INTEREST RATES, MONEYNESS, AND THE FISHER EQUATION

Lucas Herrenbrueck

Simon Fraser University

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Federal Reserve Board

What I do

1. Confront the Euler/Fisher equation with data

   - An equation central to nearly all schools of macroeconomics
   - Test four empirical hypotheses: intercept, slope, fit, stability

2. Simple theory explains data puzzles

   - What if *all* assets were priced for their liquidity (moneyness)?
   - Most particularly, the asset used to define the **policy rate** (macro) or **risk free-rate** (finance)?

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   - Most particularly, the asset used to define the **policy rate** (macro) or **risk free-rate** (finance)?

   ⇒ Big implications for many macro and finance concepts:

   – monetary policy implementation

   – convenience yield / liquidity premium behavior

   – 14 puzzles addressed or resolved

References

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. . . and more (see the paper)

Euler and Fisher

- "The" Euler equation, at the heart of modern macro:

$$1 + i_t = \left(\mathbb{E}_t \left\{ \beta_t \frac{u'(c_{t+1})}{u'(c_t)} \frac{p_t}{p_{t+1}} \right\} \right)^{-1} \quad (1)$$

  - Usual interpretation: bond interest rate = opportunity cost of holding money
  - (specifically: give up current consumption, store the wealth as money, to be used for later consumption)
  - When linearized: "New Keynesian IS curve"

- Long run version (with $u'(c) = c^{-\sigma}$): the Fisher equation

$$i = \rho + \pi + \sigma g_C$$

Euler and Fisher

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  - Usual interpretation: bond interest rate = opportunity cost of holding money
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- Long run version (with $u'(c) = c^{-\sigma}$): the Fisher equation

$$i = \rho + \pi + \sigma g_C$$

Time preference, inflation, consumption growth (& population growth?)

EULER vs DATA

The Euler equation in the short run

- Famously bad fit to data (Hall 1978, Hansen & Singleton 1982, Summers 1983, Lettau & Ludvigson 2001 & 2009, Canzoneri et al 2007, Havranek et al 2015 . . .)

- Simple illustration:
  - suppose $\log$ utility $\Rightarrow$ look at growth of nominal consumption $P \cdot C$
  - correlation in first differences is -0.15! ($+0.07$ if we use inflation)

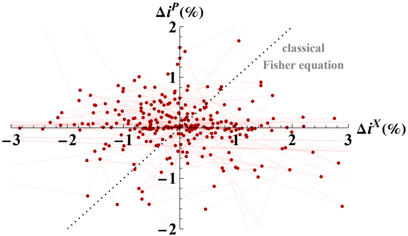


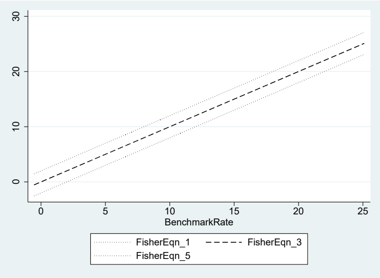
Figure: Ex-post realized nominal consumption growth, USA 1948-2022, vs short-term interest rate (3-month T-bills, secondary market rate)

FISHER vs DATA

The Fisher equation in the long run

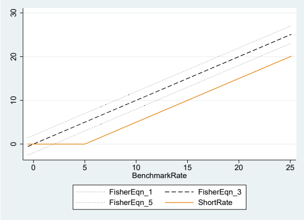
- OK – what about the long run?
- Recall the Fisher equation: $i = \rho + \pi + \sigma g_C$
  - For ρ, macroeconomists' prior is $\rho \approx 3\%$, though microstudies consistently find $\rho \geq 10\%$
  - For σ, macroeconomists' prior is $\log$ utility ($\sigma = 1$). If only inflation matters, then $\sigma = 0$. Cross-country meta-analysis suggests midpoint $\sigma \approx 2$ [HHIR'15] (but relies on the validity of the EE itself)
- I will test it using:
  - The Jordà-Schularick-Taylor *Macrohistory Database*: 17 now-developed countries, annual data 1870-2018 covering a wide range of macroeconomic and financial statistics
  - U.S. quarterly data 1948-2023, from FRED

Theory prediction

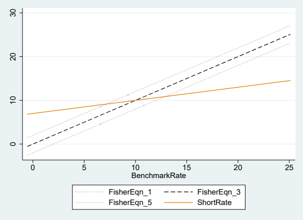


- Hypotheses:
  1. Intercept $avg(i - \pi - \sigma g_C)$ equals rate of time preference (allowing for some uncertainty about what that is)
  2. Slope $\Delta(i)/\Delta(\pi + \sigma g_C)$ equals 1
  3. Fit is good, if data is long-run enough to smooth out forecast errors
  4. Relationship consistent across eras and countries

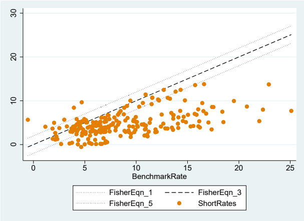
What would falsify the theory?



