Money and Banking in a New Keynesian Model

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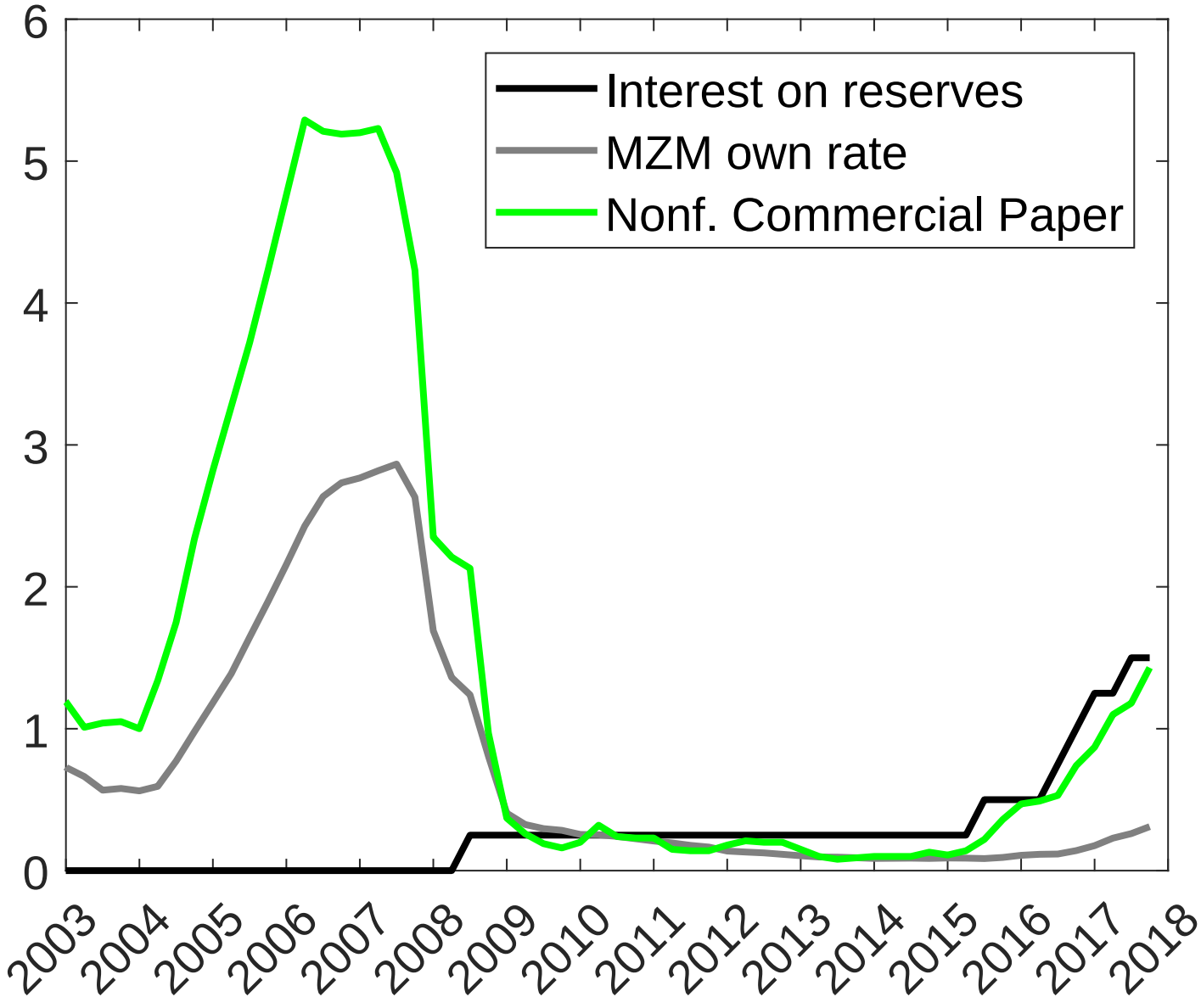
Various interest rates



Motivation

- Standard New Keynesian model
  - central bank directly controls interest rate in household Euler equations
  - focus on Taylor rule, need Taylor principle for determinacy
  - central bank also provides money supply, not important

