Money and Banking in a New Keynesian Model

Monika Piazzesi
Stanford

Ciaran Rogers
Stanford

Martin Schneider
Stanford

Belgium, December 2019

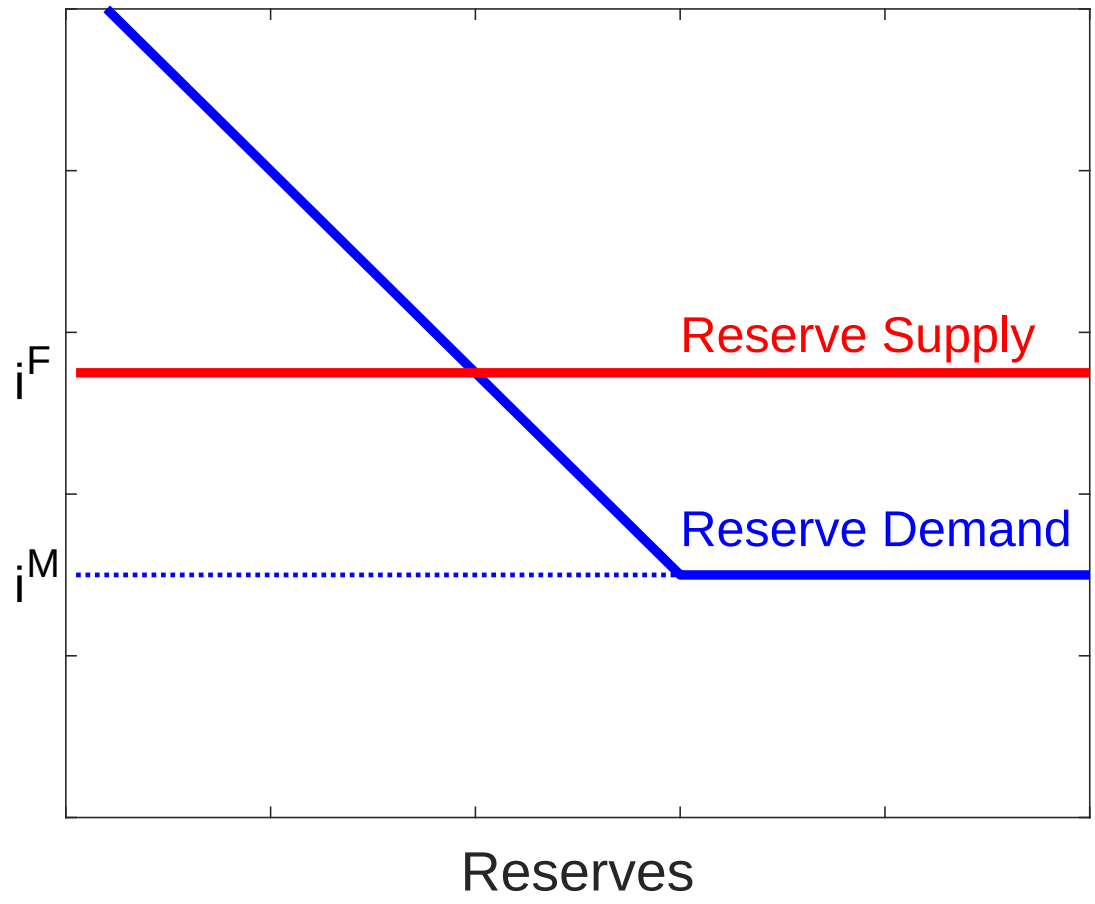
Motivation

- Standard New Keynesian model
  - central bank controls short rate in household stochastic discount factor
  - short rate = return on savings & investment
- This paper: New Keynesian model with banking sector
  - central bank controls interest rate on fed funds or reserves
  - households do not hold these assets directly
  - banks hold these assets to back inside money

  $\rightarrow$ disconnect between policy rate & short rate
- Central bank operating procedures:
  - chooses regime/reserve supply: scarce vs ample
  - matters for effectiveness of monetary policy