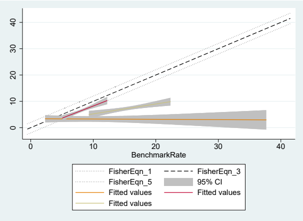
(1) Intercept problem



(2) Slope problem



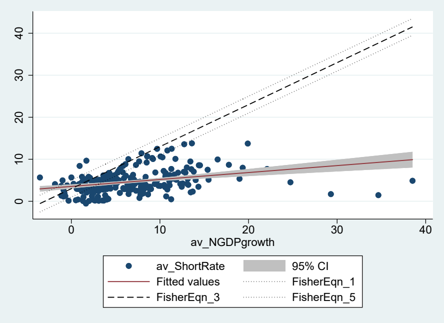
(3) Fit problem



(4) Stability problem

Macrohistory evidence

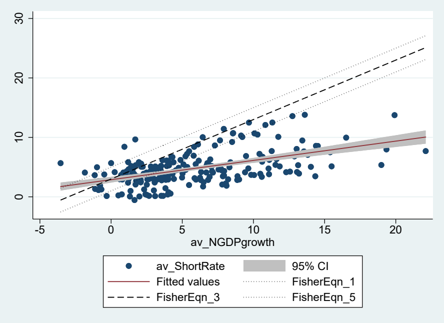
- "Long run" = **decade**, so we have 17 countries × 15 decades
- Log utility, so we compare NGDP growth with short-term interest rates, as $100 \cdot \log(1 + \text{rate})$
- Exclude Germany in the 1920s (hyperinflation)



- **Slope is 0.15** (country fixed effects) to 0.17 (random effects or pooled); overall $\mathbf{R}^2$ **is 0.12**

Macrohistory evidence

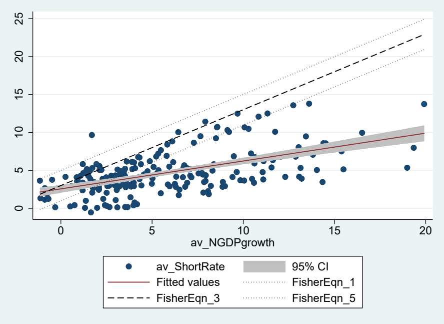
- "Long run" $=$ **decade**, so we have 15 countries $\times$ 17 decades
- Log utility, so we compare NGDP growth with short-term interest rates, as $100 \cdot \log(1 + \text{rate})$
- Exclude Germany in the 1920s (hyperinflation) and everyone in the 1940s (wartime)



- **Slope is 0.30** (country fixed effects) to 0.32 (random effects or pooled); overall $\mathbf{R}^2$ **is 0.30**

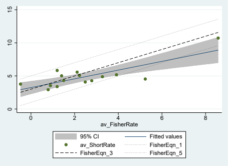
Macrohistory evidence

- "Long run" $=$ **decade**, so we have 15 countries $\times$ 17 decades
- Log utility, so we compare NGDP growth with short-term interest rates, as $100 \cdot \log(1 + \text{rate})$
- Exclude the entire 1920s (return to prewar gold standard) and 1940s (wartime)

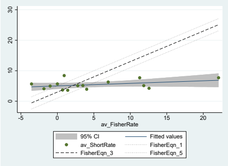


- **Slope is 0.34** (country fixed effects) to 0.37 (random effects or pooled); overall $\mathbf{R}^2$ **is 0.33**

