Banks, Liquidity Management and the Credit Channel of Monetary Policy

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Framework for Monetary Policy Analysis

- Dynamic GE model of banks' liquidity management
- Implementation & transmission of monetary policy through banks

- Classic Liquidity Management:
  - (+) Profit on Loans
    - Spread between loans and deposits
  - (-) Illiquidity Risk
    - After deposits withdrawals, bank may be short of reserves/liquid assets

- MP operates through interbank market

Model Overview

1. Bank individual decision problem:
    - Loan issuances, liquid assets, deposit creation, retain earnings
    - Capital requirements, reserve requirements
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    - Interbank-market and market rates, price level determined in equilibrium
    - Stationary equilibrium and transitional dynamics

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3. Policy lab: changes in reserve requirements, IOR, capital requirements, discount window rates, conventional/unconventional policies

Model Application

- Financial crisis:
  - What caused contraction in lending and liquidity hoarding?

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- Five Hypothesis

  1. Equity Losses
  2. Capital Requirements
  3. Precautionary Holdings
  4. Weak Loan Demand, Credit Risk
  5. Central Bank Policy

Literature Review

- **Reserve Management:** Poole (JF,1968),Bolton et al. (2012), Saunders et al. (2011), Afonso & Lagos (2015)
- **Classic Models of Banking:** Diamond & Dybvig (1983), Allen & Gale (1998), Holmstrom & Tirole (1997,1998)
- **Banking in Macro:** Gertler & Karadi(2009), Gertler & Kiyotaki (2011,2012), Curdia & Woodford(2009), Corbae & D'erasmo (2013,2014)
- **Payments:** Freeman(AER,1996), Cavalcanti et al. (1998), Piazzesi and Schneider (2015)
- **Money & Credit:** Wright et al. (2014), Brunnermeier & Sannikov (2013), Williamson (2012,2016), Kiyotaki & Moore (2012)
- **Excess Reserves:** Armenter & Lester (2015), Ennis (2014)
- **Empirical Work:** Krishnamurthy & Vissing-Jorgenson (2012), Nagel (2016), Ashcraft, McAndrews and Skeie (2011)

Model - Environment

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- Deterministic aggregate dynamics

- **Utility function:** Bankers have concave utility u over dividends c_t

$$u(c) = \frac{c^{1-\sigma} - 1}{1 - \sigma}$$

Banks' Balance Sheet

- Liabilities:
  - d_t demand deposits
  - w_t discount-window loans
  - f_t deposits from other banks
- Assets:
  - m_t liquid assets (central bank reserves, T-bills)
  - b_t loans (illiquid)
  - $-f_t$ loans to other banks

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- All assets/liabilities denominated in nominal terms
  - P_t price of goods in terms of reserves

Lending Stage

- Budget constraint

$$
\begin{aligned}
P_t c_t^j + \tilde{b}_{t+1}^j + \tilde{m}_{t+1}^j - \tilde{d}_{t+1}^j = {} & b_t^j(1+i_t^b) + m_t^j(1+i_t^{ior}) - d_t^j(1+i_t^d) \\
& - f_t^j\left(1+\bar{\imath}_t^f\right) - w_t^j\left(1+i_t^{dw}\right) - P_t T_t^j
\end{aligned}
$$

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\end{aligned}
$$

- Capital requirement constraint

$$
\tilde{d}_{t+1}^j \leq \kappa \left(\tilde{b}_{t+1}^j + \tilde{m}_{t+1}^j - \tilde{d}_{t+1}^j \right)
$$

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$$m_{t+1}^j \geq \rho d_{t+1}^j$$

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Balancing Stage

- A stochastic fraction ω^j of deposits arrive/leave the bank
- Borrow in interbank market f and from discount window w

$$d^j_{t+1} = \tilde{d}^j_{t+1} + \omega^j_t \tilde{d}^j_{t+1}$$

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$$m^j_{t+1} \geq \rho d^j_{t+1}$$

- Let s^j be the surplus after ω :

$$s^j \equiv \underbrace{\tilde{m}^j_{t+1} + \omega^j_t \tilde{d}^j_{t+1} \left(\frac{1 + i^d_{t+1}}{1 + i^{ior}_{t+1}} \right)}_{\text{Reserves left}} - \rho \underbrace{\tilde{d}^j_{t+1}(1 - \omega^j)}_{\text{Deposits left}}$$