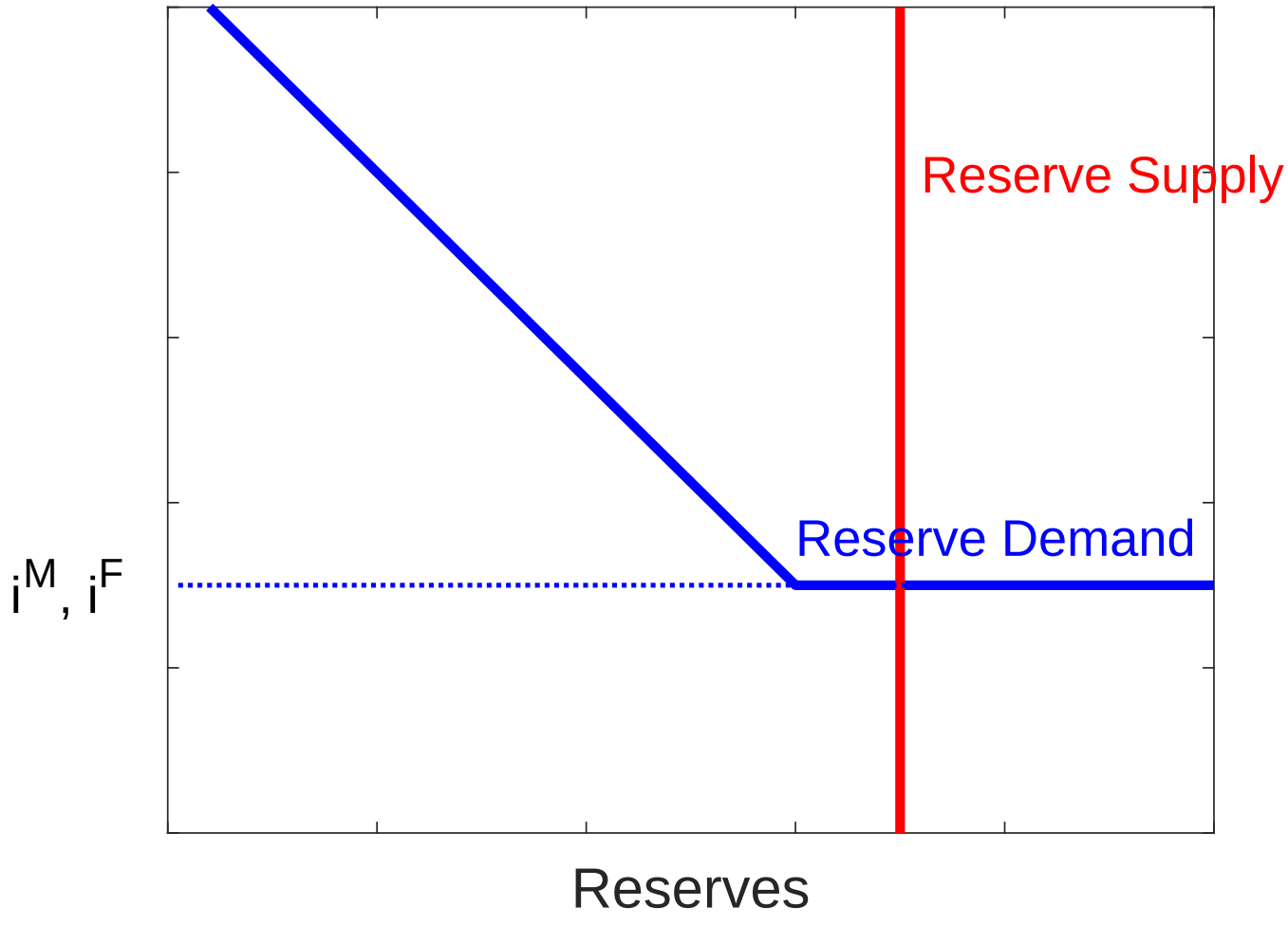
Corridor system with scarce reserves

- monetary policy targets fedfunds rate, sets reserve rate
- trading desk supplies reserves elastically to meet target
- banks' cost of liquidity > 0, rises if central bank tightens



Floor system with ample reserves

- monetary policy sets reserve rate & quantity of reserves
- banks' cost of liquidity zero, remains zero if central bank tightens



Implications

- Standard NK model
  - interest rate is all that matters, plumbing & quantities not important
- Banking & short rate disconnect: plumbing & quantities matter
  - floor system: interest rate policy only affects banks' cost of safety
    - higher reserve rate, cheaper safe collateral to back inside money, lower cost of liquidity for *households*, not banks, policy weaker
    - quantity of reserves is independent policy tool
  - corridor system: interest rate policy also affects banks' cost of liquidity
    - higher interbank rate, implemented with lower reserves (not indep.)
    - higher cost of liquidity for households & banks, stronger policy
  - both systems
    - less scope for multiple equilibria with short-rate disconnect (savings rate adjusts to inflation even if e.g. policy rate at peg)
    - nominal assets held by banks matter for output & inflation (banks' cost of safety depends on all collateral, not just reserves)

Plan for talk

- Transmission in minimal model with disconnect
  - Households make payments with CBDC (no banks)
- Introduce banks that provide inside money for payments
  - Government supplies ample reserves (floor system)
  - Scarce reserves (corridor system)

Literature

- NK models with financial frictions & banking
  Bernanke-Gertler-Gilchrist 99, Cúrdia-Woodford 10, Gertler-Karadi 11, Gertler-Kiyotaki-Queralto 11, Christiano-Motto-Rostagno 12, Del Negro-Eggertson-Ferrero-Kiyotaki 17, Diba-Loisel 17, Arce-Nuño-Thaler-Thomas 19
- Convenience yields on bonds Patinkin 56, Tobin 61, Bansal-Coleman 96, Krishnamurthy-Vissing-Jorgensen 12, Andolfatto-Williamson 14, Nagel 15, Hagedorn 18, Michaillat-Saez 19
- Convenience yield on assets that back medium of exchange
  Kiyotaki-Moore 05, Williamson 12, Venkateswaran-Wright 13, Lenel-Piazzesi-Schneider 19
- Bank 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
- Recent work on dynamics of the New Keynesian model at ZLB
  information frictions, bounded rationality, fiscal theory, incomplete markets

Minimal model with short rate disconnect (no banks)

