Transformative AI, existential risk, and real interest rates

Trevor Chow [1] **Basil Halperin** [2] **J. Zachary Mazlish** [3]

[1]Stanford, [2]Stanford, [3]Oxford & GPI

January 2025

How can we forecast the development of transformative AI?

How can we forecast the development of transformative AI?

1. Surveys

- Grace et al (2024): 2047

more

How can we forecast the development of transformative AI?

1. Surveys

- Grace et al (2024): 2047

more

2. Models / trend extrapolation:

- Kurzweil (2005): 2045
- Cotra (2022): 2040
- Davidson (2023): 2043
- Epoch (2022): 2046

more

How can we forecast the development of transformative AI?

1. Surveys

- Grace et al (2024): 2047

more

2. Models / trend extrapolation:

- Kurzweil (2005): 2045
- Cotra (2022): 2040
- Davidson (2023): 2043
- Epoch (2022): 2046

more

3. Asset prices

- Prices aggregate dispersed wisdom (Hayek 1945)...
- ...financial market prices especially so (Fama, etc)

examples

Real interest rates

Central point: short timelines for transformative AI would *increase real interest rates*

“Transformative AI”: defining the scenario under consideration

Definition (Transformative AI)

“Artificial intelligence technology that has at least as profound an impact on the human trajectory as did the industrial revolution or agricultural revolution”

“Transformative AI”: defining the scenario under consideration

Definition (Transformative AI)
“Artificial intelligence technology that has at least as profound an impact on the human trajectory as did the industrial revolution or agricultural revolution”

Want to recognize double-edged sword nature (Jones 2023):

“Transformative AI”: defining the scenario under consideration

Definition (Transformative AI)
“Artificial intelligence technology that has at least as profound an impact on the human trajectory as did the industrial revolution or agricultural revolution”

Want to recognize double-edged sword nature (Jones 2023):

1. May rapidly accelerate growth…

“Transformative AI”: defining the scenario under consideration

Definition (Transformative AI)
“Artificial intelligence technology that has at least as profound an impact on the human trajectory as did the industrial revolution or agricultural revolution”

Want to recognize double-edged sword nature (Jones 2023):

1. May rapidly accelerate growth…
2. …may pose an “existential risk”

“Transformative AI”: defining the scenario under consideration

Definition (Transformative AI)
“Artificial intelligence technology that has at least as profound an impact on the human trajectory as did the industrial revolution or agricultural revolution”

Want to recognize double-edged sword nature (Jones 2023):

1. May rapidly accelerate growth...
2. ...may pose an “existential risk”

Definition (Aligned transformative AI)
Technology that causes growth in global GDP in excess of 30% per year.

- Follows Davidson (2023): a 10× increase in growth

“Transformative AI”: defining the scenario under consideration

Definition (Transformative AI)
“Artificial intelligence technology that has at least as profound an impact on the human trajectory as did the industrial revolution or agricultural revolution”

Want to recognize double-edged sword nature (Jones 2023):

1. May rapidly accelerate growth...
2. ...may pose an “existential risk”

Definition (Aligned transformative AI)
Technology that causes growth in global GDP in excess of 30% per year.

- Follows Davidson (2023): a 10× increase in growth

Definition (*Un*aligned AI)
Technology that causes human extinction.

Theory

Empirics

Discussion

Appendix

Real interest rates are determined by the supply and demand for savings

Real interest rates are determined by the supply and demand for savings

Ramsey rule:

$$r = \rho + \frac{1}{\sigma} g$$

- r: real interest rate
- ρ: time discounting
- g: growth rate
- $\sigma > 0$: elasticity of intertemporal substitution

Real interest rates are determined by the supply and demand for savings

Ramsey rule:

$$r = \rho + \frac{1}{\sigma} g$$

- r: real interest rate
- ρ: time discounting
- g: growth rate
- $\sigma > 0$: elasticity of intertemporal substitution

1. **Time discounting and mortality risk**
   - "Intrinsic preference for the present"
     +
     Probability of death
   - Intuition: no reason to save if dead

Real interest rates are determined by the supply and demand for savings

Ramsey rule:

$$r = \rho + \frac{1}{\sigma} g$$

- r: real interest rate
- ρ: time discounting
- g: growth rate
- $\sigma > 0$: elasticity of intertemporal substitution

1. **Time discounting and mortality risk**
   - "Intrinsic preference for the present"
     +
     Probability of death
   - Intuition: no reason to save if dead
2. **Economic growth**
   - Intuition: consumption smoothing ("no reason to save if going to be rich")

Real interest rates and transformative AI

Ramsey rule:

$$r = \rho + \frac{1}{\sigma} g$$

- r: real interest rate
- ρ: time discounting
- g: growth rate
- $\sigma > 0$: elasticity of intertemporal substitution

Aligned transformative AI: $g = 30\%$

Real interest rates and transformative AI

Ramsey rule:

$$r = \rho + \frac{1}{\sigma} g$$

- r: real interest rate
- ρ: time discounting
- g: growth rate
- $\sigma > 0$: elasticity of intertemporal substitution

Aligned transformative AI: $g = 30\%$

Example calibration: $\rho = 1\%, \sigma = 1, g = 1\%$

Then:

$r = 2\%$

vs.