- This paper: layered payment system with various interest rates
  - households pay with inside money, do not hold short bonds directly
  - banks provide inside money, hold short bonds to back it,
    pay each other with reserves, provided by central bank

  $\rightarrow$ convenience yields on inside money, short bonds

- What if the policy instrument earns a convenience yield?
  - Taylor rule less powerful, don't need Taylor principle
  - money supply is important separate tool for monetary policy

Policy instruments with convenience yield: three models

1. Central bank digital currency = reserve accounts for everyone
   - central bank controls rate on deposits & their supply
   - effectiveness of policy depends on elasticity of money demand
     - imperfect pass through, don't need Taylor principle
     - money supply is separate tool, determines long run inflation

2. Banking with abundant reserves
   - central bank controls reserve rate (= bond rate) & reserve supply
   - effectiveness of policy also depends on financial structure
     - imperfect pass through due to market power, nominal debt rigidities
     - money supply shocks include changes in bank loan quality

3. Banking with scarce reserves (more liquid than bonds)
   - central bank controls reserve rate & supply, targets interbank rate
   - effectiveness of policy depends also on bank liquidity management

Literature

- NK models with financial frictions & banking
  Bernanke-Gertler-Gilchrist 99, Curdia-Woodford 10, Gertler-Karadi 11, Gertler-Kiyotaki-Queralto 11, Christiano-Motto-Rostagno 12, Del Negro-Eggertson-Ferrero-Kiyotaki 17, Diba-Loisel 17
- Asset pricing with constrained investors Lucas 90, Kiyotaki-Moore 97, Geanakoplos 00, Brunnermeier-Pedersen 08, He-Krishnamurthy 12, Buera-Nicolini 14, Lagos-Zhang 14, Bocola 14, Moreira-Savov 14, Lenel-Piazzesi-Schneider 18
- Bank structure & competition Yankov 12, Driscoll-Judson 13, Brunnermeier-Sannikov 14, Duffie-Krishnamurthy 16, Bianchi-Bigio 17, Egan, Hortacsu-Matvos 17, Drechsler-Savov-Schnabl 17, DiTella-Kurlat 17
- Multiple media of exchange Freeman 96, Williamson 12, 14, Rocheteau-Wright-Xiao 14, Andolfatto-Williamson 14, Chari-Phelan 14, Lucas-Nicolini 15, Nagel 15, Begenau-Landvoigt 18
- Recent work on dynamics of the New Keynesian model at ZLB
  information frictions, bounded rationality, fiscal theory, incomplete markets

Household problem

- Separable preferences over consumption goods, money, labor:

$$\frac{1}{1-\frac{1}{\sigma}}\left(\left(1-\omega\right)C^{1-\frac{1}{\sigma}}+\omega\left(D/P\right)^{1-\frac{1}{\sigma}}\right)-\frac{\psi}{1+\phi}N^{1+\phi}$$

- Prices
  - P = nominal price level
  - i^D = nominal interest rate on money
  - i^S = nominal short rate
  - wage

First order conditions

- Money demand

$$D_t = P_t C_t \left(\frac{1-\omega}{\omega} \frac{i_t^S - i_t^D}{1+i_t^S} \right)^{-\sigma}$$

  - unitary elasticity wrt spending
  - σ = elasticity wrt cost of liquidity = spread $i^S - i^D$

- Bonds

$$\beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\frac{1}{\sigma}} \frac{P_t}{P_{t+1}} \right] \left(1 + i_t^S \right) = 1$$

- Money valued for its convenience

$$\beta E_t \left[\left(\frac{C_{t+1}}{C_t} \right)^{-\frac{1}{\sigma}} \frac{P_t}{P_{t+1}} \right] \left(1 + i_t^D \right) + \frac{\omega}{1-\omega} \left(\frac{P_t C_t}{D_t} \right)^{\frac{1}{\sigma}} = 1$$

  - convenience yield rises with spending, falls with money

Equilibrium with government reserve accounts

- Firms
  - consumption goods = CES aggregate of intermediates; elasticity ϵ
  - intermediate goods
    - production function $Y_t = N_t$
    - Calvo price setting with probability of reset θ
- Government: reserve accounts for everyone, CBDC
  - path for money supply
  - path for interest rate on money i^D
  - lump sum taxes adjust to satisfy budget constraint
- Market clearing: goods, money, labor