- Representative household
  - utility separable in labor + CES bundle of consumption & money
  - σ = IES for bundles, η = interest elasticity of money demand
  - for now, separable in consumption & money: $\eta = \sigma$
  - later consider complementarity: $\eta < \sigma$
- Firms
  - consumption goods = CES aggregate of intermediates
  - intermediate goods made 1-1 from labor, Calvo price setting
- Government: central bank digital currency
  - path or feedback rule for money supply D_t
  - path or feedback rule for *policy rate* i_t^D = interest rate on money
  - lump sum taxes adjust to satisfy budget constraint
- Market clearing: goods, money, labor
  - i_t^S = short rate in household SDF adjusts endogenously

Linear dynamics

- Steady state with zero inflation
- Standard NK Phillips curve & Euler equation, $\kappa = \lambda\left(\varphi + \frac{1}{\sigma}\right)$

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

- Households' money demand

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

Why money does not matter in the standard NK model

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

- Solve for $(\hat{p}_t, \hat{y}_t, i_t^S, i_t^D, \hat{d}_t)$ given initial condition $\hat{p}_0$
- Standard model
  - add 2 policy rules: Taylor rule for i_t^S, peg for $i_t^D = 0$
  - quantity of money $\hat{d}_t$ endogenous, adjusts to implement policy rule

  $\rightarrow$ policy rate = short rate
  - money does not matter, system is block recursive:
    solve for $(\hat{p}_t, \hat{y}_t)$ given i_t^S, $i_t^D = 0$ and initial condition $\hat{p}_0$

Why money matters in CBDC model

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

- CBDC model
  - adds 2 policy rules: interest on money i_t^D, quantity of money D_t
  - short rate i_t^D endogenous, satisfies Euler equation

  $\rightarrow$ disconnect: policy rate $\neq$ short rate
  - money matters, system no longer block recursive:
    solve for $(\hat{p}_t, \hat{y}_t, i_t^S)$ given policy rules i_t^D and D_t
  - familiar special case: NK model with money growth rule & peg $i_t^D = 0$

Disconnect and role of money with banks

- standard model: policy rate = short rate, money does not matter
- CBDC model: policy rate $\neq$ short rate, money matters
- banking model with floor system works like CBDC model
  - rules for reserve rate i_t^M, quantity of reserves M_t
  - short rate disconnect: households do not hold reserves
- banking model with corridor system
  - rules for fed funds rate i_t^F, peg for reserve rate $i_t^M = 0$
  - reserves endogenously adjust to implement policy rule
    $\rightarrow$ closer to standard model
  - but still short rate disconnect: households do not hold fed funds

Interest rate policy

- Standard model: short rate i_t^S = policy rate

- Transmission of interest rate policy

$$\text{policy rate} \overset{+}{\longrightarrow} \text{real return on savings} \overset{-}{\longrightarrow} \text{output, inflation}$$

- Money supplied elastically to implement i_t^S, fix $i_t^D = 0$

Interest rate policy

- CBDC model: convenience yield is endogenous wedge

$$i_t^S - \delta = \underbrace{i_t^D - r^D}_{\text{policy rate}} + \underbrace{\frac{\delta - r^D}{\eta}\left(\hat{p}_t + \hat{y}_t - \hat{d}_t\right)}_{\substack{\text{convenience yield, increasing in} \\ \text{velocity = spending / money}}}$$

- Transmission of interest rate policy

$$\text{policy rate} \xrightarrow{+} \text{real return on savings} \xrightarrow{-} \text{output, inflation}$$

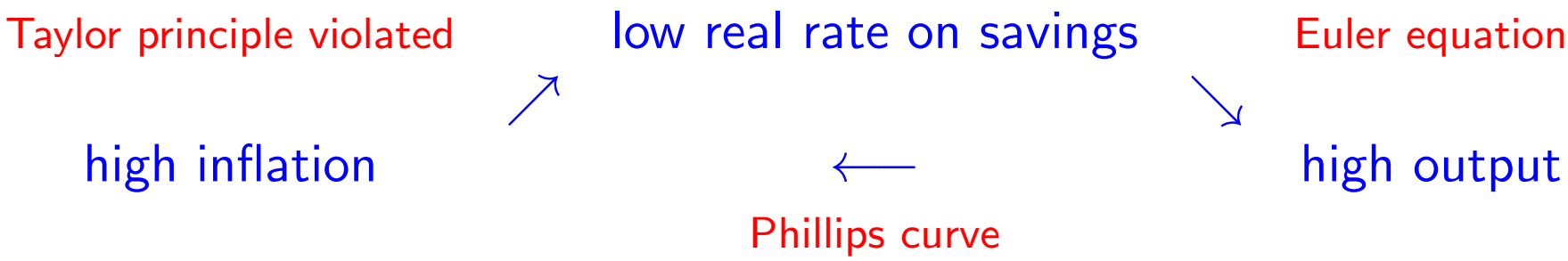
$$+\uparrow \qquad\qquad +\downarrow$$

$$\text{convenience yield} \xleftarrow{+} \text{spending, velocity}$$

$\Rightarrow$ convenience yield dampens effect

Local determinacy with interest rate peg

- Standard model: many bounded solutions to difference equation
- When do we get multiple bounded equilibrium paths?



