

Positioning

Innocuou game

Leverage optimizatio

How deep the rabbit hole goes

Only time will tell Risk optimization from a dynamics perspective

Ole Peters

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External Professor Santa Fe Institute



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Positioning

Innocuous game

Leverage optimizatio

How deep the rabbit hole goes

Name dropping:

Many thanks to Alex Adamou, Bill Klein, Reuben Hersh, Murray Gell-Mann, Ken Arrow.

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Positioning

Innocuous game

Leverage optimizatio

How deep the rabbit hole goes

1 Positioning

2 Innocuous game

3 Leverage optimization

4 How deep the rabbit hole goes

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Positioning

Innocuous game

Leverage optimizatio

How deep the rabbit hole goes

My perspective

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Positioning

Innocuous game

Leverage optimizatior

How deep the rabbit hole goes

My perspective

• 17th century: mainstream economics went down a dead-end.

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Positioning

Innocuou game

Leverage optimizatior

How deep the rabbit hole goes

My perspective

- 17th century: mainstream economics went down a dead-end.
- 19th 21st centuries: relevant mathematics developed.

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Positioning

Innocuou game

Leverage optimizatior

How deep the rabbit hole goes

My perspective

- 17th century: mainstream economics went down a dead-end.
- 19th 21st centuries: relevant mathematics developed.

Program

Re-derive formal economics from modern starting point.

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Leverage optimizatior

How deep the rabbit hole goes

<u>Thesis:</u>

Problem with randomness, *i.e.* risk.

17th-century key concept \rightarrow **parallel worlds**.

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 21^{st} -century mathematics \rightarrow **time**.



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Innocuou game

Leverage optimizatio

How deep the rabbit hole goes



Heads: win 50%.

Innocuous game



Tails: lose 40%.

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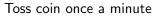


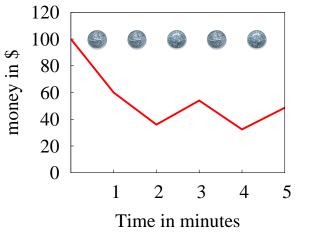
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Leverage optimizatio

How deep the rabbit hole goes Innocuous game

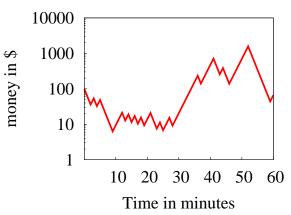




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One sequence



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Leverage optimizatio

How deep the rabbit hole goes



10 sequences

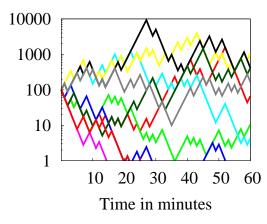
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Innocuous game

Leverage optimizatio

How deep the rabbit hole goes



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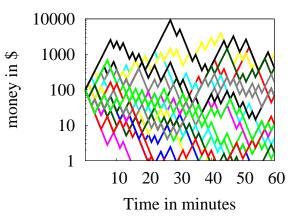


20 sequences



optimization

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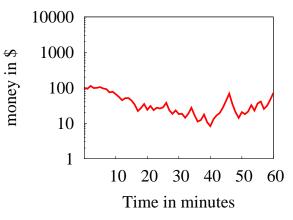
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Leverage optimizatio

How deep the rabbit hole goes

Average of 20 sequences



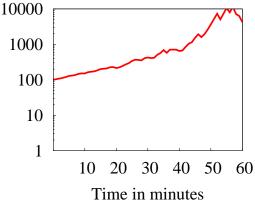
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Average of 1000 sequences

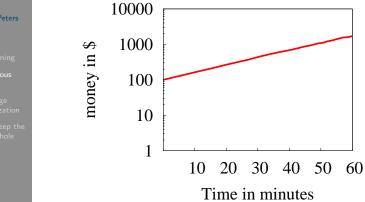




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Average of 1,000,000 sequences



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Innocuous game

Leverage optimizatio

How deep the rabbit hole goes

Good game?

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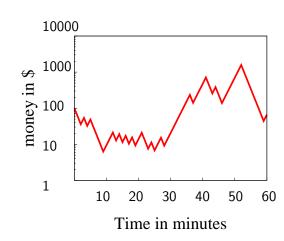
Play for one hour...

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Innocuous game

Leverage optimizatio

How deep the rabbit hole goes



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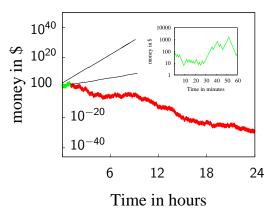
...continue one day (note scales)...