Long run

- Constant money growth π (= inflation) & nominal rate on money i^D
- Fisher equations
  - bonds: $i^S = \delta + \pi, \quad \delta := 1/\beta - 1$
  - money: $r^D = i^D - \pi$
- Constant consumption = output : $Y = \left(\frac{\varepsilon - 1}{\varepsilon} \frac{1}{\psi} \right)^{\frac{1}{\phi + \frac{1}{\sigma}}}$
- Higher interest rate on money i^D
  - does not increase long run inflation (no Fisherian effect)
  - lowers convenience yield ("permanent liquidity effect")

$$\frac{\omega}{1-\omega} \left(\frac{PY}{D} \right)^{\frac{1}{\sigma}} = \frac{i^S - i^D}{1+\delta}$$

- Now linearize around zero inflation steady state

Comparing Taylor rules

$$
\begin{array}{lrcl}
\text{Phillips curve} & \Delta\hat{p}_t & = & \beta E_t \Delta\hat{p}_{t+1} + \kappa \hat{y}_t \\
\text{Euler equation} & \hat{y}_t & = & E_t \hat{y}_{t+1} - \sigma \left(i_t^S - E_t \Delta\hat{p}_{t+1} - \delta \right) \\
\text{Money demand} & \hat{d}_t - \hat{p}_t & = & \hat{y}_t - \dfrac{\sigma}{\delta - r^D} \left(i_t^S - i_t^D - \left(\delta - r^D \right) \right) \\
\text{Evolution} & \hat{d}_t - \hat{p}_t & = & \hat{d}_{t-1} - \hat{p}_{t-1} + \Delta\hat{d}_t - \Delta\hat{p}_t
\end{array}
$$

- Taylor rule for bonds $i_t^S = \delta + \phi_\pi \Delta\hat{p}_t + v_t$, exogenous i_t^D
  - block recursive: $(\Delta\hat{p}_t, i_t^S, \hat{y}_t)$ independent of $\hat{d}_{t-1} - \hat{p}_{t-1}$
  - money supply $\Delta\hat{d}_t$ adjusts endogenously to implement target i_t^S
  - Taylor principle $\phi_\pi > 1$ ensures determinacy

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  - money supply $\Delta\hat{d}_t$ adjusts endogenously to implement target i_t^S
  - Taylor principle $\phi_\pi > 1$ ensures determinacy
- Taylor rule for money $i_t^D = r^D + \phi_\pi \Delta\hat{p}_t + v_t$, exogenous $\Delta\hat{d}_t$
  - money matters: $(\Delta\hat{p}_t, i_t^S, \hat{y}_t)$ depend on state variable $\hat{d}_{t-1} - \hat{p}_{t-1}$
  - i^D, money supply are separate policy tools
  - determinacy for any ϕ_π with stationary money supply

Comparing standard NK and CBDC model

- Both models: NK Phillips curve

$$\Delta\hat{p}_t = \beta E_t \Delta\hat{p}_{t+1} + \kappa\hat{y}_t$$

- Standard model: Taylor rule & Euler equation for short rate

$$\begin{aligned} i_t^S &= \delta + \phi_\pi \Delta\hat{p}_t + v_t \\ \hat{y}_t &= E_t\hat{y}_{t+1} - \sigma\left(i_t^S - E_t\Delta\hat{p}_{t+1} - \delta\right) \end{aligned}$$

- CBDC model: Taylor rule, Euler & transition equation for money

$$\begin{aligned} i_t^D &= r^D + \phi_\pi \Delta\hat{p}_t + v_t \\ \hat{y}_t &= E_t\hat{y}_{t+1} - \sigma\left(i_t^D - E_t\Delta\hat{p}_{t+1} - r^D\right) \\ &\quad - \left(\delta - r^D\right)\left(\hat{p}_t + \hat{y}_t - \hat{d}_t\right) \\ \hat{d}_t - \hat{p}_t &= \hat{d}_{t-1} - \hat{p}_{t-1} + \Delta\hat{d}_t - \Delta\hat{p}_t \end{aligned}$$

Transitory monetary policy shock

- Taylor rule for bonds: positive innovation to i^S at date 0 only
  - on impact: higher real rate on bonds
    - intertemporal substitution: higher real rate, lower consumption
    - lower inflation, output, spending, money supply
  - next period: back at steady state with zero inflation