- Taylor principle: policy reacts aggressively to high inflation
  $\rightarrow$ high real rate on savings
- CBDC model: savings rate = policy rate + convenience yield
  higher convenience yield $\rightarrow$ higher real rate on savings
- generalized Taylor principle: LR of savings rate to inflation > 1

When do we get local determinacy with separable utility?

- Taylor rule $i_t^D = r^D + \phi_\pi \Delta\hat{p}_t + \phi_y \hat{y}_t + v_t$
- Money supply rule $D_t = \mu D_{t-1} + P_t G, \quad \mu \leq 1$
  - choose μ, G, r^D to achieve zero inflation in steady state
  - with $\mu = 1$, $G = 0 \rightarrow$ constant money supply, nominal anchor
  - with $\mu < 1$, no nominal anchor: continuum of st.st. price levels
- Unique bounded solution iff

$$LR(i^S, \Delta\hat{p}) = \frac{\delta - r^D}{\eta}\left(\frac{\mu}{1-\mu} + \frac{1-\beta}{\kappa}\right) + \phi_\pi + \phi_y \frac{1-\beta}{\kappa} > 1$$

- Less scope for multiple equilibria if
  - lower semielasticity of money demand $\eta/(\delta - r^D)$
  - more nominal asset rigidity in balance sheet: higher μ
  - prices more sticky: lower λ
  - more aggressive inflation response: higher ϕ_π

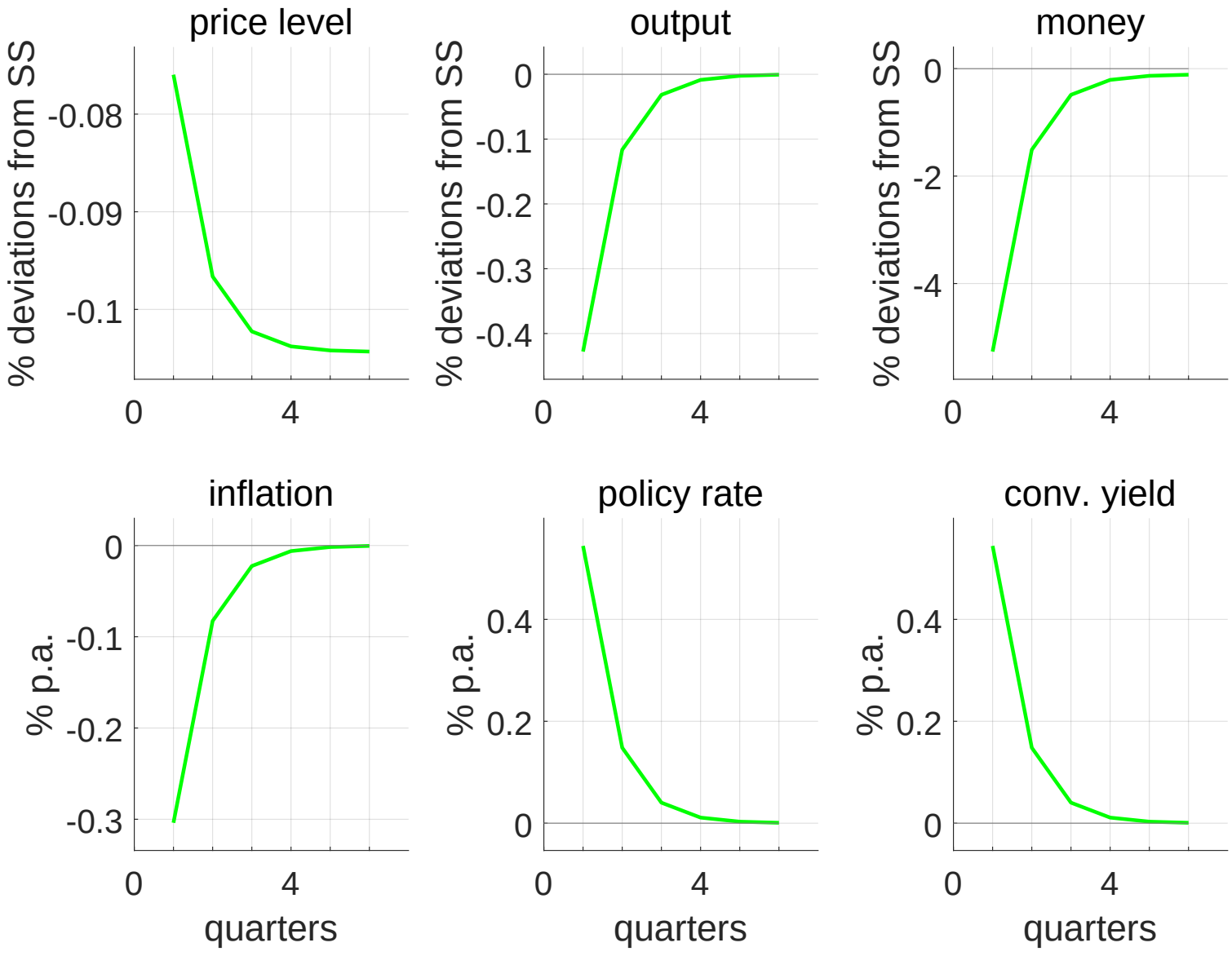
Cost channel

- Consumption & money complements in utility
  - nonseparable utility with $\eta < \sigma$
  - higher cost of liquidity $i_t^S - i_t^D$ makes shopping less attractive