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Innocuous game

Leverage optimizatio

How deep the rabbit hole goes



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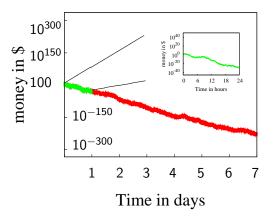
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Innocuou: game

Leverage optimization

How deep the rabbit hole goes

..continue one week (note scales)...



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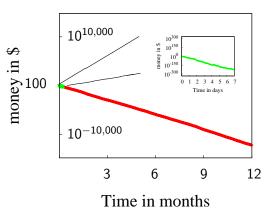
...continue one year (note scales)...

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Innocuous game

Leverage optimization

How deep the rabbit hole goes



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money in \$

Ensemble perspective Time perspective 10000 $10^{10,000}$ ÷... 100 10^{-10,000} 1000 100 10 1

10 20 30 40 50 60 Time in minutes

6 Time in months 12

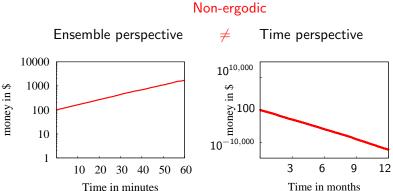
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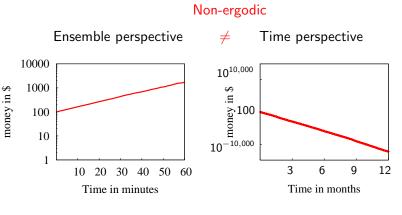


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Leverage optimizatio

How deep the rabbit hole goes



Non-commuting limits

 $\lim_{T \to \infty} \lim_{N \to \infty} g_{\text{est}} \quad \neq \quad \lim_{N \to \infty} \lim_{T \to \infty} g_{\text{est}}$

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No magic.

O. Peters

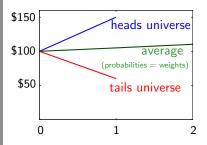
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Innocuou game

Leverage optimizatio

How deep the rabbit hole goes

Ensemble perspective



Result: \$110.25

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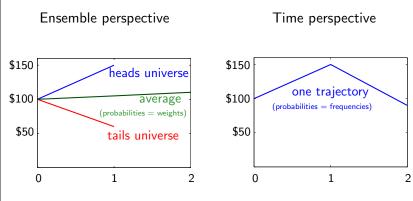


No magic.

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Leverage optimizatio

How deep the rabbit hole goes



Result: \$110.25

Result: \$90

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Leverage optimizatior

How deep the rabbit hole goes

Message:

Expectation value meaningful only if

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- observable is ergodic
- a physical ensemble exists

Otherwise meaningless.





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Innocuou game

Leverage optimization

How deep the rabbit hole goes Problem: find proportion of wealth to invest in some venture.

	Neoclassical	Time
	economics	perspective
Model	Random variable Δx	Stochastic process
	to represent changes	x(t) to represent
	in wealth.	wealth over time.
Technique	1656 –1738: compute	Find ergodic observ-
	expectation value	able $f(x)$. Optimize
	$\langle \Delta x \rangle$.	time-average perfor-
	1738 onwards: find	mance by computing
	utility function $u(x)$,	expectation value of
	optimize expectation	ergodic observable.
	value $\langle \Delta u(x) \rangle$.	



Positioning

Innocuou game

Leverage optimizatio

How deep the rabbit hole goes

Example:

geometric Brownian motion (GBM) with leverage I.

- Proportion / invested in GBM
- Proportion 1 I invested in risk-free asset
- constant rebalancing, self-financed portfolio.

Wealth follows: $dx = x((\mu_r + I\mu_e)dt + I\sigma dW)$

Solution:
$$x(t) = x_0 \exp\left(\left(\mu_r + l\mu_e - \frac{l^2\sigma^2}{2}\right)t + l\sigma W(t)\right)$$

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- \rightarrow Find optimal leverage using
 - a) Utility theory.
 - b) Time perspective.



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Innocuou game

Leverage optimizatio

How deep the rabbit hole goes a) Utility theory with power-law utility, $u(x) = x^{\alpha}$:

- Fix horizon Δt , consider random variable $x(\Delta t)$.
- Convert $x(\Delta t)$ to utility $u(x(\Delta t)) = x(\Delta t)^{\alpha}$, $u(x(\Delta t)) = x_0^{\alpha} \exp\left(\alpha \left(\mu_r + l\mu_e - \frac{l^2 \sigma^2}{2}\right) \Delta t + \alpha l \sigma W(\Delta t)\right)$
- Find expectation value of $u(x(\Delta t))$, $\langle u(x(\Delta t)) \rangle = x_0^{\alpha} \exp\left(\alpha \Delta t \left(\mu_r + l\mu_e - \frac{l^2 \sigma^2}{2} + \frac{\alpha l^2 \sigma^2}{2}\right)\right)$

Implies expected change in utility $\langle \Delta u \rangle = \langle u(x(\Delta t)) \rangle - u(x_0)$.