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- Taylor rule for money: positive innovation to i_t^D at date 0 only
  - on impact: higher real rate on money
    - intertemporal substitution: higher real rate, lower consumption
    - lower inflation, output, spending $\rightarrow$ lower convenience yield
    - lower total return on money, partly offsetting i^D increase
    - imperfect passthrough from i_t^D to i_t^S
  - over time: constant money supply creates "too much money",
    - works like an expansionary money growth shock
    - higher inflation, output & gradually decline

Nonseparable utility & elasticity of money demand

- Change utility to CES over consumption & real deposits
  - $\sigma =$ intertemporal elasticity of substitution
  - $\eta =$ elasticity of money demand
- Money demand equation is now

$$\hat{d}_t - \hat{p}_t \quad = \quad \hat{y}_t - \frac{\eta}{\delta - r^D}\left(i_t^S - i_t^D - \left(\delta - r^D\right)\right)$$

low η: money demand responds less to cost of liquidity

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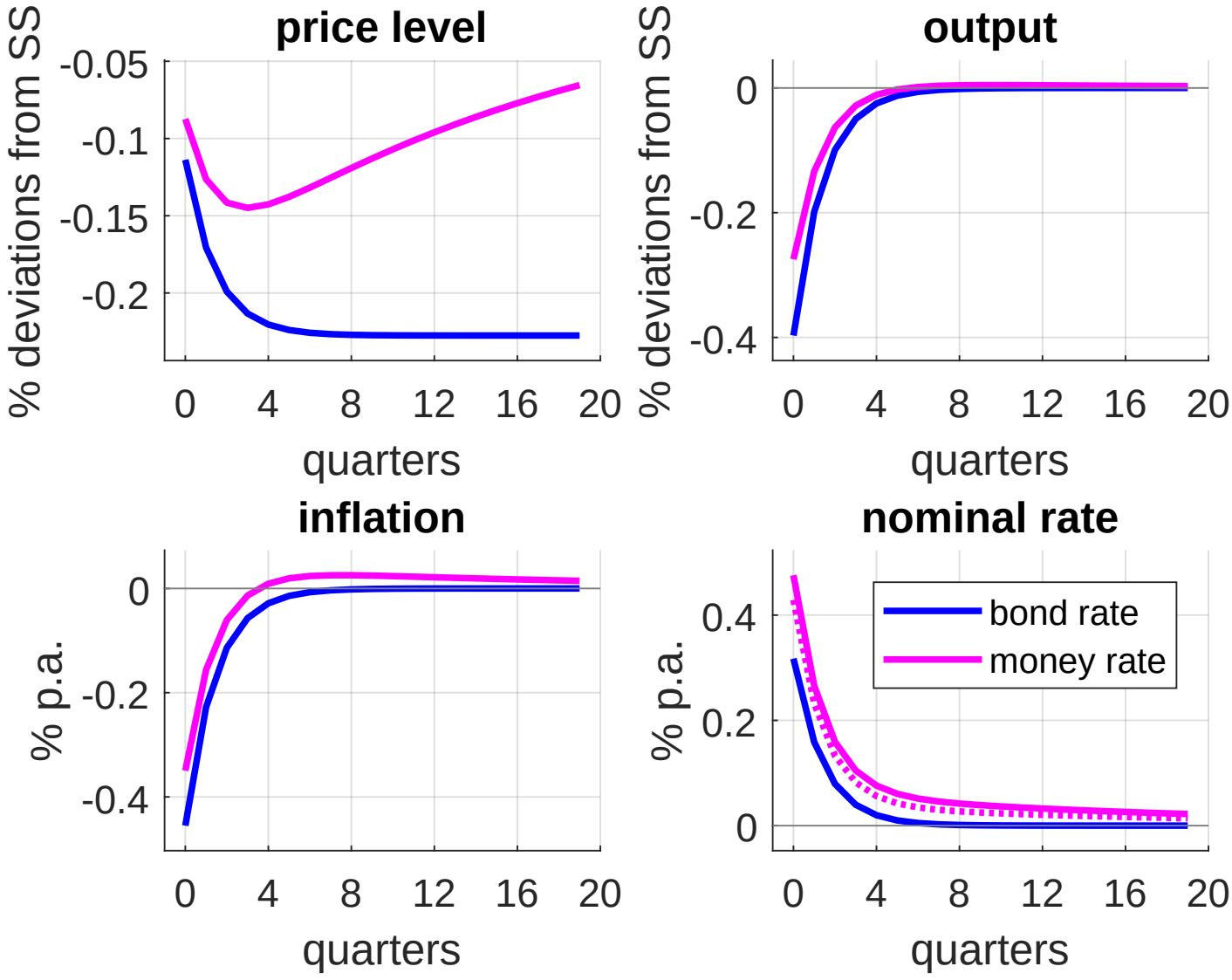
- Substitute short rate in Euler equation