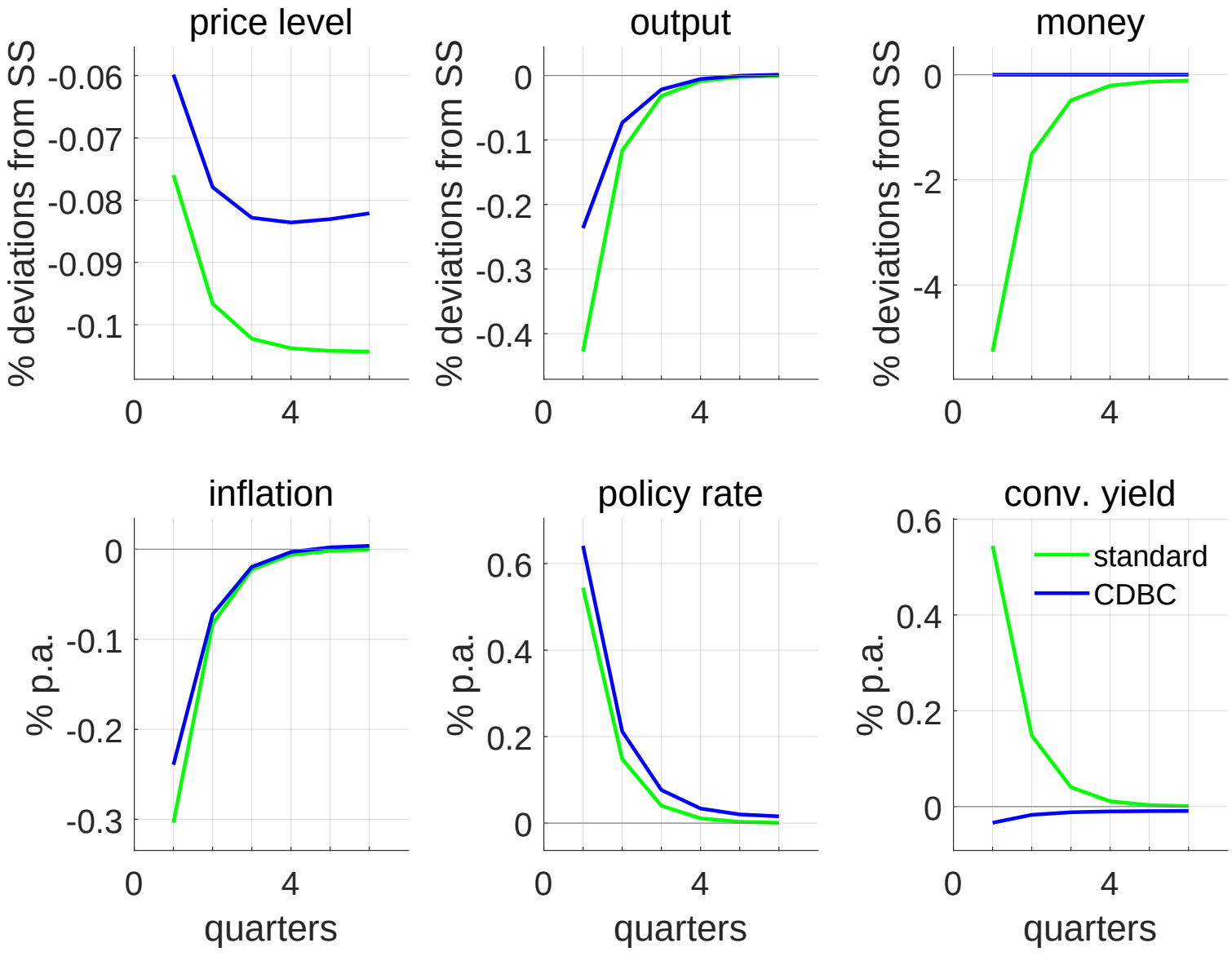
    $\rightarrow$ reduce consumption, increase leisure/decrease labor

    $\rightarrow$ lower output, higher inflation
- Effect of higher policy rate on cost of liquidity $i_t^S - i_t^D$
  - standard model: higher i_t^S with fixed $i_t^D \rightarrow$ higher cost
  - CBDC model: higher i_t^D + imperfect pass-through $\rightarrow$ lower cost
- Numerical example
  - $\delta = 4\%, r^D = 1.6\%, \sigma = 1, \eta = .2$, standard cost & Calvo pars
  - constant money supply
  - Taylor rule with coefficient 1.5 on inflation, .5 on past short rate
  - compare impulse responses to $25bp$ monetary policy shock