• Set derivative to zero, $\frac{d\langle \Delta u \rangle}{dt} = 0$

$$= x_0^{\alpha} \alpha \Delta t \left(\mu_e - l\sigma^2 + \alpha l\sigma^2 \right) \exp \left(\alpha \Delta t \left(\mu_r + l\mu_e - \frac{l^2 \sigma^2}{2} + \frac{\alpha l^2 \sigma^2}{2} \right) \right).$$

Solve for I

$$I_{\text{opt}}^u = \frac{\mu_e}{(1-\alpha)\sigma^2}.$$

(日)



b) Time perspective

• Given x(t), find ergodic observable, *i.e.* f(x) such that $\underbrace{\prod_{T \to \infty}^{\text{Time average}}}_{T \to \infty} \frac{\frac{1}{T} \int_{0}^{T} f(x(t))dt} = \underbrace{\frac{1}{N} \sum_{i}^{N} f(x_{i}(t))}_{i} = \langle f(x(t)) \rangle}_{i}.$

Positioning

Innocuous game

Leverage optimizatior

How deep the rabbit hole goes Solution is a growth rate, determined by dynamics, $f(x) = \frac{1}{\Delta t} \log(x(t + \Delta t)/x(t)).$

- Find time average (or expectation value) $\overline{t} = \mu_r + I\mu_e - \frac{l^2 \sigma^2}{\sigma}$.
- Set derivative to zero, solve for I

$$I_{\text{opt}}^t = \frac{\mu_e}{\sigma^2}.$$

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Comments:

• $I_{opt}^{u} = \frac{\mu_{e}}{(1-\alpha)\sigma^{2}}$ depends on utility function (α).

 $I_{\text{opt}}^t = \frac{\mu_e}{\sigma^2}$ set by dynamics.

- Utility: 18th century (long before ergodicity debate).
- Modern interpretation Utility theory aims for ergodic observable, *e.g.* for GBM, rate of change in log utility.

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 <u>Different questions answered</u> <u>Utility theory:</u> *I^u_{opt} corresponds to greatest expected happiness.*

Time perspective: I_{opt}^t implies greatest growth rate.

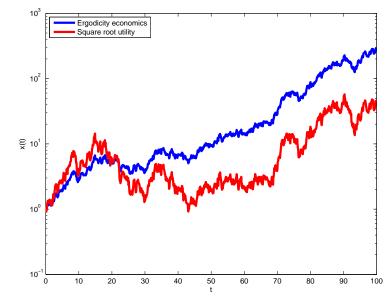


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Leverage optimizatior

How deep the rabbit hole goes

GBM parameters $\mu_r = 5.2\%$ p.a., $\mu_e = 2.4\%$ p.a., $\sigma = 15.9\%$ p. \sqrt{a} .



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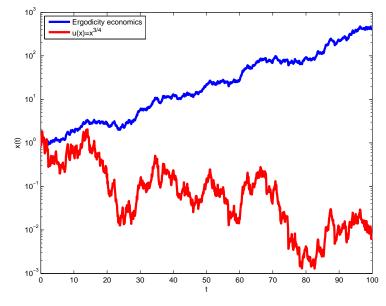


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Leverage optimizatio

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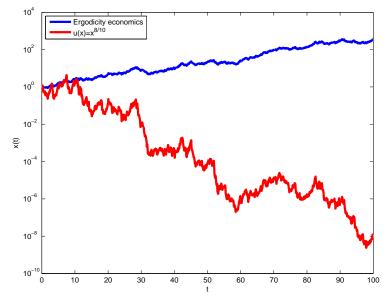


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Leverage optimizatioı

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Innocuou: game

Leverage optimizatio

How deep the rabbit hole goes Cruel world doesn't care about my risk preferences.

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Positioning

Innocuous game

Leverage optimizatior

How deep the rabbit hole goes

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384 – 322 BC

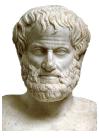
Aristotle's cosmology.

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Innocuous game

Leverage optimizatior

How deep the rabbit hole goes





384 – 322 BC Aristotle's cosmology. 310 – 230 BC Aristarchus model: heliocentric - dismissed.

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Innocuou game

Leverage optimizatio

How deep the rabbit hole goes 384 - 322 BC 310 - 230 BC ??? - 178 BC

Aristotle's cosmology.

Aristarchus model: heliocentric - dismissed.