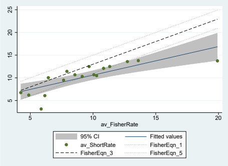
Some decades



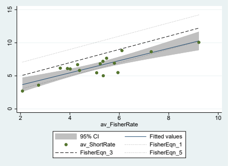
1870s



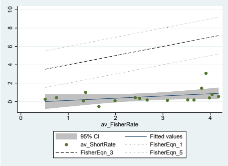
1920s, ex Germany



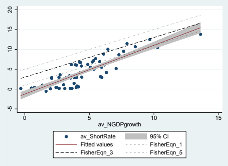
1980s



1990s

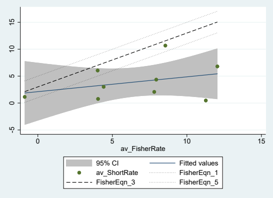


2010s

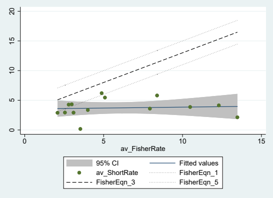


post-1980, ex Portugal

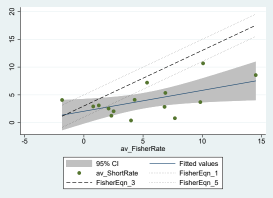
Some countries



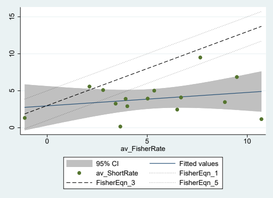
Canada



Germany, ex 1920s



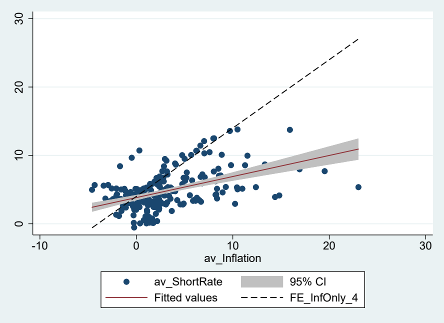
UK



USA

Inflation only

- Robustness check: inflation only, not NGDP growth (still as $100 \cdot \log(1 + \text{rate})$)
- Exclude Germany in the 1920s (hyperinflation) and everyone in the 1940s (wartime)



- Slope is 0.30; overall R^2 is 0.32
- BUT: regressing on inflation and real growth separately, **both coefficients are strongly significant and nearly equal in size** $\Rightarrow$ supports $\log$ utility

Macrohistory test

- Intercept hypothesis ✗
- Slope hypothesis ✗
- Fit hypothesis ✗
- Stability hypothesis ✗

FISHER vs USA

Evidence from postwar USA

- Define **Fisher interest rate** as the right-hand side of the Fisher equation
- Approximate with: $i_t^F \approx \rho + \mathbb{E}_t\{\log[(PC)_{t+1}/(PC)_t]\}$
  - Abstracting from second-order terms
  - Use $\sigma = 1$ (log utility) and guess $\rho = 3\%$

    These are conservative! Using literature estimates of ρ and σ would push estimated Fisher rate (and resulting liquidity premium) much higher.
- Use lags of PC-growth, T-bill rates, AAA corporate rates to forecast
  - Gaussian and LAD regressions. Latter are more robust
- Then compare with **policy rate** i^P (defined as T-bill rate)

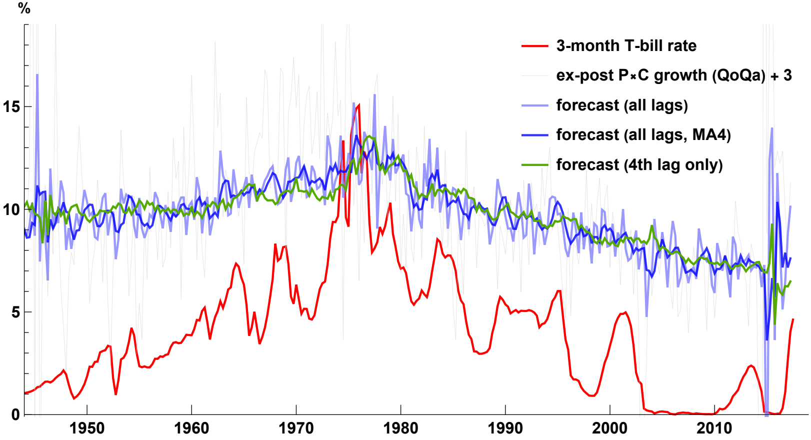
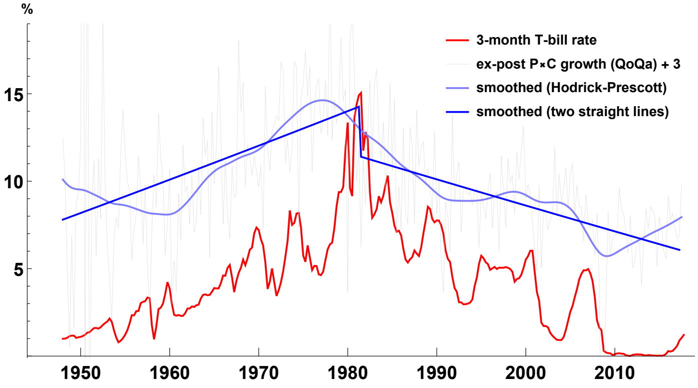


Figure: Forecast estimates of Fisher rate, shown with T-bill rate

- Maybe this is too fancy. What about simple smoothing (to 2017)?



