

Dynamic Decision Making Workshop

The Effect of Price Signals on Effort and Productivity in a 'Hard' Task

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Role of markets

Extensively studied:

→ Markets and resource allocation

Arrow (1951); Arrow & Debreu (1954)

→ Information aggregation in markets

Muth (1961); Fama (1970); Plott & Sunder (1988)

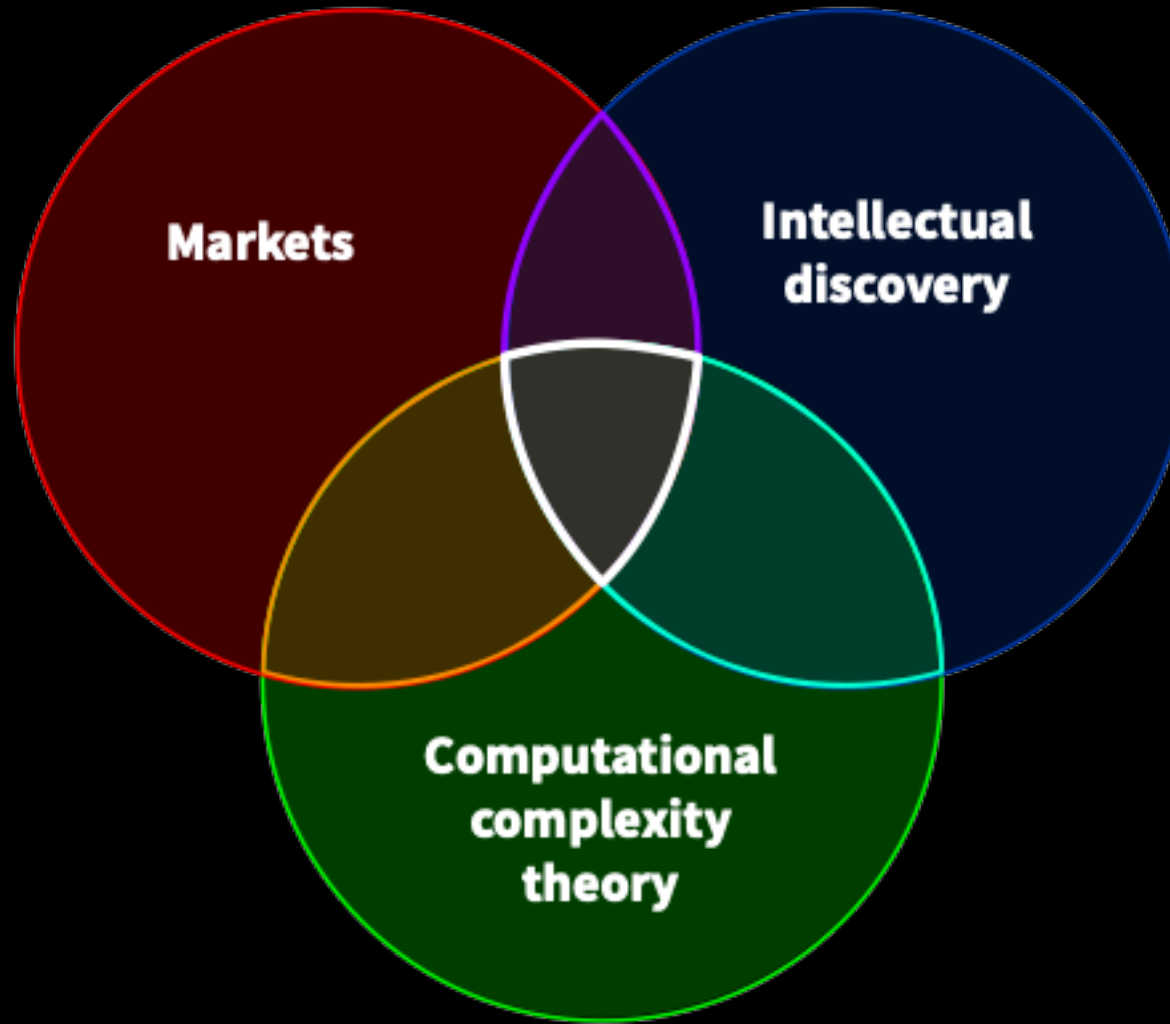
Relatively understudied:

→ Spreading knowledge of solutions to complex problems

→ Probabilistic uncertainty \neq uncertainty from complexity

Hayek (1945): "...knowledge of the kind which by its nature cannot enter into statistics ... the method by which such knowledge can be made as widely available as possible is precisely the problem to which we have to find an answer."

Background



RE and market efficiency

Muth (1961); Grossman (1976); Fama (1970); Grossman & Stiglitz (1980)

Market-based incentives

Nuvolari (2004); Meloso, et al. (2009)

Collective intelligence

Hayek (1945); Bossaerts, et al., (2025);

Combinatorial problems

Papadimitriou & Steiglitz (1982);
Pisinger (1998)

NP-hardness

Arora & Barak (2009)

Discovering new ideas is essential for growth
Schumpeter (1911)

Ideas are free to use, but costly to find
Romer (1990); Romer (1993)

Existing institutions have well-known shortcomings
Fritz (1958); Usher (1964);
Hall, et al., (2012)

Contribution

Markets as a mechanism for intellectual discovery

Disentangling the effects of incentives and price signals

Operationalising intellectual discovery

Mirror the (combinatorial) nature of discovery in the real world

Romer (1990); Romer (1993)

Canonical, with a well-defined optimum

Pisinger (1998)

Allows us to precisely vary difficulty

Franco (2026, in prep.)