Interbank Market

- Shocks to ω lead to distribution of s^j
- Banks with surplus lend to bank with deficit
- OTC Interbank market:
  - Afonso-Lagos + infinitesimal traders (Atkeson et al. 2014)
  - Closed form solutions
  - Kink in returns

Interbank Market (ctd)

- Two-sided market: borrowers and lenders

$$S^{-} \equiv \int_0^1 \min\left\{s^j, 0\right\} dj.$$

and

$$S^{+} \equiv \int_0^1 \max\left\{s^j, 0\right\} dj$$

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- Trading rounds $n = \{1, 2, ..., N\}$
- Probability of matching in each round ψ_n depend on market tightness $\theta_n \equiv S_n^{-}/S_n^{+}$ and efficiency parameter λ^N

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- Terminal outside options: DW loans or i^{ior} at FED
- Bank divides position s^j into trades of size Δ
  - Let $\hat{E}^j$ be equity of bank excluding trader

Individual Trader

- Matched trader in deficit:

$$J_M^-(n) = V(\hat{E}^j - \Delta(i_n - i^{ior}))$$

- Unmatched trader in deficit:

$$\begin{aligned} J_U^-(n) &= \psi_{n+1}^- J_M^-(n+1) + (1 - \psi_{n+1}^-) J_U^-(n+1) \quad \forall n = 1, 2 \ldots N \\ J_U^-(N+1) &= V(\hat{E}^j - \Delta(i^{dw} - i^{ior})). \qquad \text{(Terminal Value)} \end{aligned}$$

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- Matched trader in surplus:

$$J_M^+(n) = V(\hat{E}^j + \Delta(i_n - i^{ior}))$$

- Unmatched trader in surplus:

$$\begin{aligned} J_U^+(n) &= \psi_{n+1}^+ J_M^+(n+1) + (1-\psi_{n+1}^+) J_U^+(n+1) \quad \forall n = 1, 2...N \\ J_U^+(N+1) &= V(\hat{E}^j). \qquad \text{(Terminal Value)} \end{aligned}$$

Bargaining Problem

- Nash bargaining
- Solution yields Fed Funds

$$i_n^f = \arg\max_{i_n} \left(J_M^-(n) - J_U^-(n+1)\right)^\eta \left(J_M^+(n) - J_U^+(n+1)\right)^{1-\eta}$$

Analytical Solution

Special Case: Leontief matching, $\Delta \to 0$, continuous time

Proposition

Trading prob:

$$\Psi^+ = \begin{cases} 1 - e^{-\bar{\lambda}} & \text{if } \theta \geq 1 \\ \theta \left(1 - e^{-\bar{\lambda}}\right) & \text{if } \theta < 1 \end{cases}, \qquad \Psi^- = \begin{cases} \left(1 - e^{-\bar{\lambda}}\right) \theta^{-1} & \text{if } \theta > 1 \\ 1 - e^{-\bar{\lambda}} & \text{if } \theta \leq 1 \end{cases}$$

Given θ, after-trade tightness is:

$$\bar{\theta} = \begin{cases} 1 + (\theta - 1) \exp\left(\bar{\lambda}\right) & \text{if } \theta > 1 \\ 1 & \text{if } \theta = 1 \\ \left(1 + \left(\theta^{-1} - 1\right) \exp\left(\bar{\lambda}\right)\right)^{-1} & \text{if } \theta < 1 \end{cases}$$

Reduced-form bargaining param:

$$\Phi = \begin{cases} \theta \left(\frac{(\bar{\theta}/\theta)^{\eta} - 1}{\theta - 1} \right) \left(\exp\left(\bar{\lambda}\right) - 1\right)^{-1} & \text{if } \theta > 1 \\ \eta & \text{if } \theta = 1 \\ \left(1 - \theta(1/\bar{\theta} - 1)\right) \left(\frac{(\bar{\theta}/\theta)^{\eta} - 1}{\theta - 1} \right) \left(\exp\left(\bar{\lambda}\right) - 1\right)^{-1} & \text{if } \theta < 1 \end{cases}$$