Ptolemy's model: geocentric, perfect circles.





310 – 230 BC

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Innocuous game

Leverage optimizatior

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??? – 178 BC Ptolemy's model: geocentric, perfect circles.

200 BC-1500 CE No challenge (Hypatia?).



- O. Peters
- Positioning
- Innocuous game
- Leverage optimizatior
- How deep the rabbit hole goes

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1473–1543 CE Copernicus' model: perfect circles *but* heliocentric.



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Leverage optimizatior

How deep the rabbit hole goes 1473–1543 CECopernicus' model: perfect circles but heliocentric.1546–1601 CETycho Brahe – geocentric but observed comet 1577.





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Innocuous game

Leverage optimizatior

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Innocuous game

Leverage optimizatioı

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Galileo – earthly motion in perfect shapes, parabolas!

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Positioning

Innocuous game

Leverage optimizatior

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Positioning

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Leverage optimizatior

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Mid-17th century: Crisis! All or nothing time-bound?



Probability theory

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Positioning

Innocuous game

Leverage optimizatior

How deep the rabbit hole goes



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Positioning

Innocuou game

Leverage optimizatio

How deep the rabbit hole goes

Probability theory



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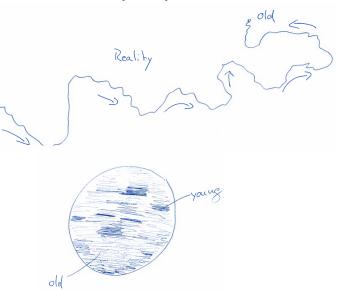
Positioning

Innocuou game

Leverage optimizatio

How deep the rabbit hole goes

Probability theory



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Positioning Innocuous

Leverage optimizatior

How deep the rabbit hole goes

Evolution of structure

Two entities follow GBM.

$$dx_1 = x_1(\mu dt + \sigma dW_1)$$
 and $dx_2 = x_2(\mu dt + \sigma dW_2)$

If entities pool resources, they will follow $dx_{12} = x_{12} \left[\mu dt + \sigma \left(\frac{1}{2} dW_1 + \frac{1}{2} dW_2 \right) \right]$

Cooperation conundrum

Lucky partner gives, unlucky partner receives.

Expectation value grows at μ , irrespective of cooperation. Lucky partner: why cooperate?

But: cooperation exists (multicellularity, firms, states etc).

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\rightarrow Expectation value model fails.



Positioning

Innocuoι game

Leverage optimizatior

How deep the rabbit hole goes

Usual story: very complicated.

Our story: non-ergodic system \rightarrow compute expectation value of ergodic observable under specified dynamics (time-average growth rate).

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1 No cooperation: $\frac{d\langle \ln(x_1)\rangle}{dt} = \frac{d\langle \ln(x_2)\rangle}{dt} = \mu - \sigma^2/2$ 2 Cooperation: $\frac{d\langle \ln(x_{12})\rangle}{dt} = \mu - \sigma^2/4$



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Innocuoi game

Leverage optimizatio

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Our story: non-ergodic system \rightarrow compute expectation value of ergodic observable under specified dynamics (time-average growth rate).

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2 Cooperation: $\frac{d\langle \ln(x_1) - dt \rangle}{dt}$

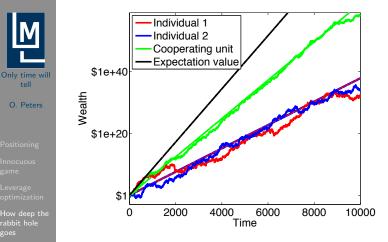
 $\frac{d\langle \ln(x_{12})\rangle}{dt} = \mu - \sigma^2/4$

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Cooperators do better *over time* (though not in expectation).

VON NEUMANN (1944): "We need inventions on the scale of a new calculus to make progress on dynamics."

Correct, and we have that since 1944 (ITÔ).



- Good risk management = faster growth.
- Evolutionary advantage of structure (multicellularity, tribes, firms, nations) over no structure.



Positioning

Innocuou game

Leverage optimizatior

How deep the rabbit hole goes

Problems we can address (solve)

- optimize leverage (for any dynamic)
- map utility theory \rightarrow dynamics
- 300-year old St. Petersburg paradox
- dynamics of wealth distribution
- better economic measures than GDP
- price insurance contracts (derivatives)

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• explain emergence of structure

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O. Peters

Positioning

Innocuou game

Leverage optimizatio

How deep the rabbit hole goes Correcting one deep conceptual flaw in economics enables powerful quantitative theory.



Positioning

Innocuou game

Leverage optimizatio

How deep the rabbit hole goes

Thank you.

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