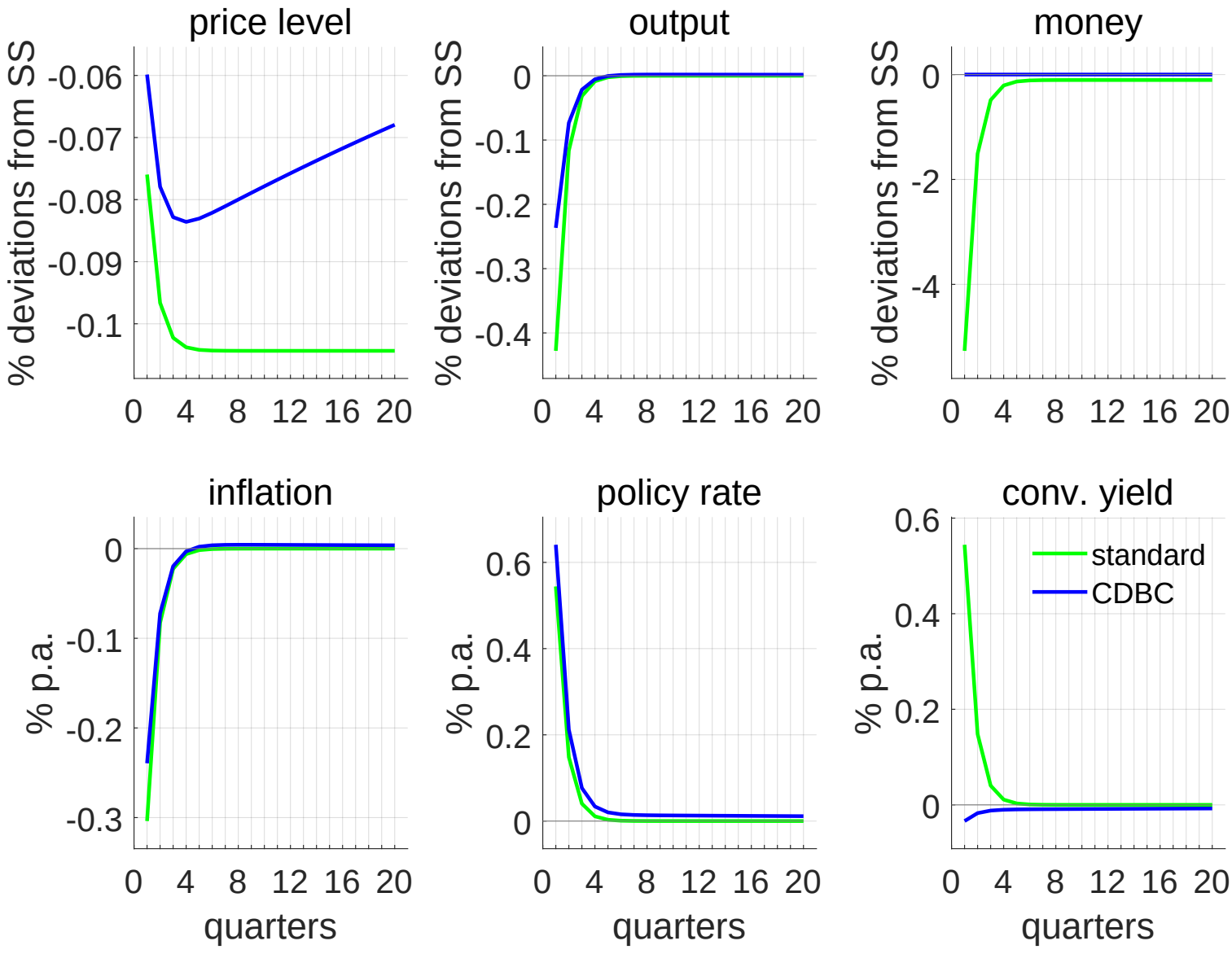
IRFs to 25 bp monetary policy shock: standard model