Analytical Solution

- $\bar{i}^f = i^{dw} - \Phi\left(i^{dw} - i^{ior}\right)$

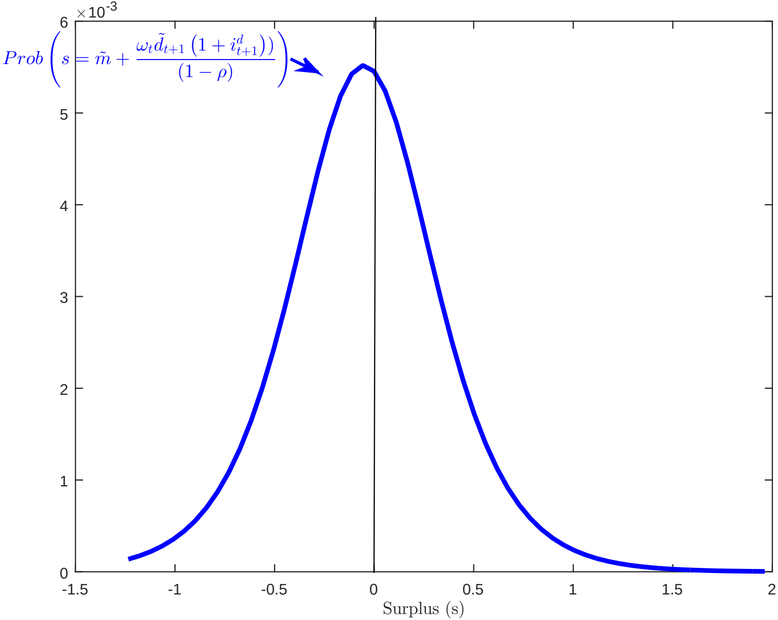
- Benefit of ending period with surplus s

$$\begin{aligned} \chi_t(s) &= \begin{cases} \chi_t^+ s & if\ s \geq 0 \\ \chi_t^- s & if\ s < 0 \end{cases}, \\ \chi_t^- &= \Psi_t^- \left(\bar{i}_t^f - i_t^{ior}\right) + \left(1 - \Psi_t^-\right)\left(i_t^{dw} - i_t^{ior}\right) \\ \chi_t^+ &= \Psi_t^+ \left(\bar{i}_t^f - i^{ior}\right). \end{aligned}$$

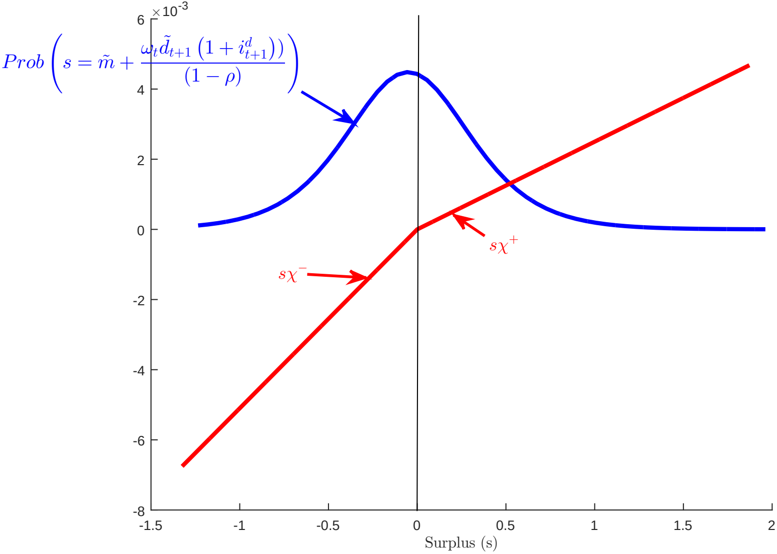
- Cost of deficit χ^- is higher when reserves are scarce
  - Ψ_t^- is decreasing in $\theta_0 \equiv S_0^- / S_0^+$
  - $\bar{i}^f$ is increasing in $\theta_0 \equiv S_0^- / S_0^+$