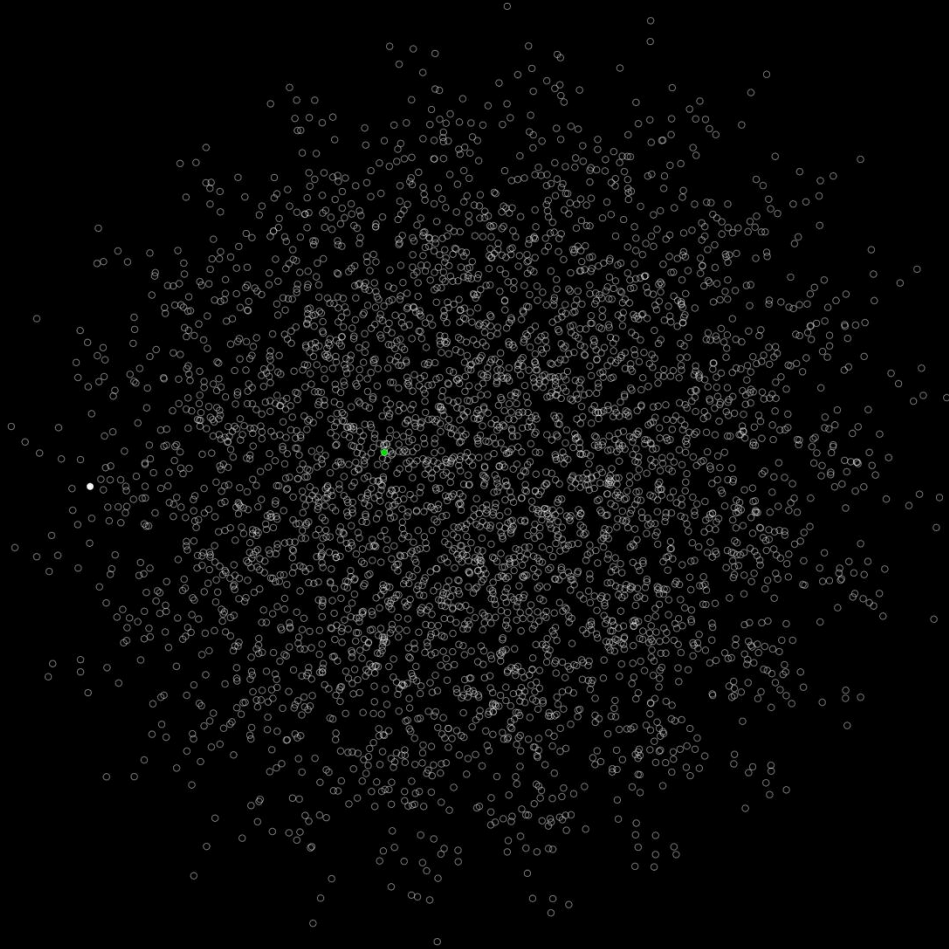
Our solution: The **Knapsack Problem**



A real instance

Knapsack		Out of knapsack	
WEIGHT: 1135	VALUE: 2604		
CAPACITY: 1151	<input type="button" value="Submit"/>		

Approximation



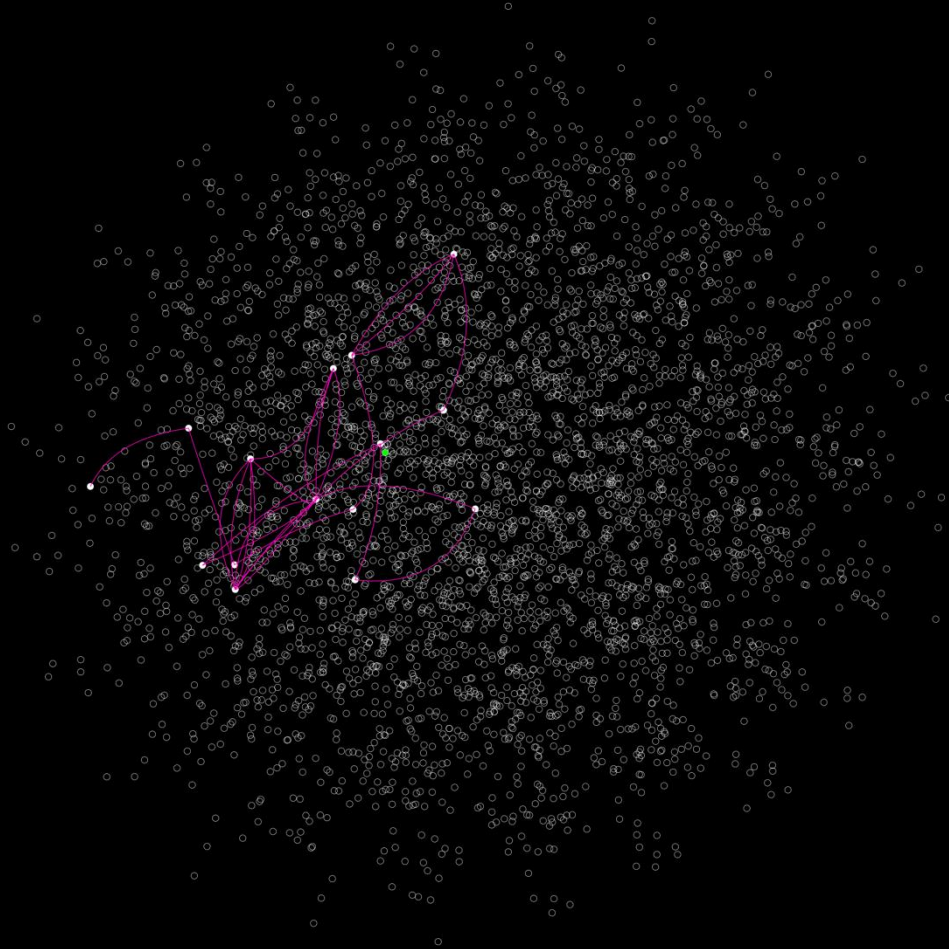
Problem: The total solution space is too vast to exhaustively explore.

Compromise: Individuals try to strike a balance between:

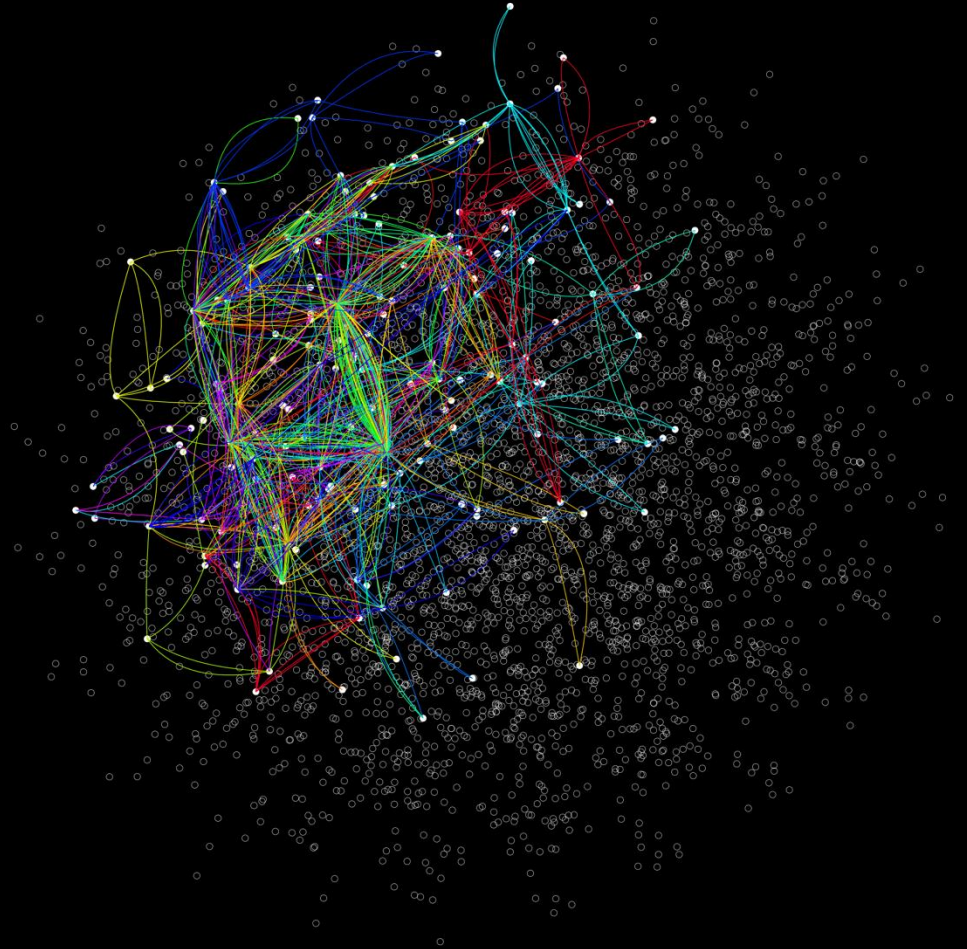
- **Solution quality:** the resulting solution should be within ϵ of the optimum.
- **Frugality:** computational cost should be minimised.

Result: Search over constrained subset of total solution space.

Collective problem-solving

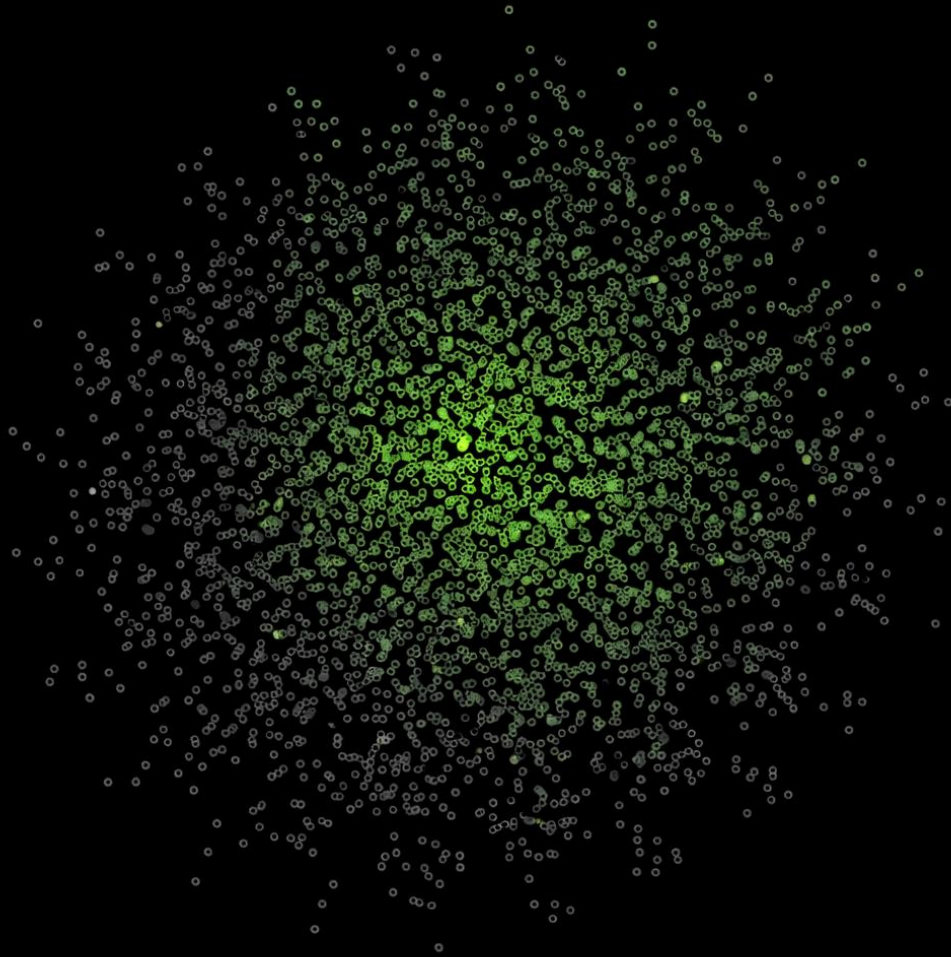


A single individual explores a small subset of the solution space.

