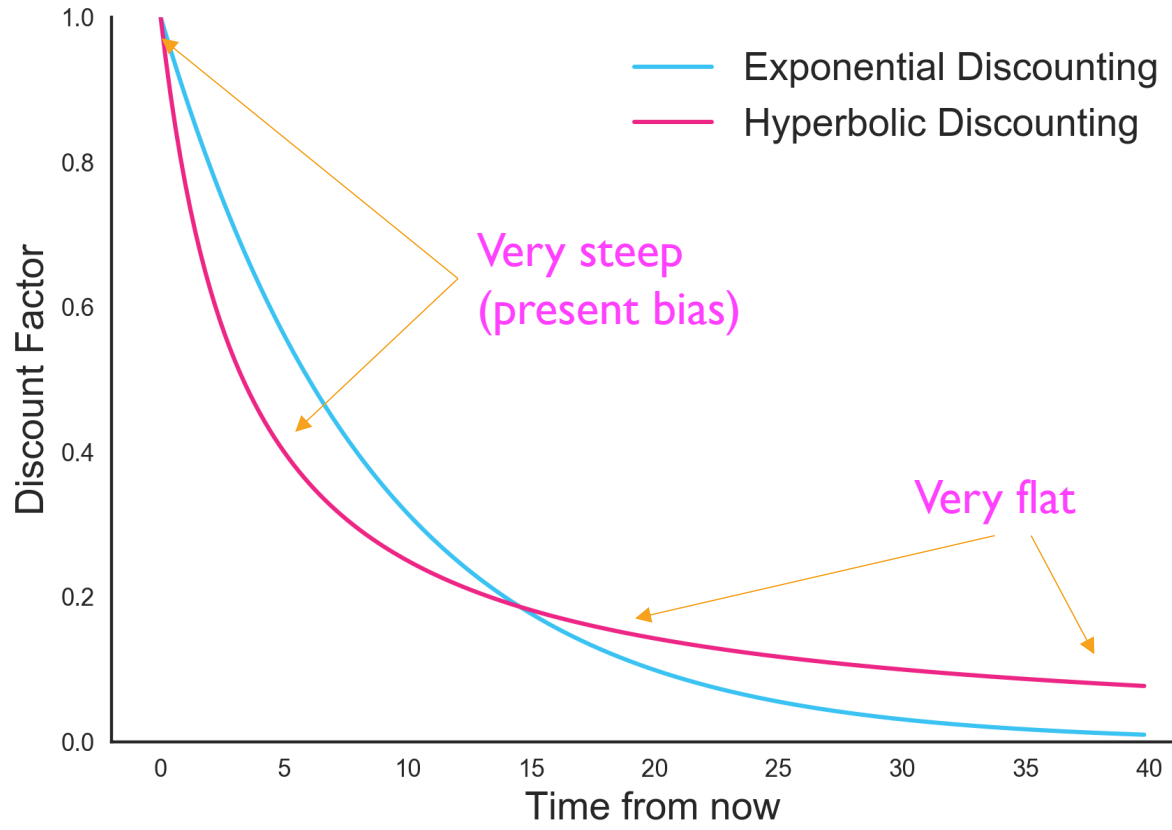
- Exp 3 (Voucher-M): replica of experiment 2 but with two changes

1. In addition to a base payment (this time $4), participants had a 25% chance of being paid an UberEats voucher equal to one of their experimental choices from one trial, selected at random