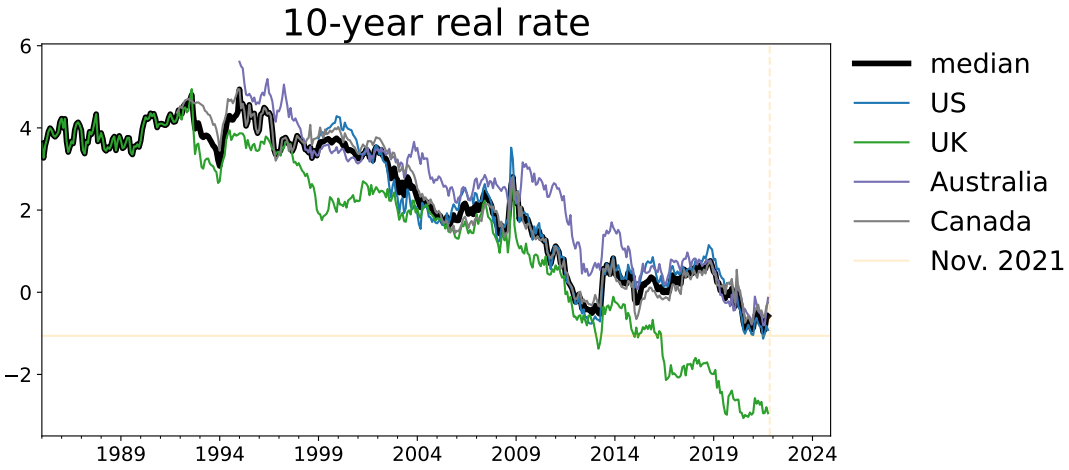
$r = 31\%$ **!**

The prospect of transformative AI would increase *real interest rates*

Central point: short AI timelines would cause *high real interest rates*

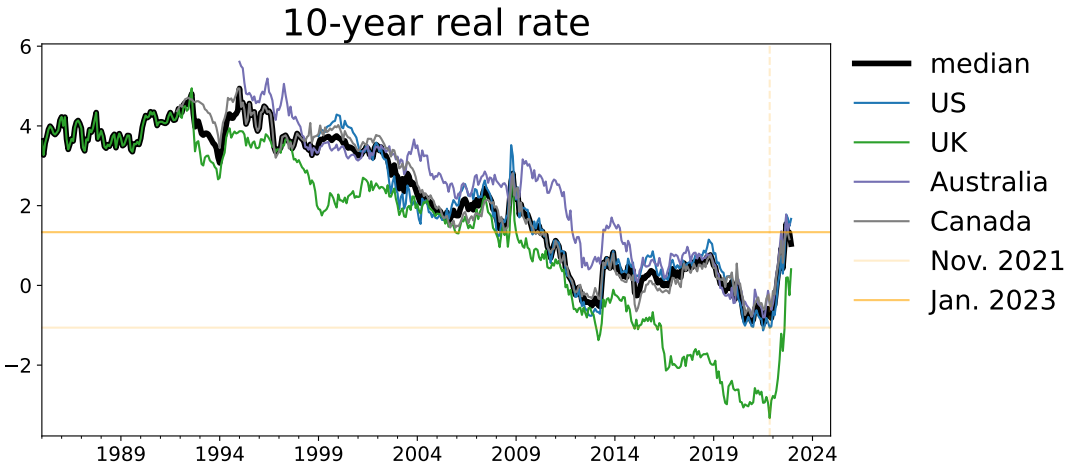
The prospect of transformative AI would increase *real interest rates*

Central point: short AI timelines would cause *high real interest rates*



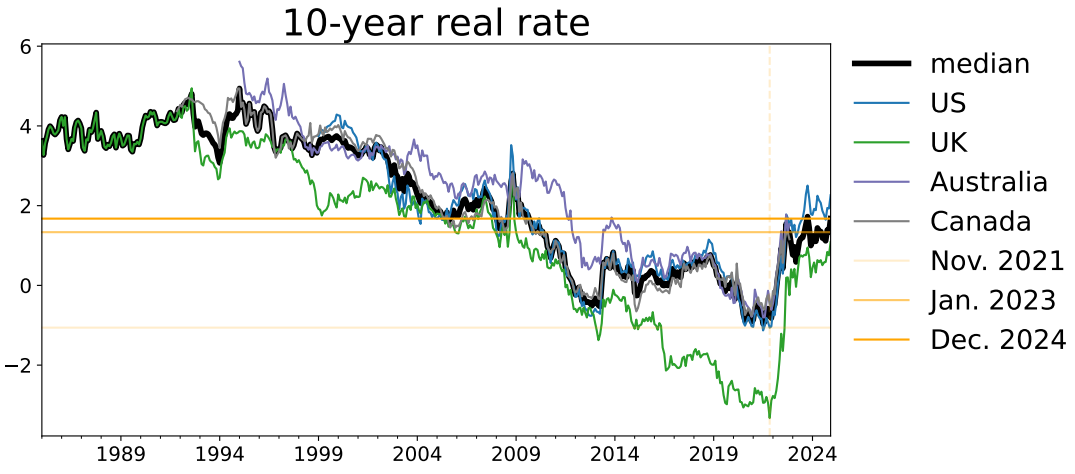
The prospect of transformative AI would increase *real interest rates*

Central point: short AI timelines would cause *high real interest rates*



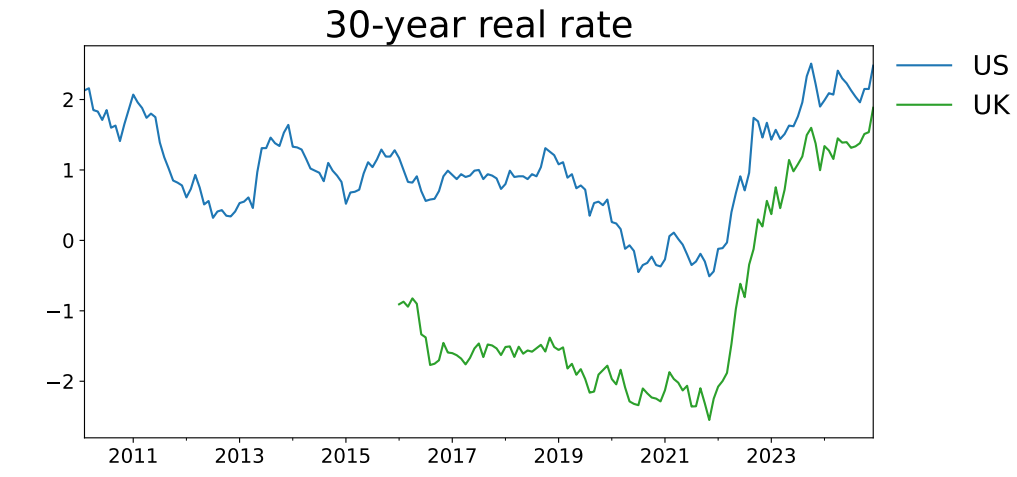
The prospect of transformative AI would increase *real interest rates*

Central point: short AI timelines would cause *high real interest rates*



The prospect of transformative AI would increase *real interest rates*

Central point: short AI timelines would cause *high real interest rates*



"I'm usually on the more frugal, conservative finance side. My whole life's been budgeting, and we're like, 'Nope, we're going to take that extra, very expensive vacation this year," said Sharon Korinek.

Korinek used to do chief financial officer-type work for private companies but hasn't returned to an office job because she doesn't see the point of it. Her husband, Anton, agrees. He's an economist at the University of Virginia who researches artificial intelligence and has aired his viewed at Marketplace Tech.