$$\begin{aligned}\hat{y}_t = {} & E_t\hat{y}_{t+1} - \sigma\left(i_t^D - E_t\Delta\hat{p}_{t+1} - r^D\right) \\ & -\frac{\sigma}{\eta}\left(\delta - r^D\right)\left(\hat{p}_t + \hat{y}_t - \hat{d}_t\right) \\ & +\sigma\nu E_t\Delta\hat{v}_{t+1}\end{aligned}$$

  - Low elasticity η : convenience yield more important, dampens more
  - Typical elasticity in the literature $\eta = .2$

IRF to monetary policy shock, $\sigma = 1, \eta = .2$



Outline

- Central bank digital currency (= reserve accounts for everyone)
  - government controls rate on deposits & their supply
  - simplest model s.t. policy instrument has a convenience yield
- Banking with abundant reserves
  - government controls rate on reserves & their supply
  - only banks hold reserves, households hold deposits
  - rate on deposits & their supply are endogenous
- Banking with scarce reserves
  - government controls reserve rate & targets interbank rate
  - endogenous reserve supply, interbank lending activity

Competitive banking sector

- Balance sheet

Assets		Liabilities	
M	Reserves	Money	D
A	Other assets	Equity	

- Shareholders maximize present value of cash flows

$$M_{t-1}\left(1+i_{t-1}^{M}\right)-M_t-D_{t-1}\left(1+i_{t-1}^{D}\right)+D_t$$
$$+A_{t-1}\left(1+i_{t-1}^{A}\right)-A_t$$

- Leverage constraint

$$D_t \leq \ell\left(M_t+\rho A_t\right)$$

  - $\rho < 1$ reflects quality of assets as collateral backing (inside) money

Bank optimization

- Required nominal rate of return on equity $= i_t^S$
- Optimal portfolio choice; $\gamma_t =$ multiplier on leverage constraint

$$\begin{aligned} i_t^S &= i_t^M + \ell\gamma_t \left(1 + i_t^S\right) \\ i_t^S &= i_t^A + \rho\ell\gamma_t \left(1 + i_t^S\right) \end{aligned}$$

  - assets valued as collateral
- Optimal money creation

$$i_t^S = i_t^D + \gamma_t \left(1 + i_t^S\right)$$

  - money requires leverage cost

$\rightarrow$ Marginal cost pricing of liquidity

$$i_t^S - i_t^D = \frac{1}{\ell}\left(i_t^S - i_t^M\right)$$

Equilibrium with banks

- Markets for reserves & other bank assets
  - exogenous supply of assets A_t
  - policy: Taylor rule for reserve rate i_t^M, exogenous path for reserves M_t
  - new endogenous objects: M_t / P_t, i_t^M, i_t^D, i_t^A
- Phillips curve & bond Euler equation unchanged
- Bank collateral demand:

$$\alpha_m \hat{m}_t + (1 - \alpha_m) \hat{a}_t - p_t = \hat{y}_t - \frac{\eta / \ell}{\delta - r^D} \left(i_t^S - i_t^M - \left(r^S - r^M \right) \right)$$

- Transition equation: reserves and other assets rather than deposits

$$\begin{aligned} \hat{m}_t - \hat{p}_t &= \hat{m}_{t-1} - \hat{p}_{t-1} + \Delta \hat{m}_t - \Delta \hat{p}_t \\ \hat{a}_t - \hat{p}_t &= \hat{a}_{t-1} - \hat{p}_{t-1} + \Delta \hat{a}_t - \Delta \hat{p}_t \end{aligned}$$