- $\chi^- > \chi^+ \Rightarrow$ Kink in interbank return

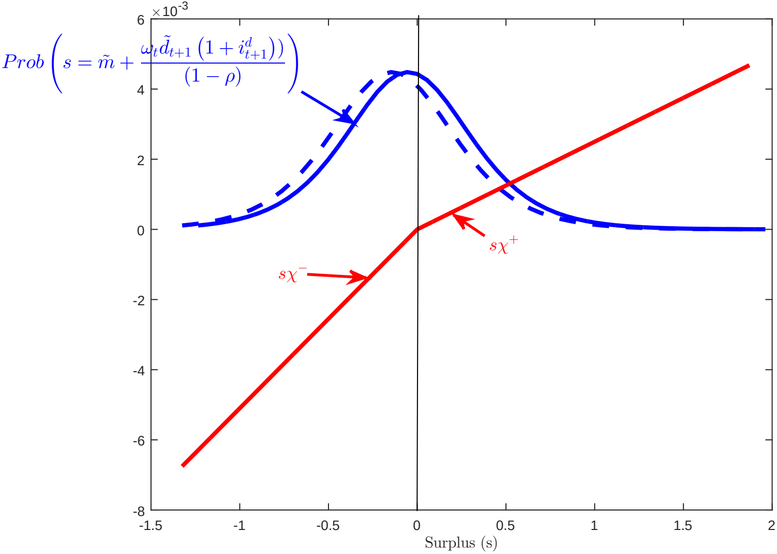
Liquidity Risk: Distribution of s



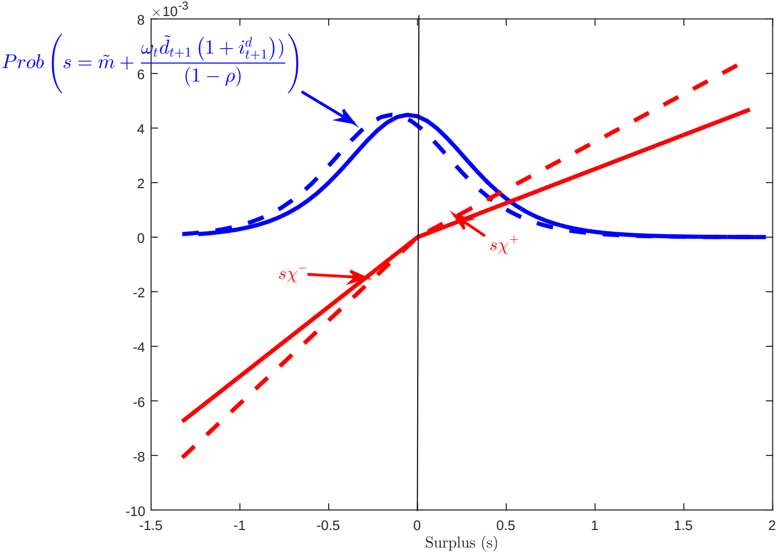
Liquidity Risk: Kink in Returns



Liquidity Risk: Lower m

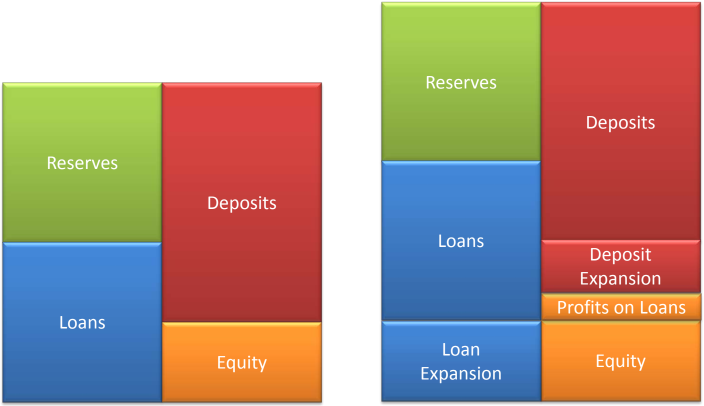


Liquidity Risk: Lower m and GE effects

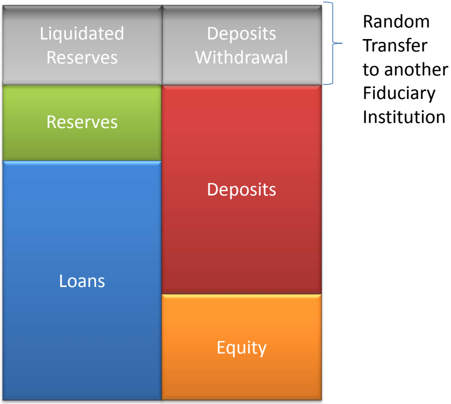


Balance Sheet

Expansion of Lending via deposit creation



Deposits leave the bank: small ω