IRFs to 25 bp monetary policy shock: standard vs CBDC

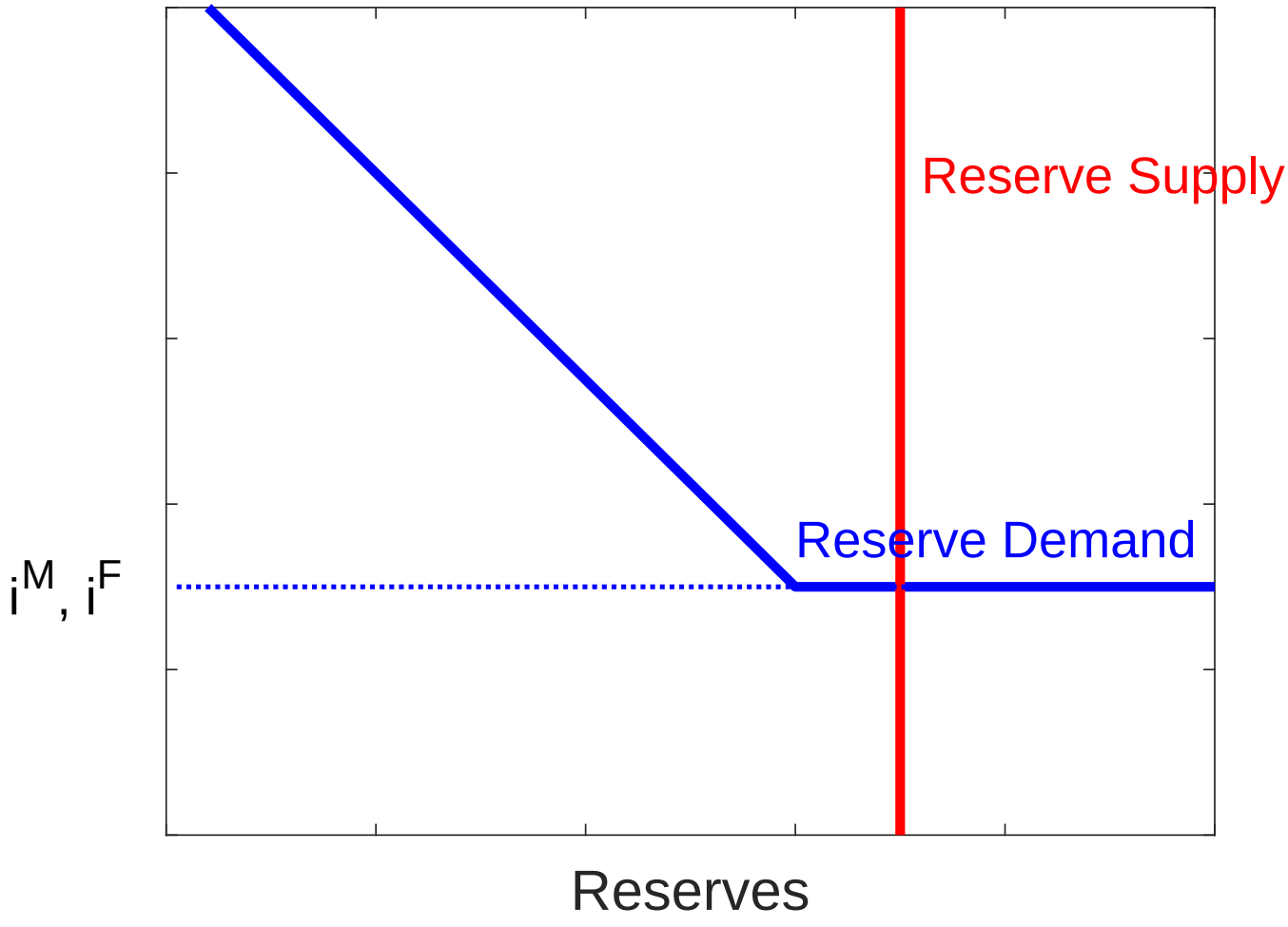


IRFs to 25 bp monetary policy shock: standard vs CBDC



NK Model with Banks

- central bank provides ample reserves ("floor system")
  - reserves are special as collateral, not needed for liquidity
  - monetary policy targets reserve rate



Banking sector

- Balance sheet

Assets		Liabilities	
M	Reserves	Money	D
A	Other assets	Equity	

- Shareholders maximize present value of cash flows

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

- Costless adjustment of equity
- Leverage constraint: $D_t \leq \ell\left(M_t+\rho A_t\right)$
  - $\rho < 1$ other assets are lower quality collateral to back (inside) money

Bank optimization: perfect competition

- Nominal rate of return on equity $= i_t^S$
  - banks equate returns on assets & liabilities to cost of capital i_t^S
  - $\gamma_t =$ multiplier on leverage constraint
- Optimal portfolio choice: assets valued as collateral

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

- Optimal money creation: money requires leverage cost

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

$\Rightarrow$ Marginal cost pricing of liquidity

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

Bank market power

- Many monopolistically competitive banks
- Households care about CES bundle of deposit varieties

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

  - η_b = elasticity of substitution between bank accounts

$\Rightarrow$ Constant markup over marginal cost

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

Equilibrium with ample reserves

- Government: floor system with ample reserves
  - path or rule for supply of reserves M_t
  - path or rule for interest rate on reserves i_t^M
- Market clearing for reserves & other bank assets
  - exogenous path A_t^r of real assets, so $A_t = P_t A_t^r$
  - stands in for borrowing by firms or against housing
- Characterizing equilibrium
  - NK Phillips curve & Euler equation unchanged

Dynamics with ample reserves

- Interest rate pass-through: reserve rate to short rate

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

  - reserves back inside money, inherit convenience yield of deposits

- Money supply

$$\hat{d}_t = \frac{M}{M + \rho A}\hat{m}_t + \frac{\rho A}{M + \rho A}\hat{a}_t$$

  - reserves a separate policy instrument: QE stimulates economy!
  - other bank assets also matter: bad loan shocks contractionary

$\Rightarrow$ Works like CBDC model, but coefficients depend on banking system

Banking with scarce reserves

- Banks manage liquidity
  - deposit outflow/inflow $\tilde{\lambda} D_t$ to/from other banks
  - iid liquidity shock $\tilde{\lambda}$ has mean zero, cdf G with bounded support
  - satisfy leverage constraint after deposit inflow/outflow
  - borrow/lend in competitive fed funds market at rate i^F
- Assets valued as collateral, reserves also for liquidity
- Government:
  - path or rule for fed funds rate i_t^F, reserve rate i^M ; here $i^M = 0$
  - reserve supply adjusts to meet interest rate targets
- Market clearing for reserves, Fed funds
  - reserves scarce: quantity small relative to support of liquidity shocks
  - otherwise $i^F = i^M$ & no active Fed funds market, back to floor
  - government selects type of equilibrium