The Korineks can fund that extra vacation partly because they're not saving for one very-big-ticket item in the future.

"I've had so many arguments about this. I'm like, 'Our kids aren't going to college,'" Sharon said. "Most people look at us like we're crazy."

Sharon and Anton have two kids, ages 8 and 6. The thought of opening a 529 college savings plan feels absurd to them, considering that they envision a future in which AI will be smarter than most humans.

Zachary Anglin @zachanglin · Sep 26, 2022

Have you?

1

Kelsey Piper

@KelseyTuoc

taken out large (>1M) long-term loans? yes

9:12 PM · Sep 26, 2022

Cate Hall
@catehall

In 2017 I was convinced AI timelines were <5 years so I cashed in my 401k and blew away the money and let me tell you this particular form of intellectual consistency is Not Recommended

OpenAI

Benefits

For employees

- ✓ Health, dental, and vision insurance
- ✓ Mental healthcare support and services
- ✓ Commuter benefits
- ✓ 401(k) with generous matching
- ✓ Domestic conference budget for each employee

Theory

Empirics

Discussion

Appendix

Measuring real rates: challenges

$$r_t = i_t - \mathbb{E}_t \pi_{t+1}$$

Measuring real rates: challenges

$$r_t = i_t - \mathbb{E}_t \pi_{t+1}$$

Most bonds have historically been **nominal**

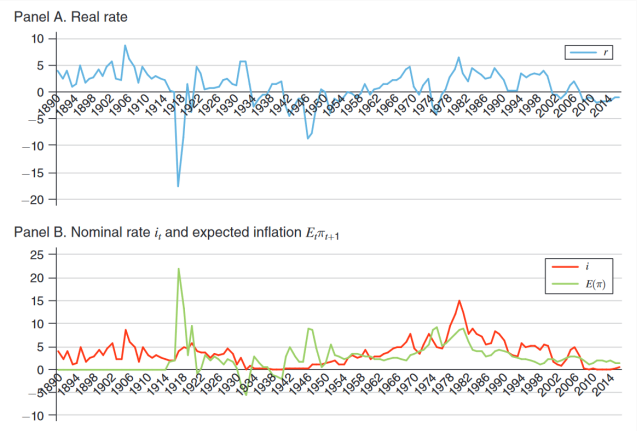
- Most research: start with i_t, **estimate** $\mathbb{E}_t \pi_{t+1}$, calcuate r_t

Measuring real rates: challenges

$$r_t = i_t - \mathbb{E}_t \pi_{t+1}$$

Most bonds have historically been **nominal**

- Most research: start with i_t, **estimate** $\mathbb{E}_t \pi_{t+1}$, calcuate r_t
- Most research: estimate $\mathbb{E}_t \pi_{t+1}$ using AR(1)
  - Not great, especially at turning points

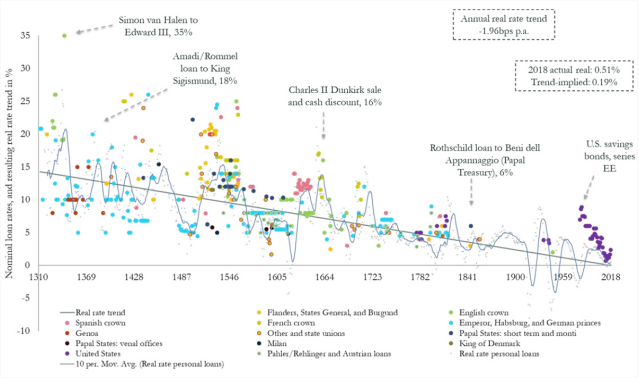


Measuring real rates: challenges

$$r_t = i_t - \mathbb{E}_t \pi_{t+1}$$

Most bonds have historically been **nominal**

- Most research: start with i_t, **estimate** $\mathbb{E}_t \pi_{t+1}$, calcuate r_t
- Most research: estimate $\mathbb{E}_t \pi_{t+1}$ using AR(1)
  - Not great, especially at turning points
- (Other problem: credit risk)



Measuring real rates: challenges

$$r_t = i_t - \mathbb{E}_t \pi_{t+1}$$

Most bonds have historically been **nominal**

- Most research: start with i_t, **estimate** $\mathbb{E}_t \pi_{t+1}$, calcuate r_t
- Most research: estimate $\mathbb{E}_t \pi_{t+1}$ using AR(1)
  - Not great, especially at turning points
- (Other problem: credit risk)

Real rates should have very different drivers in the short run versus in the long run

- **Long run:** prices/wages are flexible. High growth $\implies$ high r
- **Short run:** prices/wages are sticky. 'Excessively' high $r \implies$ low growth!

Measuring real rates: challenges

$$r_t = i_t - \mathbb{E}_t \pi_{t+1}$$

Most bonds have historically been **nominal**

- Most research: start with i_t, **estimate** $\mathbb{E}_t \pi_{t+1}$, calcuate r_t
- Most research: estimate $\mathbb{E}_t \pi_{t+1}$ using AR(1)
  - Not great, especially at turning points
- (Other problem: credit risk)

Real rates should have very different drivers in the short run versus in the long run

- **Long run:** prices/wages are flexible. High growth $\implies$ high r
- **Short run:** prices/wages are sticky. 'Excessively' high $r \implies$ low growth!

Credible measurement of r: two simple approaches

$$r_t = i_t - \mathbb{E}_t \pi_{t+1}$$

Looking exclusively at long-term (10+) year horizon:

Credible measurement of r: two simple approaches

$$r_t = i_t - \mathbb{E}_t \pi_{t+1}$$

Looking exclusively at long-term (10+) year horizon:

1. Use *real* bonds instead of nominal bonds

- ("inflation-linked bonds"; "TIPS")

Credible measurement of r: two simple approaches

$$r_t = i_t - \mathbb{E}_t \pi_{t+1}$$

Looking exclusively at long-term (10+) year horizon:

1. Use *real* bonds instead of nominal bonds

- ("inflation-linked bonds"; "TIPS")
- Why not used previously? Only ~20y of data in US; ~30y in UK/AU/CA

Credible measurement of r: two simple approaches

$$r_t = i_t - \mathbb{E}_t \pi_{t+1}$$

Looking exclusively at long-term (10+) year horizon:

1. Use *real* bonds instead of nominal bonds

- ("inflation-linked bonds"; "TIPS")
- Why not used previously? Only ~20y of data in US; ~30y in UK/AU/CA