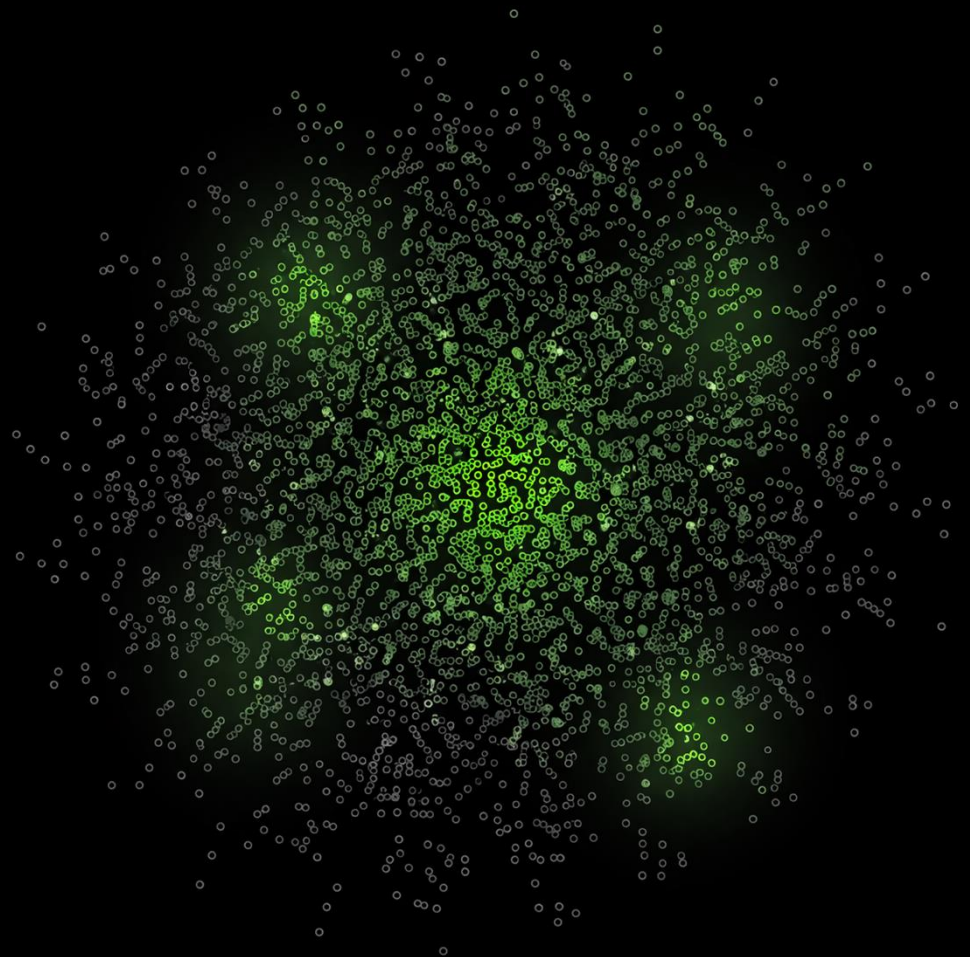


A group of individuals collectively explore a large portion of the solution space.

Modulating complexity



Smooth landscape = **easy** instance



Rugged landscape = **hard** instance



Experiment design

Sample of N = 120

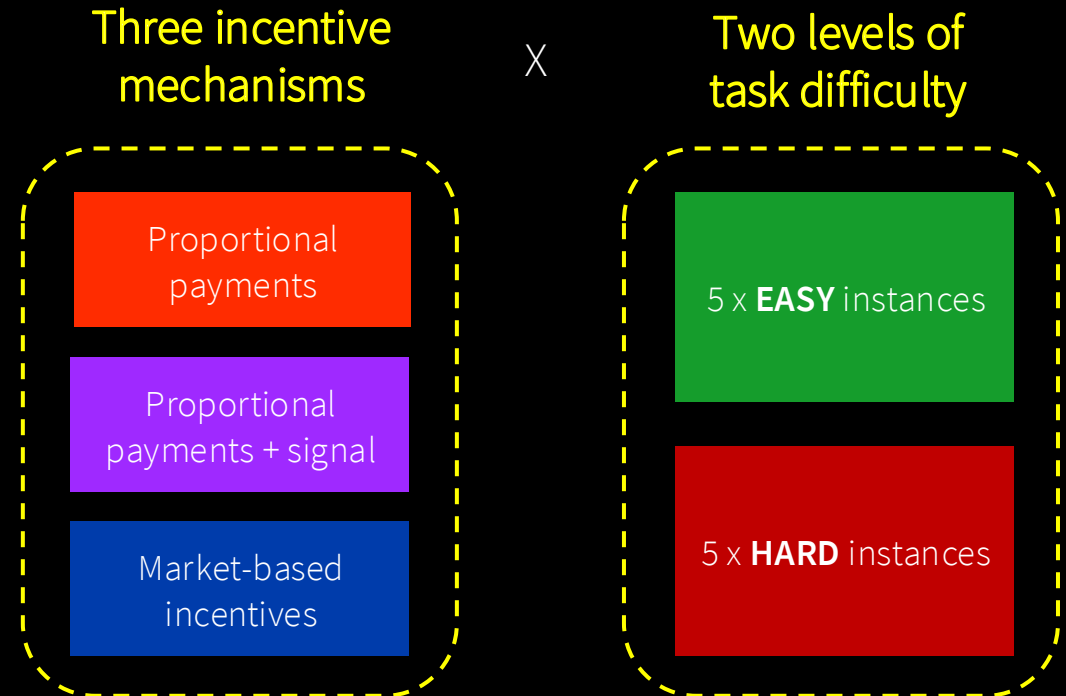
- University of Melbourne community
- Mean age: 26;
- Gender: 78F, 41M, 1 prefer not to say.

3 (treatments) x 2 (difficulty)

- 10 KP instances (5 easy, 5 hard)

Within-subject design

- Six blocks of ~20 participants
- Treatments perfectly counterbalanced.



Treatments

- **Proportional payments**

Participants paid in proportion to their effort.

\$1.50 in proportion to submitted value

\$1.50 bonus for finding the optimal solution

- **Proportional payments + signal (signal)**

Identical to proportional payment treatment.

Except that participants were told the optimal value before attempting to solve the instance.

A



B



Treatments

- **Market treatment¹**

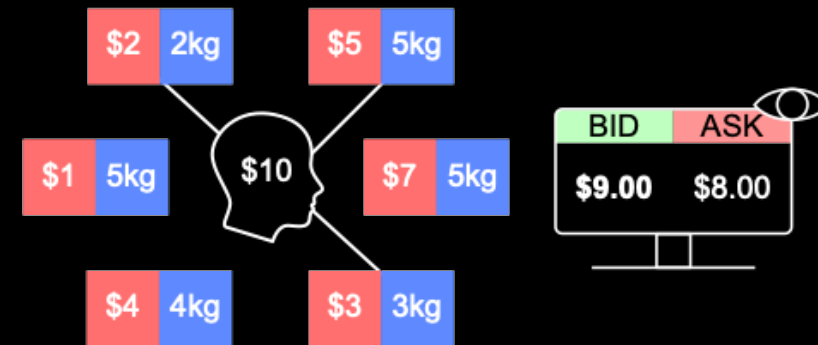
Participants trade experimental assets (“stocks”), while solving the knapsack problem.

The stock’s value equals the highest solution discovered by anyone.