- equivalence result: same structure as CBDC model

Characterizing equilibrium with banks

- Bank collateral demand:

$$\alpha_m \hat{m}_t + (1 - \alpha_m) \hat{a}_t - p_t = \hat{y}_t - \frac{\eta / \ell}{\delta - r^D} \left(i_t^S - i_t^M - \left(r^S - r^M \right) \right)$$

- Key coefficient: collateral demand elasticity, lower with higher $\bar{\ell}$
- Shocks to bank assets matter!
  - shock to quantity of assets works like transitory money supply shock
- Assumption here: other collateral is fixed in nominal terms
  - with real assets, more effective interest rate policy
  - data: long term debt, nominally fixed in the short run

Bank market power

- Many monopolistically competitive banks

$$D_t = \left(\int \left(D_t^i \right)^{1-\frac{1}{\eta_b}} \right)^{\frac{1}{1-\frac{1}{\eta_b}}}$$

η_b = elasticity of substitution between bank accounts

- Constant markup over marginal cost

$$i_t^S - i_t^D = \frac{\eta_b}{\eta_b - 1} \ell^{-1} \left(i_t^S - i_t^M \right)$$

Combining effects

- Bank collateral demand

$$\alpha_m \hat{m}_t + (1-\alpha_m)\,\hat{a}_t - \hat{p}_t = \hat{y}_t - \frac{\eta_b}{\eta_b - 1}\frac{\eta/\ell}{\delta - r^D}\left(i_t^S - i_t^M - \left(\delta - r^M\right)\right)$$

  - interest elasticity: household & bank components
  - higher elasticity with more market power

- Modified Euler equation

$$\begin{aligned}\hat{y}_t &= E_t\hat{y}_{t+1} - \sigma\left(i_t^M - E_t\Delta\hat{p}_{t+1} - r^M\right) + \sigma\nu E_t\Delta\hat{v}_{t+1} \\ &\quad -\frac{\eta_b - 1}{\eta_b}\,\ell\,\frac{\delta - r^D}{\eta}\left(\hat{p}_t + \hat{y}_t - \alpha_m\hat{m}_t - (1-\alpha_m)\,\hat{a}_t\right)\end{aligned}$$

  - reserves = policy instrument with convenience yield
  - convenience yield depends on private sector shocks, dampens more with low interest elasticity

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Banks with scarce reserves

- IID liquidity shocks
  - arrive after banks have chosen reserves, loans, deposits
  - bank must pay/receive $\tilde{\lambda} D_t$ to/from other banks; $E[\tilde{\lambda}] = 0$
  - competitive Fed funds market: borrow, lend reserves at rate i_F
  - bank budget constraints

$$M_t - \tilde{\lambda} D_t = M'_t + F_t^+ - F_t^-$$

- Leverage constraint must hold *after* liquidity shocks

$$\left(1 - \tilde{\lambda}_t\right) D_t + F_t^- = \ell \left(M' + \rho_f F^+ + \rho A\right)$$

- Optimal policy with $i_F > i_R$
  - borrow if too few reserves to pay deposit outflows
  - try to lend out reserves
- When are reserves scarce?
  - large liquidity shocks + few reserves / other collateral
  - otherwise no active Fed funds market

Equilibrium with scarce reserves

- Fed funds market & policy
  - Taylor rule for fed funds rate i_t^F, fixed reserve rate i^M
  - reserve supply adjusts to meet target
  - new endogenous object: i_t^F
- Again substitute using spread equations & balance sheet ratios

$\rightarrow$ Bank collateral demand depends on $i_t^S - i_t^F$ and $i_t^S - i^M$

- Same structure as earlier
  - policy instrument determines demand for bank collateral
  - coefficients on spreads depend on financial structure, including liquidity shock distribution
  - reserves now endogenous, but loan shocks still important!

Conclusions

- Equivalence result between CBDC model and banking models:
  - policy instrument has a convenient yield
  - determinacy of the NK model for broad range of policy rules
  - both interest rate & supply of reserves matter
- Key parameter for transmission: interest elasticity of reserve demand
  1. household component: interest elasticity of broad money demand
  2. bank layer component: depends on financial structure

     leverage, nominal rigidities in bank assets, competition etc.
- Shocks to other bank assets
  - matter via effect on production of inside money