2. *Directly measure* expected inflation using rich cross-country survey data on long-term expected inflation

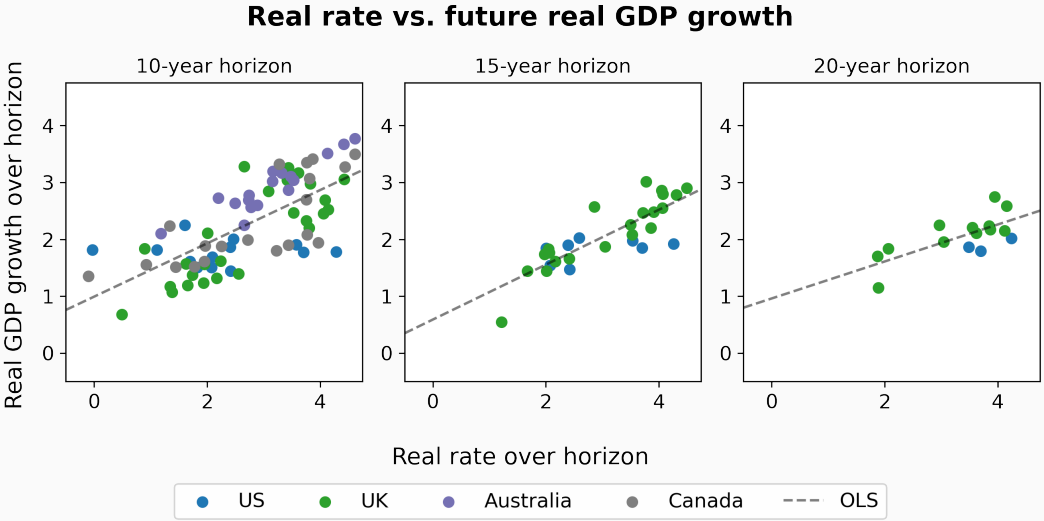
- Source: Consensus Economics ($$$)
- 89 countries over 30 years
- 10y horizon

Inflation-linked bonds and *realized* growth

more

Inflation-linked bonds and *realized* growth

more

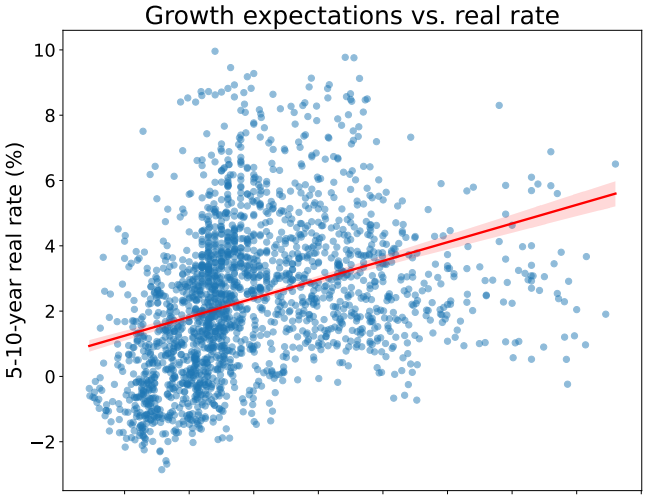


Ex ante real rates and *expected* growth

more

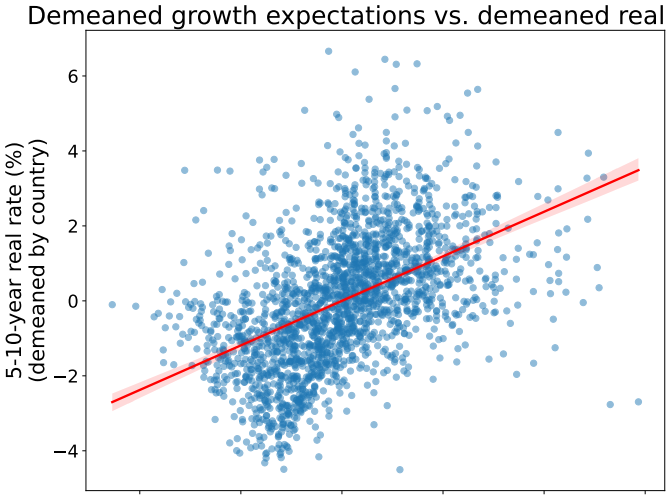
Ex ante real rates and *expected* growth

more



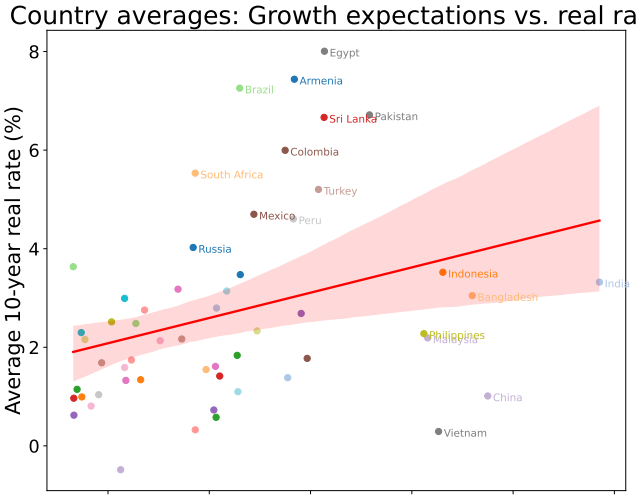
Ex ante real rates and *expected* growth

more



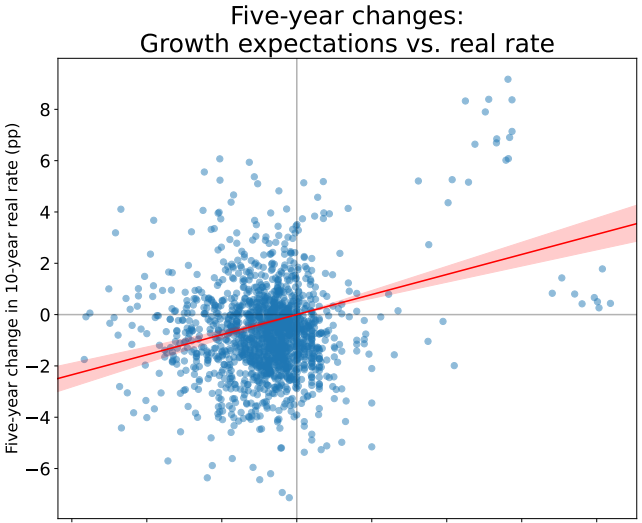
Ex ante real rates and *expected* growth

more



Ex ante real rates and *expected* growth

more



Best arguments against

1. Non-*transformative* AI is consistent even with low rates

Best arguments against

1. Non-*transformative* AI is consistent even with low rates
   - Precautionary savings against automation

Best arguments against

1. Non-*transformative* AI is consistent even with low rates
   - Precautionary savings against automation
   - TAI won't affect growth