Profit comes from:

- Buying stocks at prices below the final best solution, and
- Selling stocks at prices above the final best solution.

C



1. Adapted from experiment two in Bossaerts, Peter, et al. "Resource allocation, computational complexity, and market design." *Journal of Behavioral and Experimental Finance* 42 (2024): 100906.

Trading interface

×
FLEX-E-MARKETS beta

1395

SETTLED AVAILABLE

CASH \$10,000.00 \$10,000.00

STOCK 8 8

> STOCK <

ORDER BOOK			TRADE HISTORY	
UNITS	PRICE	MINE		
1	\$1,635.00		1	\$1,621.00 ↘ 12:12:15.653649
1	\$1,630.00		1	\$1,601.00 ↗ 12:11:40.076285
1	\$1,629.00		1	\$1,600.00 ↗ 12:11:33.408663
5	\$1,628.00		1	\$1,599.00 ↗ 12:11:32.055053
1	\$1,625.00		1	\$1,599.00 ↗ 12:11:31.449416
1	\$1,624.00		1	\$1,578.00 ↘ 12:11:29.961996
1	\$1,623.00		1	\$1,600.00 ↗ 12:11:29.591124
7	\$1,622.00		1	\$1,579.00 ↗ 12:11:23.832215
<i>spread</i> \$5.00 $\frac{1}{4}$			1	\$1,579.00 ↘ 12:11:20.677043
1	\$1,617.00		1	\$1,579.00 ↘ 12:11:19.880675
1	\$1,616.00		1	\$1,600.00 ↘ 12:11:19.860863
1	\$1,602.00		1	\$1,601.00 ↗ 12:11:18.852256
1	\$1,601.00		1	\$1,600.00 ↗ 12:11:09.014648
1	\$1,601.00		1	\$1,598.00 ↗ 12:11:01.493633
1	\$1,600.00		1	\$1,598.00 ↗ 12:10:58.571631
1	\$1,457.00		2	\$1,579.00 ↗ 12:10:44.022596
1	\$1,421.00		1	\$1,578.00 ↗ 12:10:40.072490
2	\$1,331.00		1	\$1,599.00 ↗ 12:10:03.885024