$\Rightarrow$ Either way, the Fisher rate and the “policy rate” / “risk-free rate” look **nothing alike**

Narrative evidence: policy eras

- Gold standard and Monetarist era: imperfect pass-through from i^F to i^P

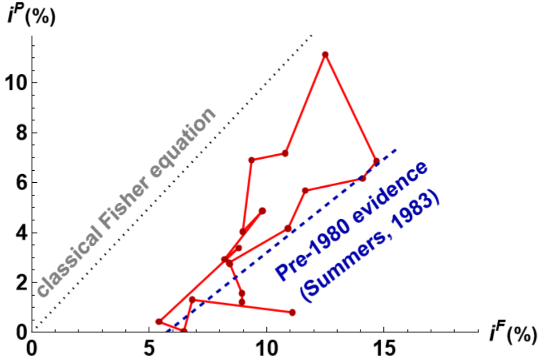


Figure: U.S. i^P and ex-post i^F from 1948-2022, in 4-year bins. Slope of dashed line: 0.75

Narrative evidence: policy eras

- Volcker disinflation: i^P hike causes i^F to drop

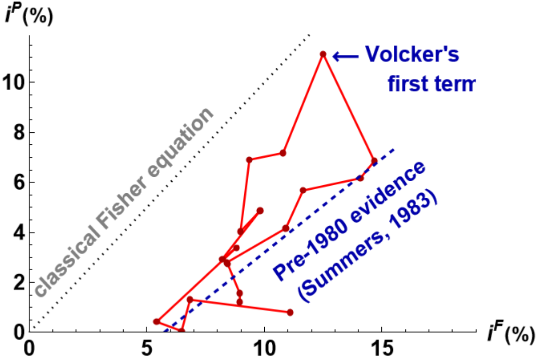


Figure: U.S. i^P and ex-post i^F from 1948-2022, in 4-year bins. Slope of dashed line: 0.75

Narrative evidence: policy eras

- Taylor rule era: i^P is made to react aggressively to i^F

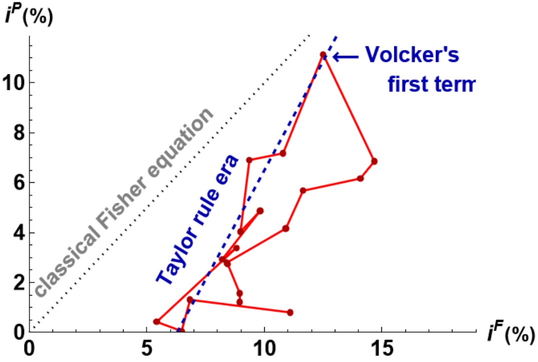
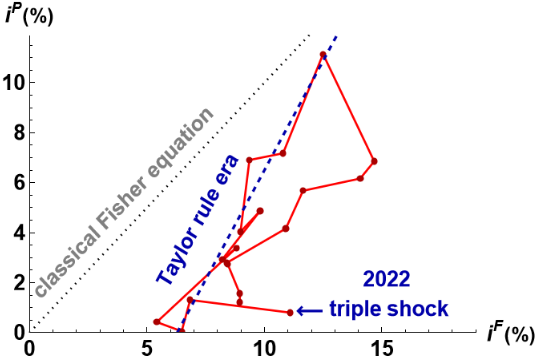


Figure: U.S. i^P and ex-post i^F from 1948-2022, in 4-year bins. Slope of dashed line: 1.75

Narrative evidence: policy eras

- Taylor rule era: i^P is made to react aggressively to i^F



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THEORY: MONEY AND INTEREST

Stylized facts a theory should match

1. Short-term safe interest rates satisfy **inequalities**:

$$0 \leq i^P \leq \rho + \mathbb{E}\pi + \sigma \cdot \mathbb{E}g_C$$

2. Within this cone, interest rates and inflation can be chosen **independently** by monetary authority

   - Pay attention to ‘narrative’, i.e., what the monetary authority says it is doing

Proposal

1. Use **monetary** theory to price liquid bonds
   - This means all bonds
   - Define policy rate i_t^P as yield on a particular, highly liquid short-term bond
2. Define Fisher rate i_t^F via Equation (1)
   - It prices a short-term, safe, perfectly illiquid bond – but **no such bond exists**
   - A good estimate is essential for quantitative monetary analysis
   - Don't expect i^P to behave like i^F in theory. In many models, comparative statics go in opposite directions!
   - Don't expect i^P to behave like i^F in data; relationship is not structural

Moneyness

"To test the Fisher Equation one should not compare [inflation and the nominal rate on liquid bonds], but [inflation and] the nominal rate on an illiquid asset. That may be hard to implement empirically since most assets have some degree of liquidity."
[Rocheteau, Wright, & Xiao, 2018]

- What makes for a liquid, "money-like", asset?
  (a) Serving as a medium of exchange [ancient]
  (b) The ability to liquidate via an intermediary or on a secondary market [Baumol-Tobin, GH'16, many others]
  (c) Serving as collateral for a loan when money is needed [VW'14, many others]
  (d) The expectation that it turns into money shortly, before the money is needed [GHS'16; "cash equivalents"]

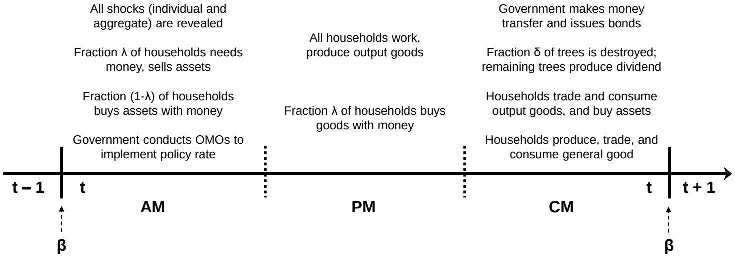
$\Rightarrow$ Equation (1) has a hard time pricing *any* real-world asset. It never had a chance to price the monetary policy instrument