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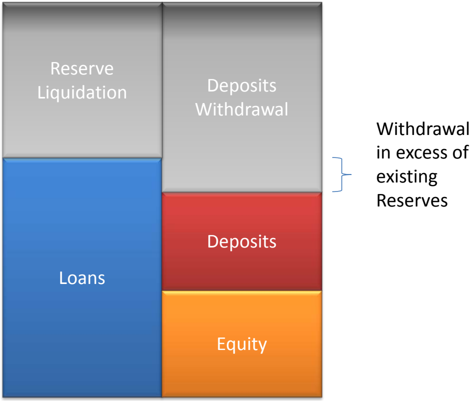

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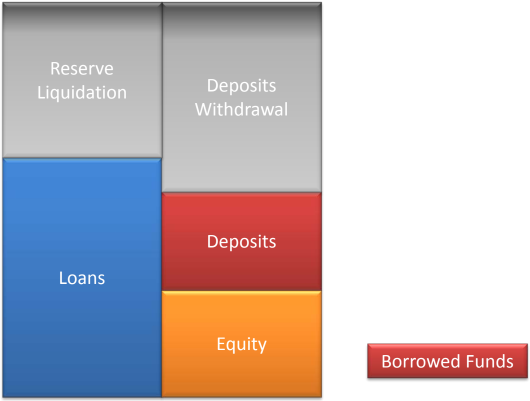
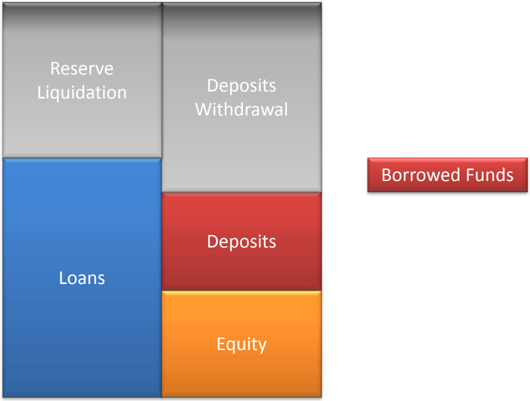
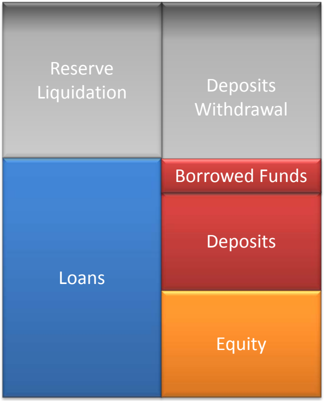


Deposits leave the bank: large ω



Deposits leave the bank: large ω



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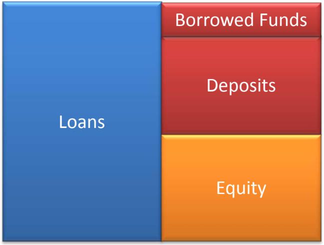

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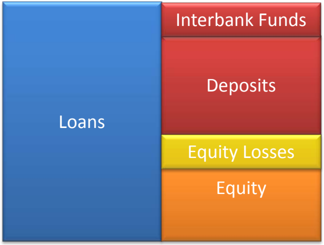