Dynamics with scarce reserves

- Interest rate pass-through: fed funds rate to short rate

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

- Inside money in reserveless limit: share of reserves in bank assets $\to 0$

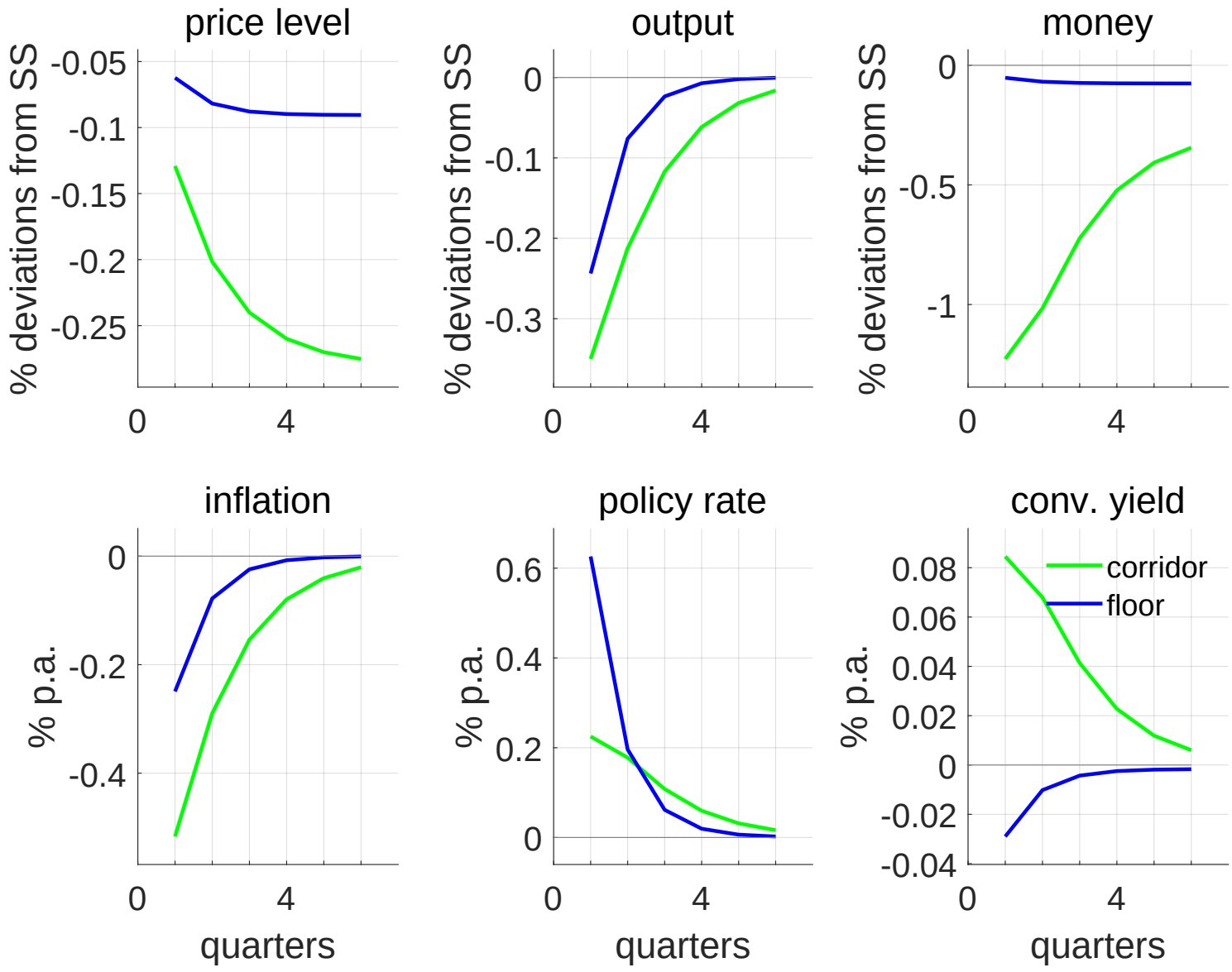
$$\hat{d}_t = \frac{\eta}{\eta + \varepsilon}\hat{a}_t + \frac{\varepsilon}{\eta + \varepsilon}\left(\hat{p}_t + \hat{y}_t - \frac{\eta}{r^F}\left(i_t^F - r^F\right)\right)$$

  - $\varepsilon =$ function of bank technology parameters

$\Rightarrow$ Works like CBDC model with more elastic money supply

- Numerical example to compare floor & corridor system

25bp increase in policy rate: corridor vs floor systems



Conclusion

- Disconnect between policy rate and short rate
  - convenience yield is endogenous wedge, changes transmission
  - less scope for multiple equilibria, even without Taylor principle
  - policy weaker if more nominal rigidities in balance sheets
- Bank models vs CBDC model
  - same basic transmission mechanism
  - difference to standard model depends on details of banking system:
    - ★ nominal rigidities in bank balance sheets, bank market power
    - ★ liquidity management & elasticity of deposit supply
- Corridor vs floor system
  - with cost channel, significant differences in IRFs
  - corridor system closer to standard model than floor system