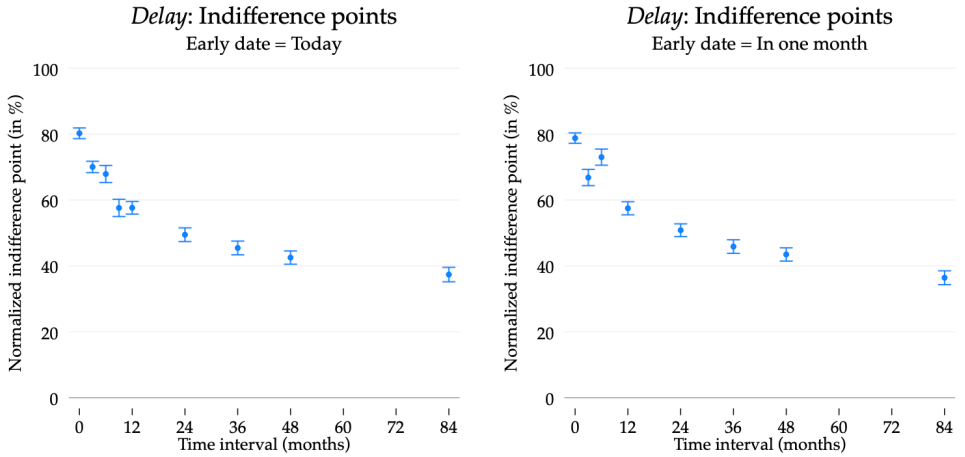
2. There was no complexity/difficulty manipulation