Best arguments against

1. Non-*transformative* AI is consistent even with low rates
   - Precautionary savings against automation
   - TAI won't affect growth

2. Marginal utility may remain high post-singularity
   - New products [Trammell (2024)]
   - Habit formation

Best arguments against

1. Non-*transformative* AI is consistent even with low rates
   - Precautionary savings against automation
   - TAI won't affect growth

2. Marginal utility may remain high post-singularity
   - New products [Trammell (2024)]
   - Habit formation

Bad arguments:

(i) "Want to invest more – to have a shot at controlling the lightcone". Maresca 2025: you want to save more, but this still pushes up *r*

(ii) "High expected returns": *movement along supply curve* vs. *shift* in supply curve
   - Also distinguish between high risk-free rate (discussion here) versus high *risk premium* (not discussed here)

Real rates and mortality risk

Challenge: measuring existential risk over time

Challenge: near-existential disasters could lower real rate!

- E.g. nuclear war $\Longrightarrow$ precautionary saving $\Longrightarrow$ lower real rate

Real rates and mortality risk

Challenge: measuring existential risk over time

Challenge: near-existential disasters could lower real rate!

- E.g. nuclear war $\Longrightarrow$ precautionary saving $\Longrightarrow$ lower real rate

***Individual* mortality risk and *individual* savings behavior**

- $\Longrightarrow$ Test mechanism

1. New AIDS therapy rollout $\Longrightarrow$ more savings, more education
2. Information treatment $\Longrightarrow$ more investment in agriculture, livestock
3. Huntington's disease testing $\Longrightarrow$ 30pp less likely to go to college

Real rates and mortality risk

Challenge: measuring existential risk over time

Challenge: near-existential disasters could lower real rate!

- E.g. nuclear war $\Longrightarrow$ precautionary saving $\Longrightarrow$ lower real rate

***Individual* mortality risk and *individual* savings behavior**

- $\Longrightarrow$ Test mechanism

1. New AIDS therapy rollout $\Longrightarrow$ more savings, more education
2. Information treatment $\Longrightarrow$ more investment in agriculture, livestock
3. Huntington's disease testing $\Longrightarrow$ 30pp less likely to go to college
4. Cross-sectionally: pessimistic survival beliefs are correlated with a lower savings rate

Real rates and mortality risk

Challenge: measuring existential risk over time

Challenge: near-existential disasters could lower real rate!

- E.g. nuclear war $\Longrightarrow$ precautionary saving $\Longrightarrow$ lower real rate

***Individual* mortality risk and *individual* savings behavior**

- $\Longrightarrow$ Test mechanism

1. New AIDS therapy rollout $\Longrightarrow$ more savings, more education
2. Information treatment $\Longrightarrow$ more investment in agriculture, livestock
3. Huntington's disease testing $\Longrightarrow$ 30pp less likely to go to college
4. Cross-sectionally: pessimistic survival beliefs are correlated with a lower savings rate
5. Cold War evidence (sorta)

Other asset prices: stocks

Stocks are harder to use to forecast timelines:

1. Only reflect aligned case (future profits)

Other asset prices: stocks

Stocks are harder to use to forecast timelines:

1. Only reflect aligned case (future profits)
2. Stocks only reflect public companies (private companies, nonexistent companies)

Other asset prices: stocks

Stocks are harder to use to forecast timelines:

1. Only reflect aligned case (future profits)
2. Stocks only reflect public companies (private companies, nonexistent companies)
3. Capped profits / nationalization

Other asset prices: stocks

Stocks are harder to use to forecast timelines:

1. Only reflect aligned case (future profits)
2. Stocks only reflect public companies (private companies, nonexistent companies)
3. Capped profits / nationalization
4. TAI could lower stock prices: depends if $\sigma \gtrless 1$

$$P = \frac{D}{r - g}$$

r affects all assets

Other asset prices: stocks

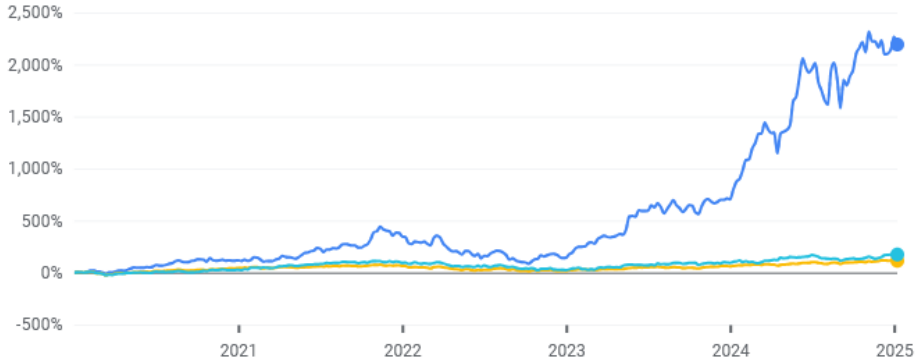
Stocks are harder to use to forecast timelines:

1. Only reflect aligned case (future profits)
2. Stocks only reflect public companies (private companies, nonexistent companies)
3. Capped profits / nationalization
4. TAI could lower stock prices: depends if $\sigma \gtrless 1$

$$
\begin{aligned}
P &= \frac{D}{r-g} \\
&= \frac{D}{(\rho + \sigma \cdot g) - g} \\
&= \frac{D}{\rho + (\sigma - 1) \cdot g}
\end{aligned}
$$

r affects all assets

Other asset prices: stocks



NVIDIA Corp	$140.11	+$134.00	↑2,193.13%
Nasdaq Composite	19,478.88	+10,300.02	↑112.21%
Alphabet Inc Class C	$195.39	+$123.90	↑173.31%

Conclusion: Two possibilities

1. Markets are are efficient information aggregators

2. Markets are wrong

- Trade opportunity? (“Get rich or die trying”)
- Opportunity to borrow cheaply? (“*Im*patient philanthropy”)