Usually: overnight interbank loans, transmitted to the real economy via short-maturity government debt and bank deposits

MODEL

Summary of formal model

- Details in the paper. Model is adapted from [GH'17 "LAMMA"]
  - Assets: money, liquid bond, possibly other tradable assets (capital, trees...) Government controls money and bonds
  - Markets: centralized market, production market (money for goods), secondary asset market (HHs reallocate assets, gov't conducts OMO)
  - i_t^P is the *secondary market rate* on the liquid bond



Euler equations

Money:

$$1 = \mathbb{E}_t \left\{ \beta \frac{u'(c_{t+1})}{u'(c_t)} \frac{p_t}{p_{t+1}} \cdot \left(\lambda_{t+1} \frac{1}{q_{t+1}} + (1 - \lambda_{t+1})(1 + i^P_{t+1}) \right) \right\} \quad (3)$$

- λ_t is the probability HH needs money, sells other assets
- $q_t < 1$ is the wedge between the purchase price of output and its use value (< 1 to compensate people for holding money)

Euler equations

Aggregate liquidity premium:

$$\ell_t \equiv \lambda_t \left(\frac{1}{(1+j_t)q_t} - 1 \right)$$

Liquid bond and asset X:

$$p_t^B = \mathbb{E}_t \left\{ \beta \frac{u'(c_{t+1})}{u'(c_t)} \frac{p_t}{p_{t+1}} \cdot (1 + \ell_{t+1}) \right\}$$

$$\approx \mathbb{E}_t \left\{ \frac{1}{1 + i_{t+1}^P} \right\}$$

$$1 = \mathbb{E}_t \left\{ \left[\beta \frac{u'(c_{t+1})}{u'(c_t)} \frac{p_t}{p_{t+1}} (1 - \delta^X) \left(1 + \eta^X \ell_{t+1}\right) \right] \cdot \left(1 + r_{t+1}^X\right) \right\}$$

Informal model

"Different types of general equilibrium models are needed for different purposes. For exploration and pedagogy, the criteria should be transparency and simplicity and, for that, toy models are the right vehicles." [Blanchard, 2018]

- Get reduced-form 'toy model' as special case of the formal model
  - But many other famous models yield essentially the same reduced form! [FH'83, W'12, A'15, HG'17, RWX'18]

Informal model

- There is an illiquid bond (return i^F) and a liquid bond (i^P)
  - Illiquid bond must be used for consumption at a particular time
  - Liquid bond is not MoE but can be turned into MoE at will (like BCW'07)
- Abstract from shocks, risk, and second-order terms. Suppose:
  (a) people discount the future at rate ρ
  (b) $u'(c) = c^{-\sigma}$, so that σ is the inverse elasticity of intertemporal substitution
  (c) people expect consumption to grow at rate γ and prices to grow at rate π
  (d) i^P is a known function G of i^F and the relative supply of liquid bonds to money, B/M, increasing in both arguments

$$\Rightarrow \qquad i^P = G\left(i^F, \frac{B}{M}\right) \tag{4}$$

$$i^F = \rho + \sigma g_C + \pi \tag{5}$$

Lessons

- i^F is a bad model of the monetary policy instrument
  - Data doesn't fit Equation (5)
  - Implemented how? ...via π? ...via g_C? ...via ρ?!
- i^P is a good model of the monetary policy instrument
  - $0 \leq i^P \leq i^F$, but they can vary independently
  - Desired level of i^P can be implemented by changing the bounds: 0 and i^F
  - But also via OMO *within* the bounds [RWX'18, H'19], or via IOER.
    Invert G:

$$\frac{B}{M} = H\left(i^F, i^P\right) \qquad (6)$$

Liquidity-augmented asset pricing

- The spread $i^F - i^P$ equals the *aggregate liquidity premium*:

$$\ell \equiv i^F - i^P \tag{7}$$

- Crucially, ℓ acts like a residual

  $\Rightarrow$ Not exogenous (like "convenience yield" in [DGGT'17] and others); not "small" (like in many estimates of the liquidity premium *on particular assets*)

  $\Rightarrow$ Pass-through from policy to i^F or ℓ is never structural, always depends on the policy regime

  $\Rightarrow$ Aggregate liquidity premium is an order of magnitude larger than "liquidity premia" estimated for single assets (like TIPS, off-the-run bonds, . . .)