- N=500

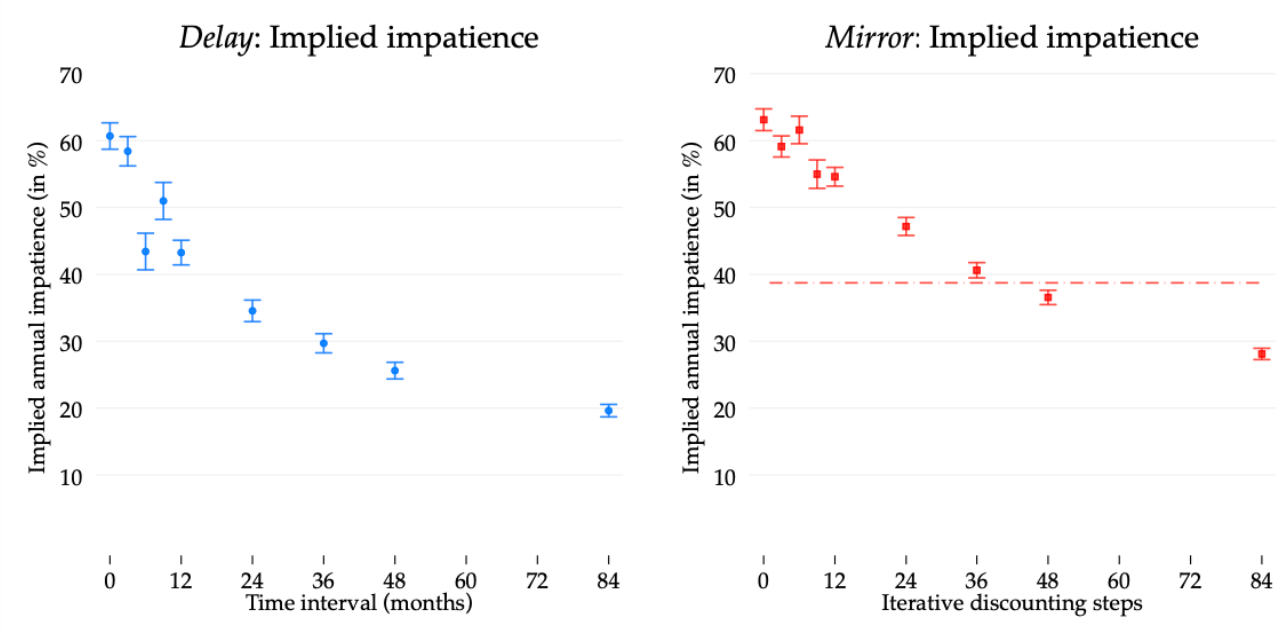
REMEMBER WHAT WE'RE LOOKING FOR



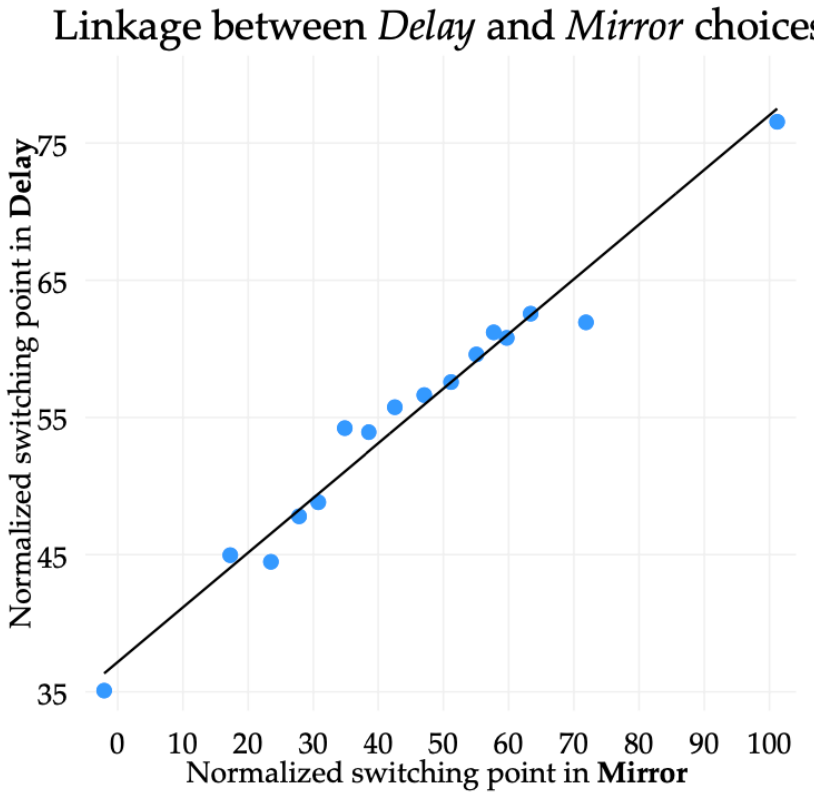
H1: SIMILAR PATTERN OF HYPERBOLIC DISCOUNTING IN MIRROR AND DELAY



H1: SIMILAR PATTERN OF IMPATIENCE B/W MIRROR AND DELAY



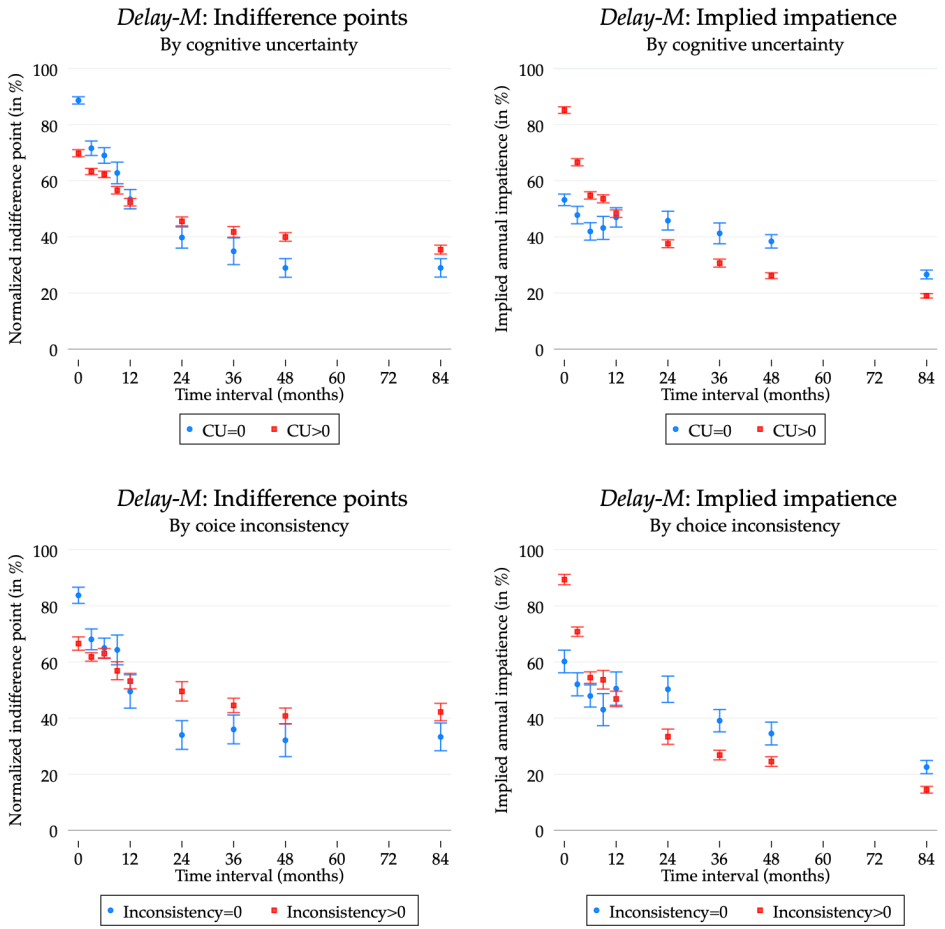
H2: THE SWITCH POINT B/W THE MIRROR AND DELAY TREATMENTS ARE CORRELATED



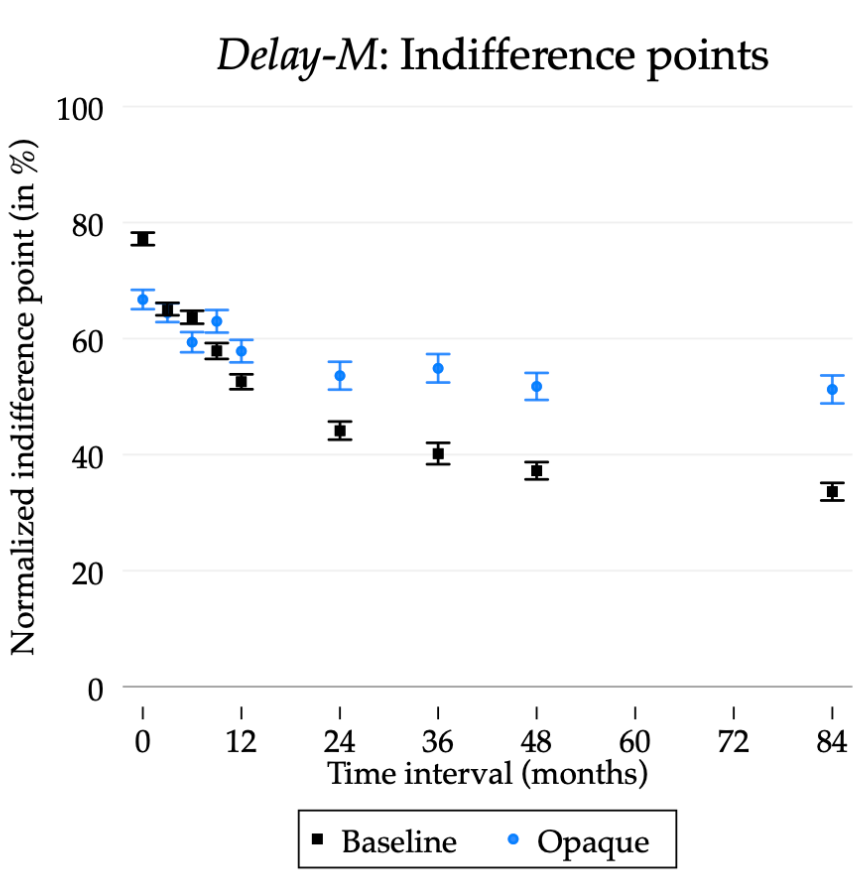
Null: no correlation, as the delay treatment involves time preferences while the mirror treatment is objective computation

Partial correlation = 0.34
$p < 0.01$

H3: PRESENT BIAS INCREASES WITH COGNITIVE UNCERTAINTY/INCONSISTENCY



H4: PRESENT BIAS INCREASES WITH COMPLEXITY / TASK DIFFICULTY



H5: COMPLEXITY DOES NOT EXPLAIN THE FRONT-END DELAY EFFECT

Table 3: Complexity and front-end delay effects

	Dependent variable:					
	Implied annual impatience (in %)					
Phenomenon:	Front-end delay					
Treatment:	*Delay*	*Mirror*	*Delay-M*		*Voucher-M*	
	(1)	(2)	(3)	(4)	(5)	(6)
1 if front end delay	-4.24**	3.79**	-3.07***	-2.51	-4.11***	-7.23***
	(1.85)	(1.69)	(0.99)	(1.53)	(1.09)	(2.12)
Cognitive uncertainty				0.38***		0.38***
				(0.06)		(0.07)
1 if front end delay × Cognitive uncertainty				-0.058		0.070
				(0.05)		(0.07)
Payment amount FE	Yes	Yes	Yes	Yes	Yes	Yes
Task set FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	508	492	2393	2393	2337	2337
R^2	0.07	0.02	0.02	0.07	0.02	0.08