STOCK

BUY
SELL

UNITS
●

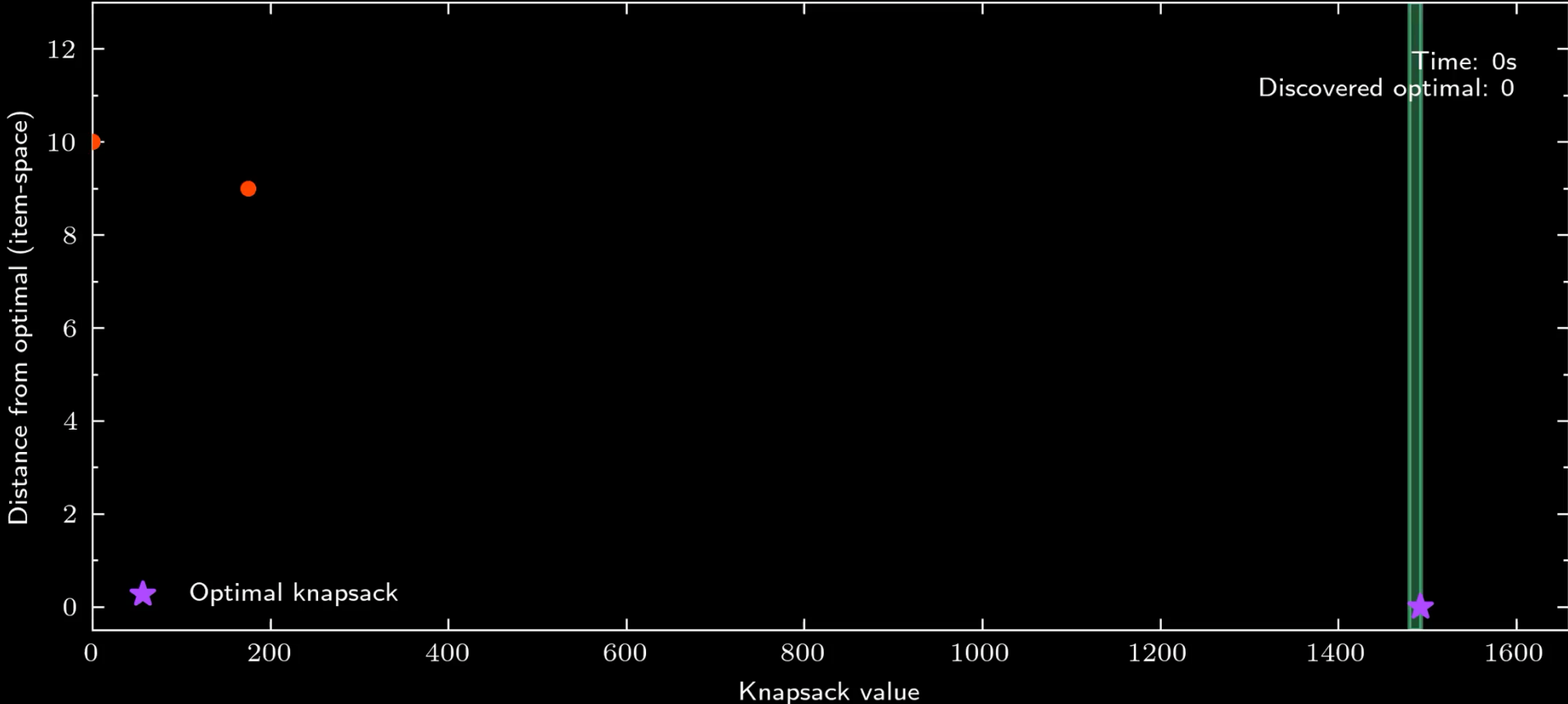
1
-
+

PRICE
●

\$1.00
-
+

PLACE BUY ORDER

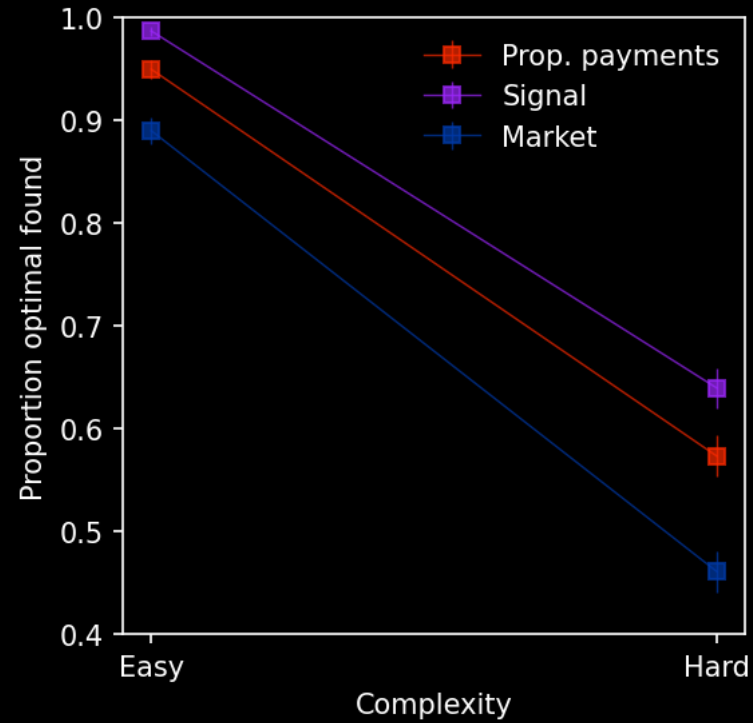
Market condition



Outcome measures

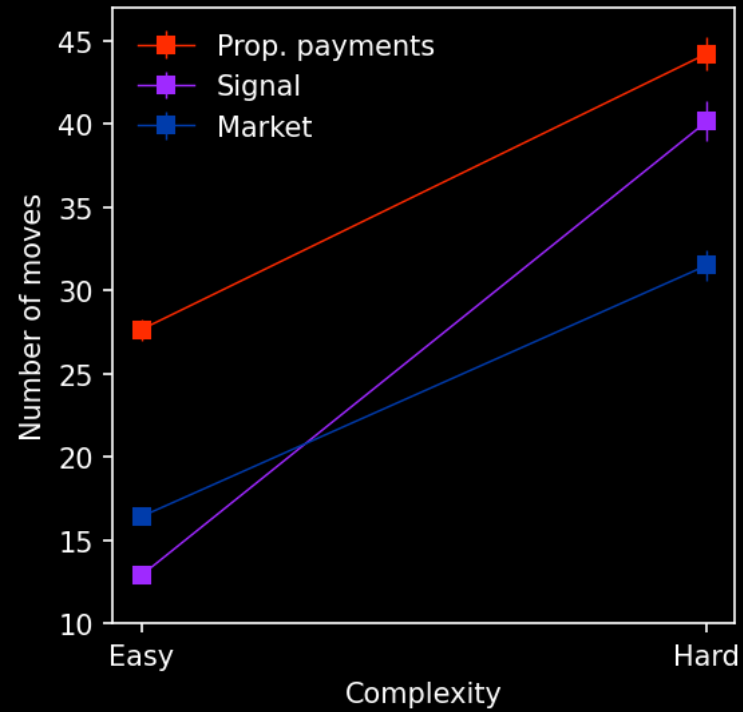
- 1. Quality**
Probability optimal solution attained
- 2. Effort**
Number of 'item moves'
- 3. Productivity**
Submitted value / number of moves

Quality



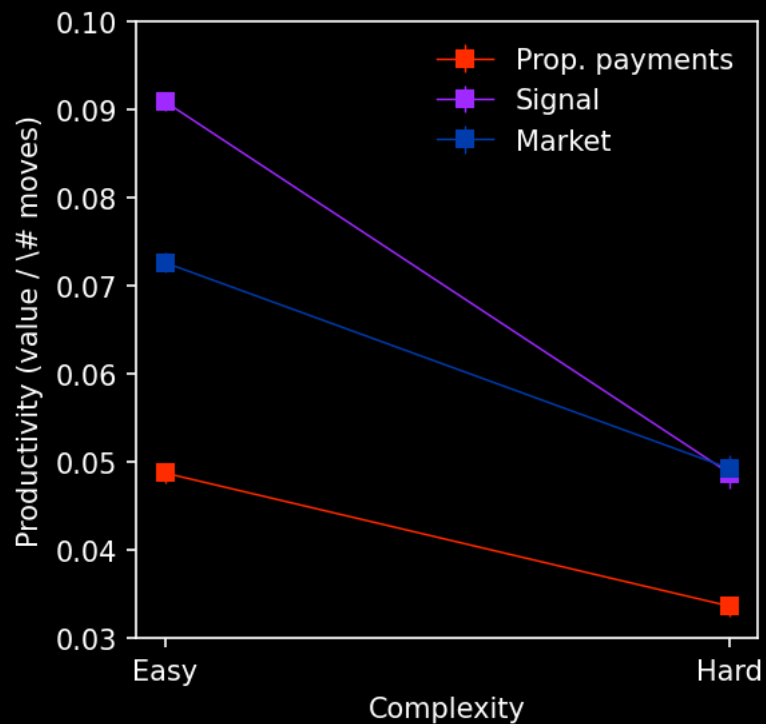
Signals help, but indirect incentives
weaken solution quality