Liquidity-augmented asset pricing

- Price an asset X that can be liquidated with probability $\eta^X \in [0,1]$
  - (Or, almost equivalently, used as collateral subject to a haircut $1-\eta^X$)
  - Allow for depreciation / risk premium δ^X
  - (Linearized) no-arbitrage equation for nominal return on X:

$$
\begin{aligned}
& r^X = \delta^X + (1-\eta^X)i^F + \eta^X i^P && (8) \\
\leftrightarrow \quad & = \delta^X + i^F - \eta^X \ell \\
\leftrightarrow \quad & = \delta^X + i^P + (1-\eta^X)\ell
\end{aligned}
$$

SUPPORTING EVIDENCE

Estimating Equation (3)

- LAMMA money demand, via GMM:
  - Somewhat fragile, of course
  - ρ is not identified. Fix $\rho = 3\%$
  - $\sigma \in (0.4, 0.6)$
  - Fix λ and q. Get $\bar{\lambda} \in (0.4, 0.7)$
- Can add “cycle terms” – deviations from trend – of C and P
  - Suggest that λ_t is procyclical and/or or q_t is countercyclical
  - In fact, λ_t is a plausible driver of the cycle (“demand shocks”)
  - Need full DSGE estimation to be sure. Working on it!

Safe but illiquid: AAA corporate bonds

- U.S. AAA corporate bonds are virtually default-free yet known to be "illiquid"
  - "Illiquid" only by contrast. Definitely tradable
  - By correlation (levels or FD), closer to j than to ex-post i
  - Also confounded (as a measure of short-term i) by long maturity
- Regress AAA on GS10 and TB3MS (in first differences)
  - Can't identify both η_{GS10} and η_{AAA}. But, coefficient on GS10 equals η_{AAA}/η_{GS10}
  - Estimate: 0.74, consistent with theory
  - Coefficient on TB3MS is negative (p-value 0.14), consistent with theory

Capital asset pricing

- [GH'17] estimate Equation (8) for capital stock, using Macrohistory data
- Good but not perfect fit
  - But capital is a risky asset, so the linearized equation can only do so much
- Supports $\eta^K \in [0.4, 0.6]$ overall
  - $\eta \approx 0.8$ for tradable equities, $\eta \approx 0.6$ for housing, $\eta \to 0$ for private equities?

QUESTIONS ANSWERED AND PUZZLES RESOLVED

- Practically every interest rate puzzle is resolved this way
    - At least partially. Other factors may still be important
- Here, I collect a summary
    - No claim that this paper is the first to point any of these out
    - But to see the big picture, it helps to have them all lined up

$\Rightarrow$ Liquidity-augmented asset pricing is of first-order importance for macro

Questions and puzzles

1. How exactly is the monetary authority able to set interest rates?
   - As in Macro 101: via OMOs in secondary asset markets (Equation 4)
   - Can achieve any $i^P \in [0, i^F]$
2. The awkward coexistence of the Fisher effect and the liquidity effect
   - FE: $M \uparrow \rightarrow \pi \uparrow \rightarrow i^F \uparrow$
   - LE: $M \uparrow \rightarrow i^P \downarrow$
   - No problem: Fisher effect applies to i^F and liquidity effect applies to i^P. Linked via $i^P \leq i^F$ in theory and by policy rule in the data, but conceptually distinct

Questions and puzzles

3. Has the U.S. been at the Friedman rule in 2009-14 and 2020?
   - Certainly not in 2009-14. Allowing uncertainty about ρ and expectations, still $i^F \in [4\%, 10\%]$ in that time
   - *Possibly yes*, briefly, in mid-2020!

Questions and puzzles

3. Has the U.S. been at the Friedman rule in 2009-14 and 2020?
   - Certainly not in 2009-14. Allowing uncertainty about ρ and expectations, still $i^F \in [4\%, 10\%]$ in that time
   - *Possibly yes*, briefly, in mid-2020!
4. The "lowflation" puzzle
   - No problem since Equations (4)-(5) hold even in steady state
   - Given i^F, different i^P's just correspond to different B/M (relative to demand)
5. "Lowflation 2023" – why isn't inflation accelerating, given that interest rates remain far below any Taylor Rule?
   - As in Macro 101: interest $\nearrow \Rightarrow$ demand $\searrow \Rightarrow$ future inflation $\searrow$, while "triple shock" is expected to abate
   - Taylor Rule not required for stability; that was an artifact of using the NKIS curve (linearized Euler equation) as model of how policy rate affects the economy

Questions and puzzles

6. The risk-free rate puzzle
   - Obvious, since a liquidity premium necessarily reduces bond yields below their fundamental levels
7. The equity premium puzzle
   - Lagos (2010): need only minimally lower liquidity of equity to explain EPP
8. The positive term premium
   - Geromichalos et al (2016): short-term bonds are endogenously more liquid
9. The prominence of a “liquidity factor” in empirical asset pricing
   - Observed by Liu (2006). See Equation (8)
10. The uncovered interest parity puzzle
    - Explained by differential liquidity between different countries’ bonds (Linnemann & Schabert 2015, Jung & Lee 2015, Engel & Wu 2018)