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. The data are restricted to problems that have a front-end delay structure. Task set FE are fixed effects for each pair of tasks that have a front-end delay structure. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

H5: COMPLEXITY CAN EXPLAIN THE SUBADDITIVITY EFFECT

Table 4: Complexity and subadditivity

	Dependent variable:					
	Implied annual impatience (in %)					
Phenomenon:	Subadditivity					
Treatment:	*Delay*	*Mirror*	*Delay-M*		*Voucher-M*	
	(1)	(2)	(3)	(4)	(5)	(6)
1 if one long interval	-7.57***	-9.93***	-8.58***	-3.55***	-9.39***	-1.14
	(1.38)	(1.16)	(0.63)	(1.34)	(0.60)	(1.60)
Cognitive uncertainty				0.47***		0.45***
				(0.06)		(0.08)
1 if one long interval × Cognitive uncertainty				-0.24***		-0.33***
				(0.06)		(0.06)
Payment amount FE	Yes	Yes	Yes	Yes	Yes	Yes
Task set FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	508	492	1948	1948	2000	2000
R^2	0.09	0.06	0.03	0.08	0.04	0.08

Notes. OLS estimates, robust standard errors (in parentheses) are clustered at the subject level. The data are restricted to problems that have a subadditivity structure. We combine the three choices that make up a subadditivity set into two observations according to fn. 5. Task set FE are fixed effects for each pair of tasks that have a subadditivity structure. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

SUMMARY

Table 5: Summary of results across experiments

	Short-run impatience	Decreasing impatience	Sub-additivity	Front-end delay effect	Estimated present bias
Present in atemporal mirrors?	✓	✓	✓	–	✓
More pronounced with cognitive uncertainty?	✓	✓	✓	x	✓
More pronounced with choice inconsistency?	✓	✓	n/a	n/a	✓
More pronounced in difficult problems?	✓	✓	✓	–	✓

Notes. "✓" means that an anomaly is present / more pronounced, "x" that it is not present / not more pronounced and "–" that the opposite is present / the anomaly is less pronounced. "n/a" means that data limitations do not allow us to assess a relationship.

CONCLUSION: MOST PRESENT BIAS IS DRIVEN BY COMPLEXITY

- Many studies find that the present bias parameter $0.8 < \beta < 0.85$
- Here, they find $\hat{\beta} = 0.83$ and $\hat{\delta} = 0.96$ in the mirror treatment
  - δ was set to be $\delta = 0.96$, so the model perfectly recovered δ
  - This suggests the full impact of complexity is being felt on $\hat{\beta}$
- What is the counterfactual? Front-end delay effects are thought to represent 'true' present bias. When focusing only on those instances, they get $\widehat{\beta_F} = 0.95$
  - Back of the envelope: the 'true' extent of present bias is $1 - 0.95 = 0.05$
  - The 'complexity' effect of present bias is $\widehat{\beta_F} - \hat{\beta} = 0.95 - 0.83 = 0.12$
  - Thus, of an observed present bias of 0.17 units, approximately two thirds of this is due to complexity and not underlying preferences
  - Mechanism: complexity causes hyperbolicity by generating a general insensitivity to interval length (subadditivity)

WRAP-UP

- Implication: failure to account for complexity is leading to severe model misspecification
- Application: can the 'mirroring' technique be applied to other domains?
  - Yes! They have another paper that looks at risky choice and prospect theory
  - Main idea: mirror treatment involves doing probability-like computations, but without any actual uncertainty. Do we still see the prospect theory inverse-S shaped curves?
- Outstanding questions:
  - How to measure complexity?
    - 'Mirrors' allow them to show complexity matters without having to measure complexity
  - Is there a complexity-preference curve? To what extent do different levels of complexity affect present bias?

ANY QUESTIONS?