Conclusion: Two possibilities

1. Markets are are efficient information aggregators

2. Markets are wrong

- Trade opportunity? (“Get rich or die trying”)
- Opportunity to borrow cheaply? (“*Im*patient philanthropy”)

Contribution:

1. **AI safety:** *outside view* evidence on AI timelines
2. **Mainline economics:** fundamental question about determinants of real interest rates

Theory

Empirics

Discussion

Appendix

1. Surveys

back

1. Surveys

back

- Grace et al. (2018) survey of AI researchers: “when unaided machines can accomplish every task better and more cheaply than human workers”
  - Median: **2061**
- Grace et al. (2022):
  - Median: **2058**

1. Surveys

back

- Grace et al. (2018) survey of AI researchers: “when unaided machines can accomplish every task better and more cheaply than human workers”
  - Median: **2061**
- Grace et al. (2022):
  - Median: **2058**
- Grace et al. (2024):
  - Median: **2047**

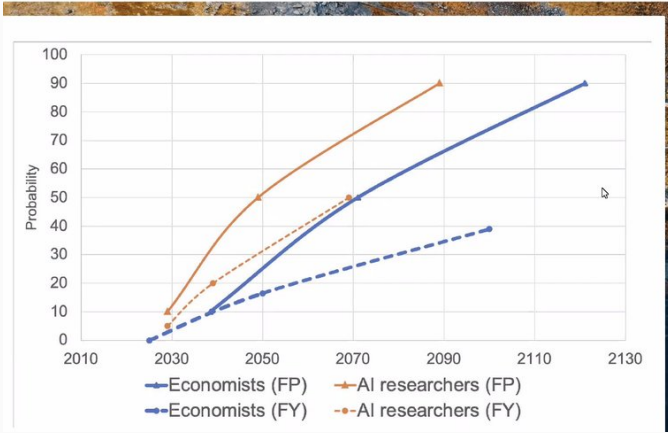
1. Surveys

back

- Grace et al. (2018) survey of AI researchers: “when unaided machines can accomplish every task better and more cheaply than human workers”
  - Median: **2061**
- Grace et al. (2022):
  - Median: **2058**
- Grace et al. (2024):
  - Median: **2047**
- Metaculus forecasting platform
  - Median: **2031**

Korinek et al. (2022) survey of economists: **2070-2130+**

HLMI PREDICTIONS: ECONOMISTS & AI RESEARCHERS



Economists ascribe a median 10% probability to HLMI never being developed.

FP = fixed probability (shown probability, asked for years)

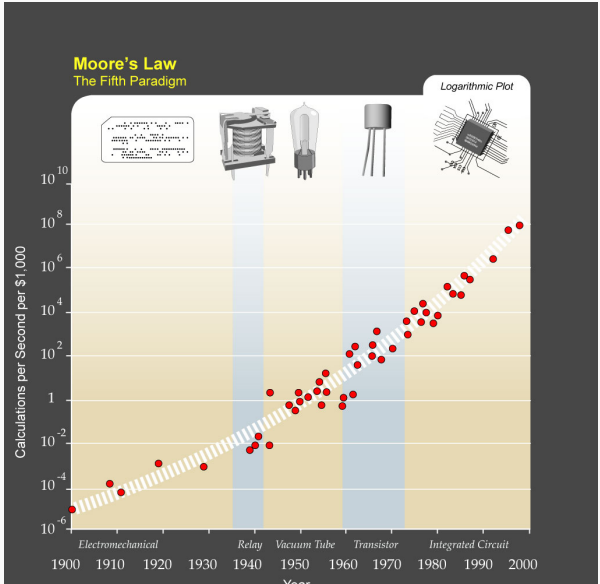
FY = fixed year (shown year, asked for likelihood)

2. Models / trend extrapolation

back

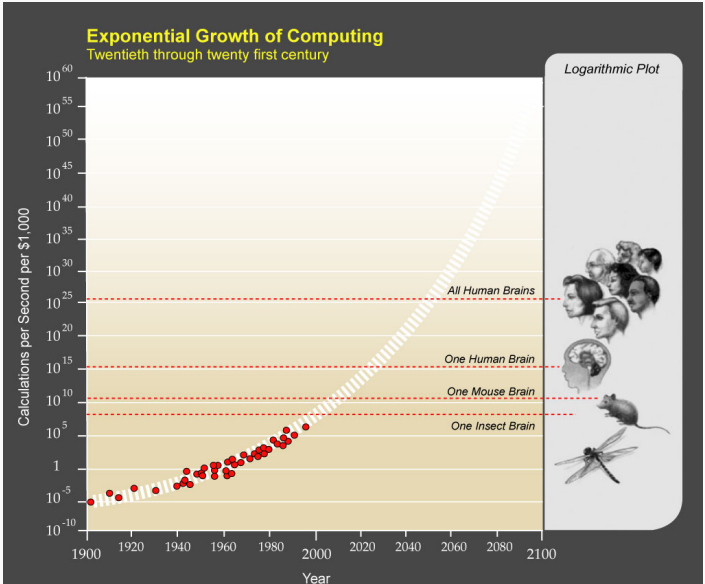
2. Models / trend extrapolation

back



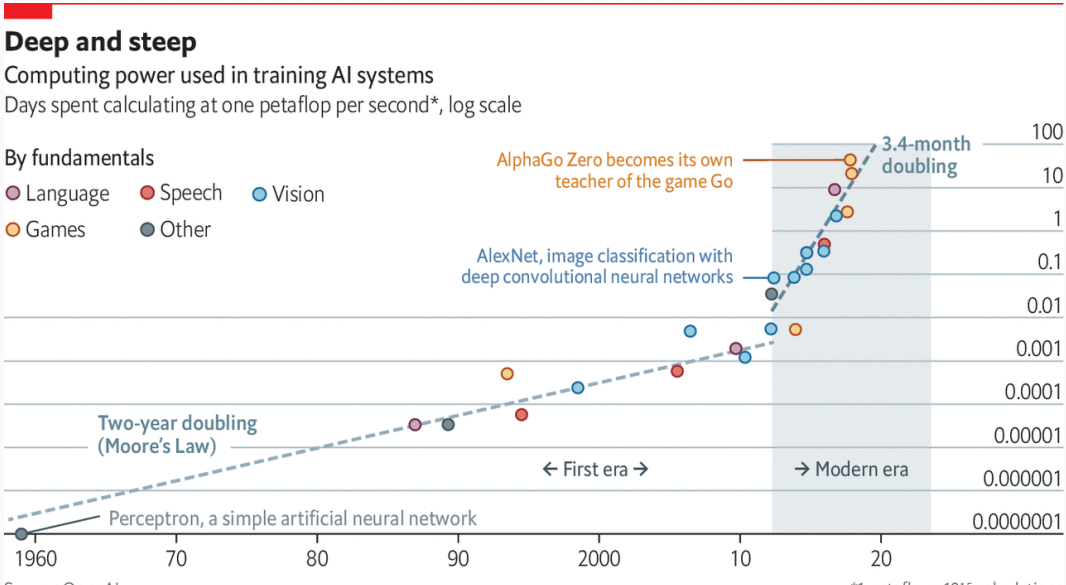
2. Models / trend extrapolation

back



2. Models / trend extrapolation

back



2. Models / trend extrapolation

back

Compute-centric forecasting models:

1. Estimate # of computations brain per second

2. Models / trend extrapolation

back

Compute-centric forecasting models:

1. Estimate # of computations brain per second
2. Project forward trends in power of computers (e.g. Moore's Law)

2. Models / trend extrapolation

back

Compute-centric forecasting models:

1. Estimate # of computations brain per second
2. Project forward trends in power of computers (e.g. Moore's Law)
3. $\Longrightarrow$ project date when computers can do as many calculations per second as brain

2. Models / trend extrapolation

back

Compute-centric forecasting models:

1. Estimate # of computations brain per second
2. Project forward trends in power of computers (e.g. Moore's Law)
3. $\Longrightarrow$ project date when computers can do as many calculations per second as brain

Seminal paper: Cotra (2020)

2. Models / trend extrapolation

back

Compute-centric forecasting models:

1. Estimate # of computations brain per second
2. Project forward trends in power of computers (e.g. Moore's Law)
3. $\Longrightarrow$ project date when computers can do as many calculations per second as brain

Seminal paper: Cotra (2020)

- "Biological anchors" or "bio anchors"

2. Models / trend extrapolation

back

Compute-centric forecasting models:

1. Estimate # of computations brain per second
2. Project forward trends in power of computers (e.g. Moore's Law)
3. $\Longrightarrow$ project date when computers can do as many calculations per second as brain

Seminal paper: Cotra (2020)

- "Biological anchors" or "bio anchors"
- Performance = compute $\times$ \$ $\times$ algorithms

2. Models / trend extrapolation

back

Compute-centric forecasting models:

1. Estimate # of computations brain per second
2. Project forward trends in power of computers (e.g. Moore's Law)
3. $\Longrightarrow$ project date when computers can do as many calculations per second as brain

Seminal paper: Cotra (2020)

- "Biological anchors" or "bio anchors"
- Performance = compute $\times$ \$ $\times$ algorithms
  - Temporarily high growth

2. Models / trend extrapolation

back

Compute-centric forecasting models:

1. Estimate # of computations brain per second
2. Project forward trends in power of computers (e.g. Moore's Law)
3. $\Longrightarrow$ project date when computers can do as many calculations per second as brain

Seminal paper: Cotra (2020)

- "Biological anchors" or "bio anchors"
- Performance = compute $\times$ \$ $\times$ algorithms
  - Temporarily high growth
  - Made up [cf Nostalgebraist, 2022]

2. Models / trend extrapolation

back

Compute-centric forecasting models:

1. Estimate # of computations brain per second
2. Project forward trends in power of computers (e.g. Moore's Law)
3. $\Longrightarrow$ project date when computers can do as many calculations per second as brain

Seminal paper: Cotra (2020)

- "Biological anchors" or "bio anchors"
- Performance = compute $\times$ \$ $\times$ algorithms
  - Temporarily high growth
  - Made up [cf Nostalgebraist, 2022]
- Follow up work by Davidson (2022) and Epoch

2. Models / trend extrapolation

back

Compute-centric forecasting models:

1. Estimate # of computations brain per second
2. Project forward trends in power of computers (e.g. Moore's Law)
3. $\Longrightarrow$ project date when computers can do as many calculations per second as brain

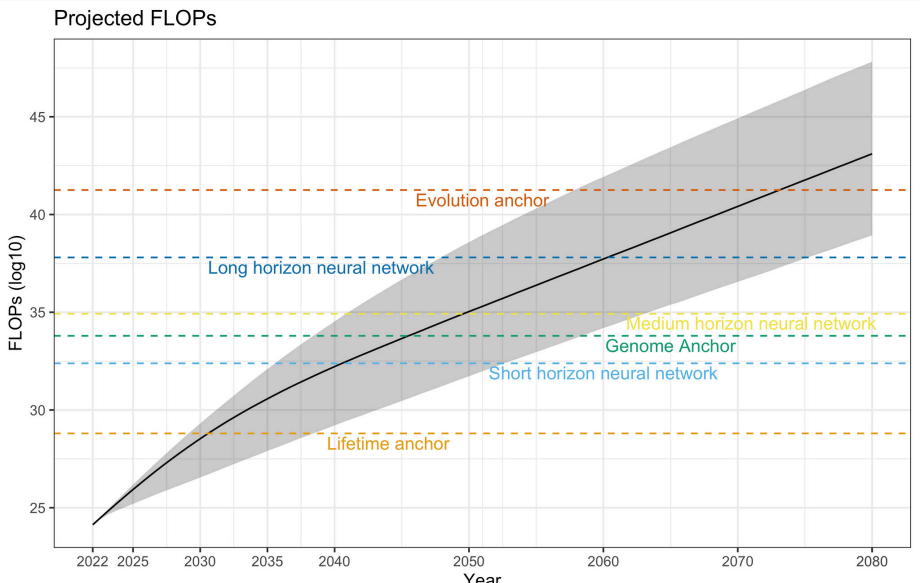
Seminal paper: Cotra (2020)

- "Biological anchors" or "bio anchors"
- Performance = compute $\times$ \$ $\times$ algorithms
  - Temporarily high growth
  - Made up [cf Nostalgebraist, 2022]
- Follow up work by Davidson (2022) and Epoch

- **Cotra (2020):** 2050
- **Cotra (2022):** 2040
- **Davidson (2023):** 2043
- **Epoch (2022):** 2046