Questions and puzzles

11. The forward guidance puzzle

    - Iterating Equation (2) forward, consumption today should be affected by all future rates equally; no discounting. Not plausible in reality
    - Explanation: policy interest rates should satisfy Equation (3), not (2). Future interest rates are discounted by $(1-\lambda)$

12. The long-run volatility of the risk-free rate of return

    - Risk-free rate is more volatile than risky rate across decades and between countries (Jorda et al, 2017)
    - Explanation: policy rate is governed by policy, while risky rate (which is less liquid) is governed by fundamentals. Fundamental risk averages out in the medium-long run but policy can be slow-moving and persistent

Questions and puzzles

13. The fact that interest rates do not forecast consumption growth well

- Equation (3) suggests two reasons:

  (1) The fact that $\lambda > 0$ on average (liquidity is valued)

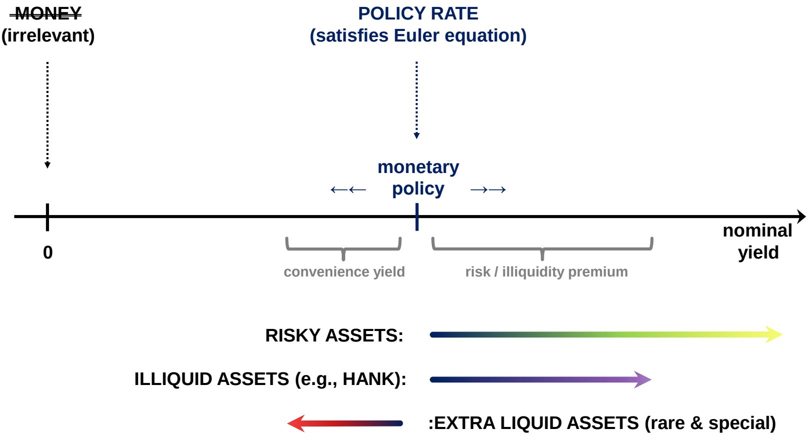
  (2) The possibility that λ_t is positively correlated with interest rates and/or consumption growth

14. Low elasticity of c_{t+1} in estimates of the Euler equation

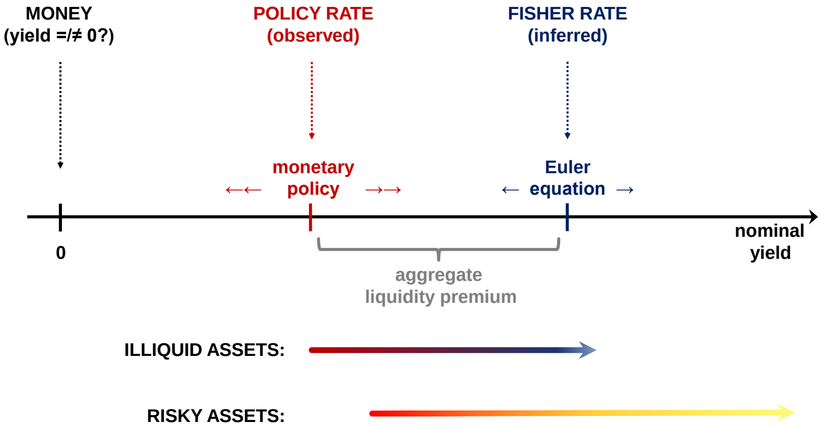
- Typically explained with bounded rationality. Not needed here
- Technical reason: procyclical λ_t or countercyclical q_t
- Deep reason? Is λ_t driving the cycle?

SUMMARY

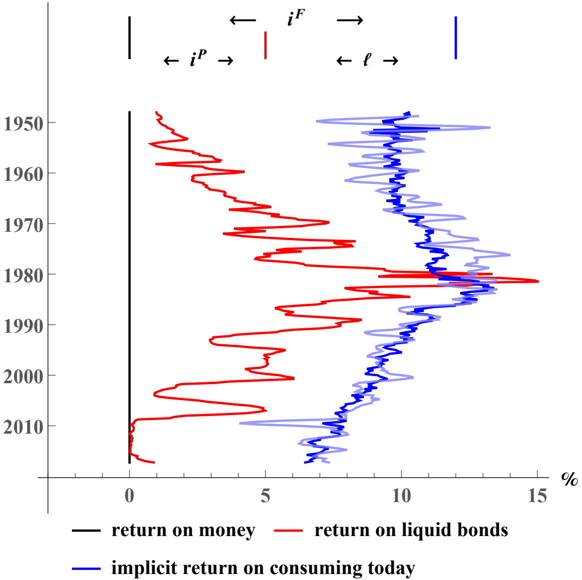
Traditional macro-finance



Liquidity-augmented macro-finance



Three rates, three gaps



1. Real-world assets are rarely illiquid
    - They are in substitution with money and are priced for that
    - CCAPM can't price cash. Shouldn't be used to price "cash equivalents", either. *Especially* not the monetary policy instrument
    - 14+ "puzzles" addressed or resolved
2. Time to expand our lexicon
    - The Fisher interest rate, i^F, is an important benchmark rate. But it's not *the* interest rate. In particular, it is never the policy rate
    - For practical purposes, the Fisher equation is an inequality:

$$i^P \leq \rho + \pi + \sigma g_C$$

3. The rate on a liquid bond can be varied *independently* from inflation
    - The causal relationship is not "Fisherian" [GH'17]
    - The empirical slope can be > 1, < 1, or even < 0
    - A world where i^P is set via interest on money (CBDC?) is likely to work very differently from a world where it is set via market intervention