Effort



Markets and signals **reduce redundant effort.**

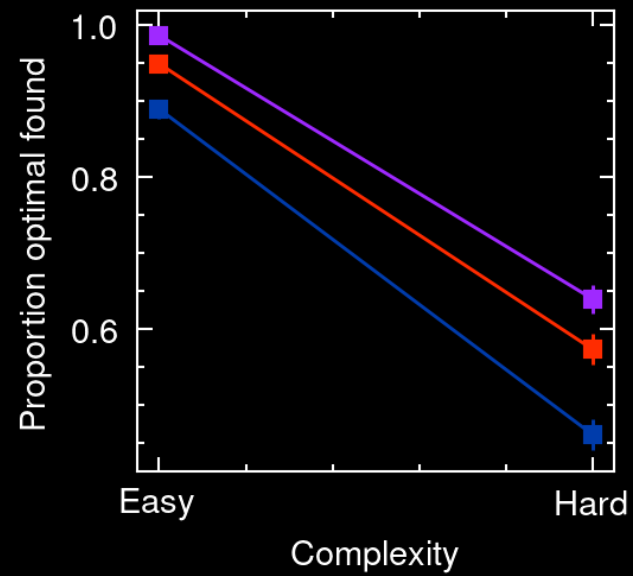
Productivity



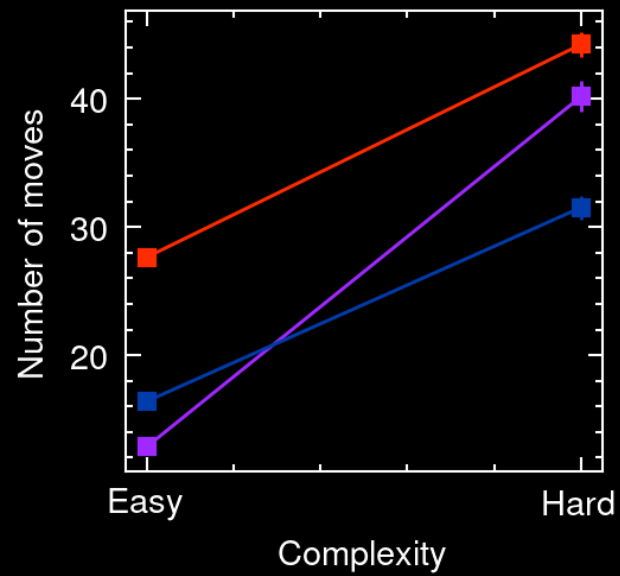
Markets and signals **increase productivity** by coordinating stop signals.

What did we learn?

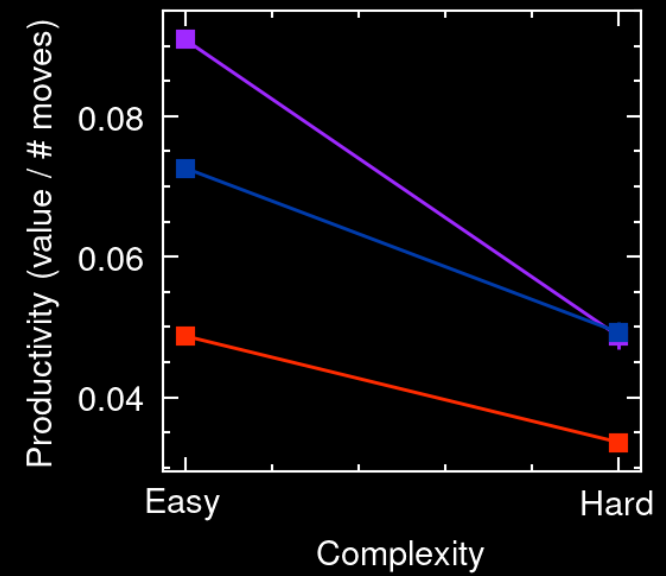
A



B



C

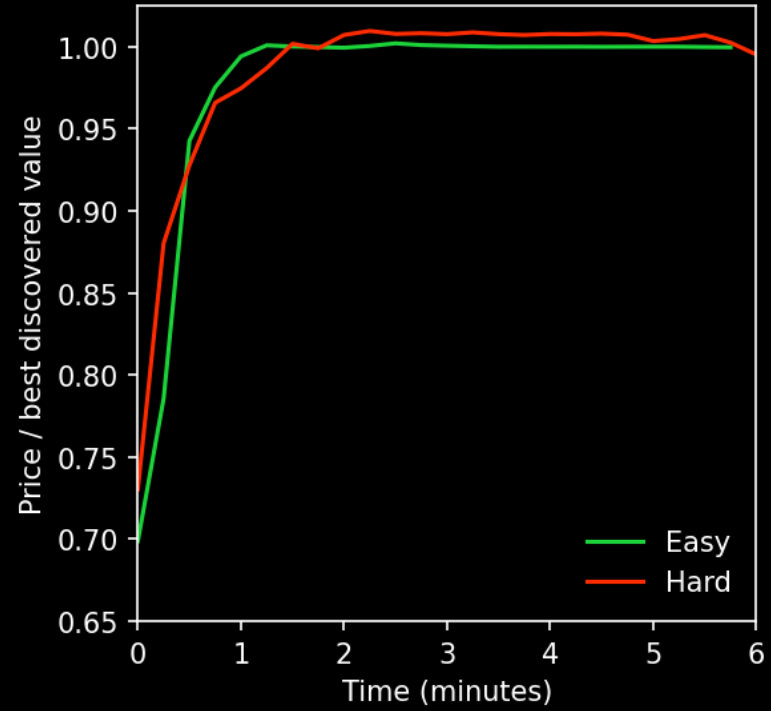


Prop. payments Signal Market

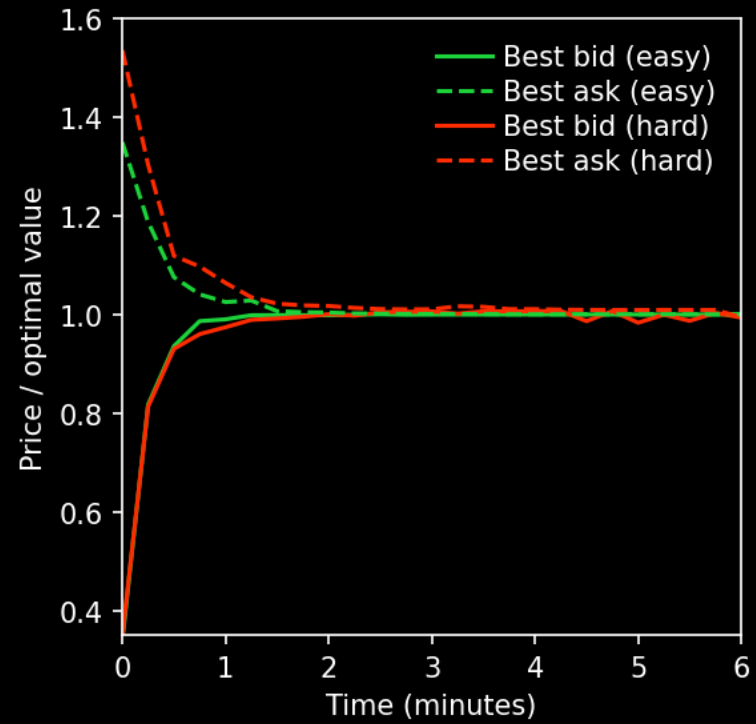
Price efficiency

How well do prices aggregate knowledge?