Bio anchors (Epoch version)

back



Motivation: financial markets are powerful information aggregators

back

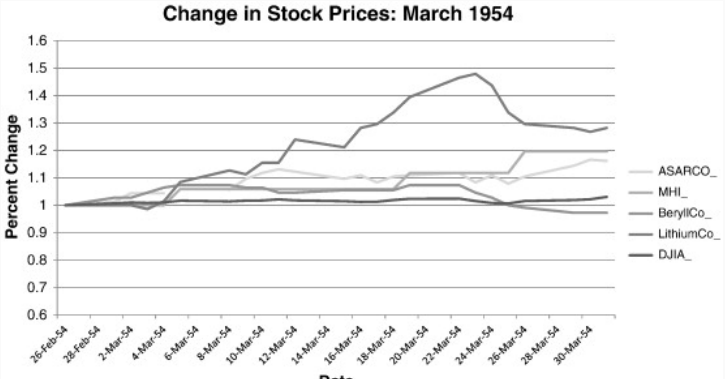
Prices aggregate dispersed information (Hayek 1945); financial market prices especially so (Fama, etc)

Motivation: financial markets are powerful information aggregators

back

Prices aggregate dispersed information (Hayek 1945); financial market prices especially so (Fama, etc)

- Alchian and the hydrogen bomb

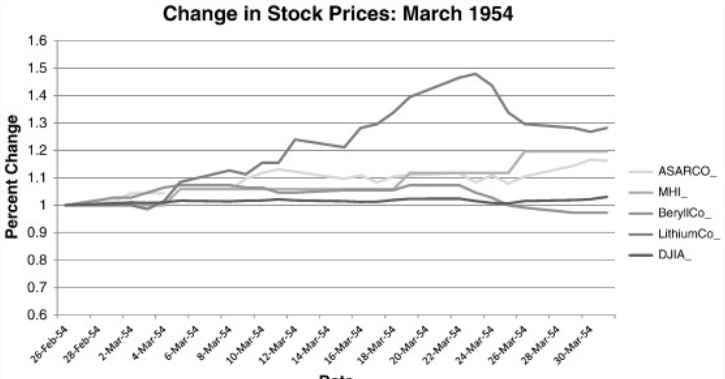


Motivation: financial markets are powerful information aggregators

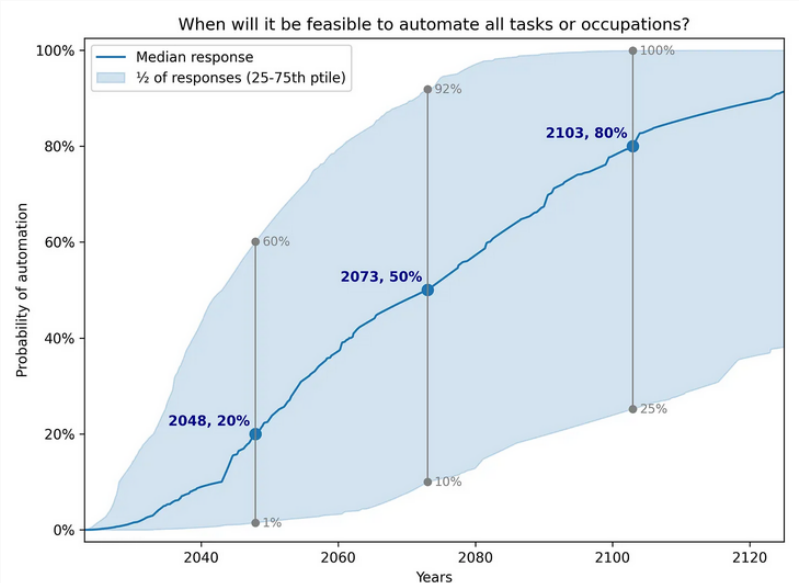
back

Prices aggregate dispersed information (Hayek 1945); financial market prices especially so (Fama, etc)

- Alchian and the hydrogen bomb
- Space shuttle Columbia disaster; election markets; inflation breakevens; ...



Weinstein-Raun (2024): Grace et al (2024) reanalysis



General case and extensions

Euler equation:

$$1 = \beta\delta\mathbb{E}_t\left[\frac{u'(C_{t+1})}{u'(C_t)}(1+r_t)\right] \tag{1}$$

General case and extensions

Euler equation:

$$1 = \beta\delta\mathbb{E}_t\left[\frac{u'(C_{t+1})}{u'(C_t)}(1+r_t)\right] \tag{1}$$

Uncertainty: risk-neutral expected value. E.g. if $\Delta C_{t+1} \sim \text{LogNormal}(g, \text{Var})$, then

$$r_t = \rho + \frac{1}{\sigma}g - \frac{1}{2\sigma^2}\text{Var}$$

General case and extensions

Euler equation:

$$1 = \beta\delta\mathbb{E}_t\left[\frac{u'(C_{t+1})}{u'(C_t)}(1+r_t)\right] \tag{1}$$

Uncertainty: risk-neutral expected value. E.g. if $\Delta C_{t+1} \sim \text{LogNormal}(g, \text{Var})$, then

$$r_t = \rho + \frac{1}{\sigma}g - \frac{1}{2\sigma^2}\text{Var}$$

Incomplete markets: *slope* unaffected in benchmark

$$r_t = \rho + \frac{1}{\sigma}g - \text{constant}$$

General case and extensions

Euler equation:

$$1 = \beta\delta\mathbb{E}_t\left[\frac{u'(C_{t+1})}{u'(C_t)}(1+r_t)\right] \tag{1}$$

Uncertainty: risk-neutral expected value. E.g. if $\Delta C_{t+1} \sim \text{LogNormal}(g, \text{Var})$, then

$$r_t = \rho + \frac{1}{\sigma}g - \frac{1}{2\sigma^2}\text{Var}$$

Incomplete markets: *slope* unaffected in benchmark

$$r_t = \rho + \frac{1}{\sigma}g - \text{constant}$$

OLG, recursive preferences: slope unaffected

General case and extensions

Euler equation:

$$1 = \beta\delta\mathbb{E}_t\left[\frac{u'(C_{t+1})}{u'(C_t)}(1+r_t)\right] \tag{1}$$

Uncertainty: risk-neutral expected value. E.g. if $\Delta C_{t+1} \sim \text{LogNormal}(g, \text{Var})$, then

$$r_t = \rho + \frac{1}{\sigma}g - \frac{1}{2\sigma^2}\text{Var}$$

Incomplete markets: *slope* unaffected in benchmark

$$r_t = \rho + \frac{1}{\sigma}g - \text{constant}$$

OLG, recursive preferences: slope unaffected

- Habit formation

Expected growth vs. realized growth

back