BACKGROUND

Approaches

1. New Keynesian / Neo-Wicksellian
   - Linearize Eqn (1)
   - Monetary policy "picks" i_t
   - $\mathbb{E}\pi$ and $\mathbb{E}c_{t+1}$ are sticky, so i_t determines c_t
   - Fisher equation only satisfied in the long run, via a stability condition
   - HANK: "liquid" asset is priced by Euler equation, "illiquid" asset is subject to transaction cost thus has an even higher yield

2. (Most) New Monetarism
   - Money growth determines $\mathbb{E}\pi$, which determines i
   - i affects c through inflation tax
   - Other liquid assets may be considered but are often treated as secondary

Also contrast with

3. Natural rate theory

   - Fisher rate i^F is related to natural rate concept: both reflect time preference, growth and inflation trends
   - Big differences: (i) Fisher rate is upper bound rather than average; (ii) prices are flexible here and the reason $i^P \leq i^F$ is moneyness of bonds; (iii) natural rate is supposed to be "attractor" of actual rate in a determinate model, but i^F does not "attract" i^P

4. User cost of money (Barnett, 1978)

   - Closely related concept to Fisher rate i^F
   - My estimates of i^F are larger and smoother; existing user cost estimates are more-or-less ad-hoc transformations of actual interest rates

EXTRAS

$\rho = 10\%$, consistent with micro data

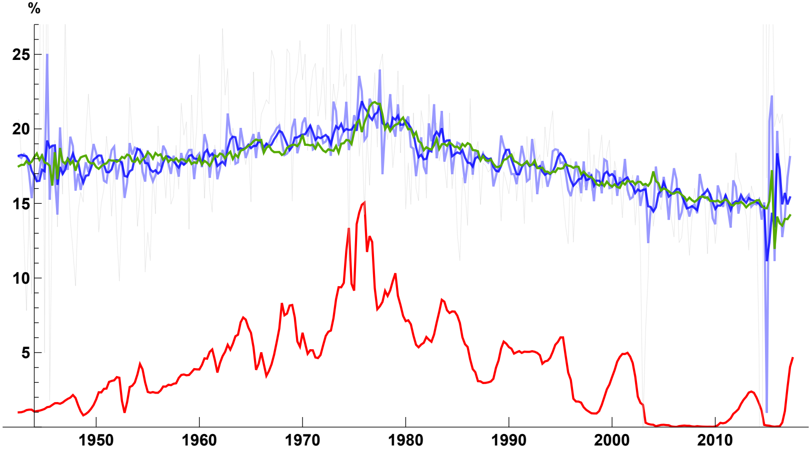


Figure: Forecast estimates of i^F with $\rho = 0.1$; T-bill rate represents i^P (USA 1948-2022)

Inflation and interest rates in the USA

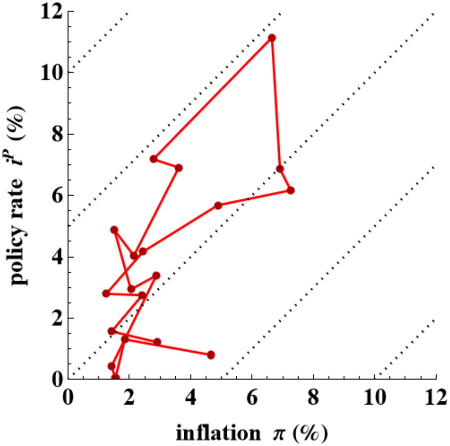


Figure: U.S. i^P and ex-post inflation from 1948-2022, in 4-year bins. Slope of dotted lines: 1

Why we should care

- Distinguish return on hypothetical illiquid bond from policy rate
  - Comparative statics can go in opposite directions! E.g., money demand:

$$\frac{1+\pi}{\beta} = \lambda \times \text{ marginal value } + (1-\lambda) \times \text{ policy rate}$$

  - Substitution between assets: governed by policy rate or Fisher rate?
  - Depending on policy regime, pass-through from interest rates to inflation could be ≈ 0, and from interest rates to the liquidity premium ≈ -1

- Implications
  - Empirical issues with the Euler / Fisher equation explained
  - Puzzles resolved (14 and counting)
  - Richer understanding of monetary policy: three rates, three gaps