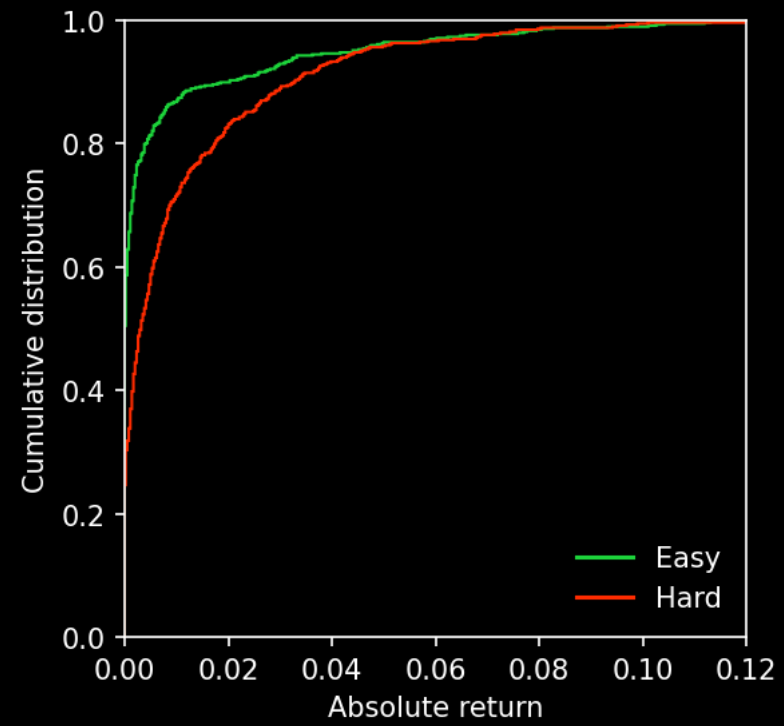
Trade prices



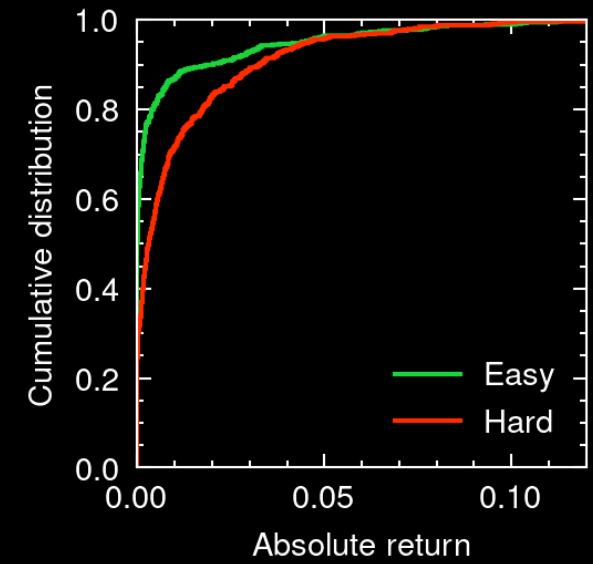
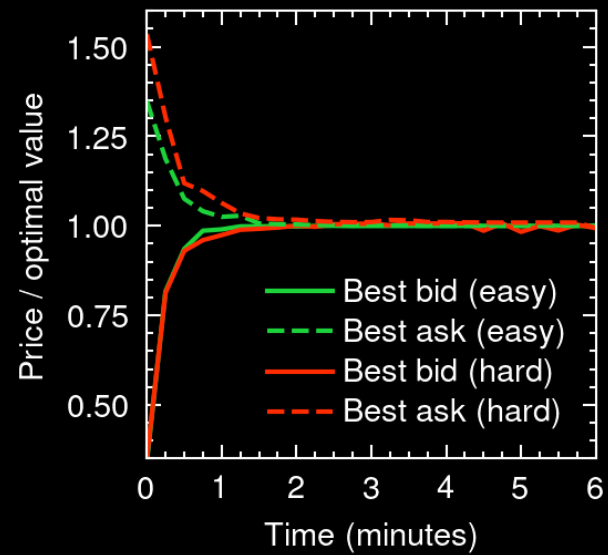
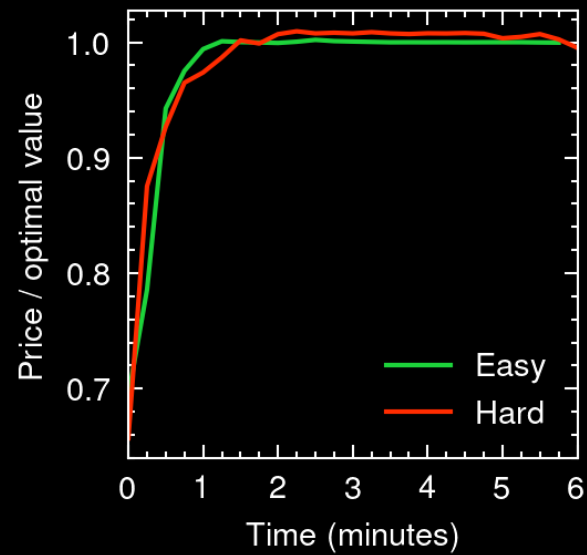
Bid-ask spread



Bid-ask spread



Price efficiency and returns



Summary

Complexity matters

→ Higher problems reduce performance but markets and signals can mitigate this.

Markets enable coordination

→ Groups explore larger portions of the solution space, trading shares information and reduces redundant effort.

Market efficiency degrades with complexity

→ Prices are less efficient when it is computationally difficult to estimate fundamental value

Future directions

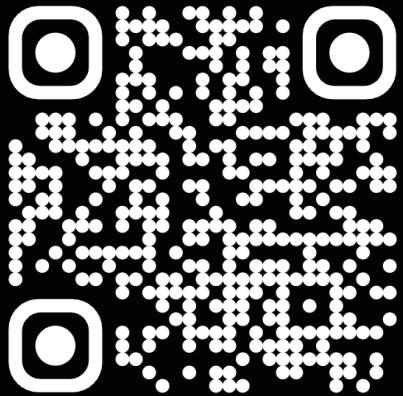
→ Investigating market failures (bubbles)

→ Distributed problems

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Thanks to my supervisors for this work →

Link to my website ↓



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