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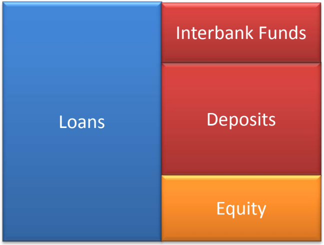
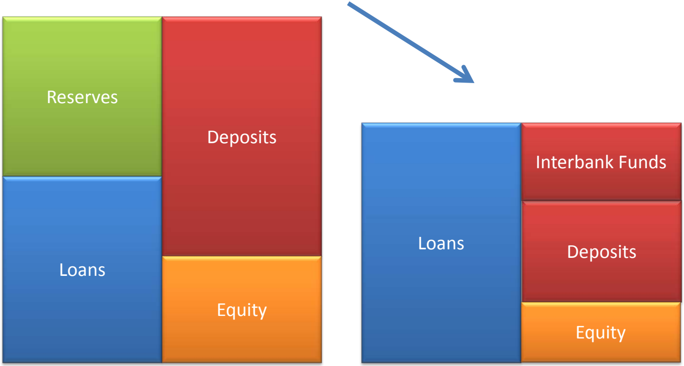


Withdrawal Risk



Value Function - Lending Stage

$$V_t^l\left(b,m,d,f,w\right)=\max_{\left\{c,\tilde{b},\tilde{d},\tilde{m}\right\}\geq 0} u\left(c\right)+\mathbb{E}\left[V_t^b(\tilde{b},\tilde{m},\tilde{d},\omega)\right]$$

$$\begin{aligned}
&P_t c+\ \tilde{b}+\tilde{m}-\tilde{d}\\
&=b(1+i_t^b)-d(1+i_t^d)+m(1+i_t^{IOR})-(1+\bar{\imath}_t^f)f\ -\left(1+i_t^{dw}\right)w\ -P_tT_t
\end{aligned} \qquad \text{(Budget Constraint)}$$

$$\tilde{d}\leq\kappa\left(\tilde{b}+\tilde{m}-\ \tilde{d}\right). \qquad \text{(Capital Requirement)}$$

Value Function - Balancing Stage

$$
\begin{aligned}
V_t^b(\tilde{b}, \tilde{m}, \tilde{d}, \omega) &= \beta V_t^l(b', \tilde{m}', d', f, w) \\
b' &= \tilde{b} && \text{(Evolution of Loans)} \\
d' &= \tilde{d} + \omega \tilde{d} && \text{(Evolution of Deposits)} \\
m' &= \tilde{m} - \omega \tilde{d} \left(\frac{1 + i_{t+1}^{d}}{1 + i_{t+1}^{ior}} \right) + f + w \\
& && \text{(Evolution of Reserves)} \\
s &= \ \tilde{m} + \frac{\omega_t \tilde{d}_{t+1} \left(1 + i_{t+1}^{d}\right)}{1 + i_{t+1}^{IOR}} - \rho \tilde{d}_{t+1} \left(1 + \omega\right) \\
& && \text{(Reserve Balance)} \\
m' &\geq \rho d' && \text{(Reserve Requirement)} \\
f &= \Psi_t^- s \text{ and } w_{t+1} = \left(1 - \Psi_t^-\right) s \text{ for } s < 0 && (1) \\
f &= \Psi_t^+ s \text{ and } w_{t+1} = 0 \text{ for } s > 0.
\end{aligned}
$$

One Value Function and a Single State

$$V_t(e) = \max_{\{c,\tilde{m},\tilde{b},\tilde{d}\}\geq 0} u(c) + \beta \mathbb{E}_t \left[V_{t+1}(e')\right],$$

$$e = \frac{\tilde{b} + \tilde{m} - \tilde{d}}{P_t} + c, \qquad \text{(Budget Constraint)}$$

$$e' = \left((1 + i^{ior}_{t+1})\tilde{m} + \left(1 + i^{b}_{t+1}\right)\tilde{b} - \left(1 + i^{d}_{t+1}\right)\tilde{d} + \chi_{t+1}(s)\right)\frac{(1 - \tau_{t+1})}{P_{t+1}}, \qquad \text{(Evolution of Equity)}$$

$$s = \tilde{m} + \frac{\omega_t \tilde{d}' \left(1 + i^{d}_{t+1}\right)}{1 + i^{IOR}_{t+1}} - \rho \tilde{d}' (1 + \omega) \qquad \text{(Reserve Balance)}$$

$$\tilde{d} \leq \kappa \left(\tilde{b} + \tilde{m} - \tilde{d}\right). \qquad \text{(Capital Requirement)}$$

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$$\tilde{d} \leq \kappa\left(\tilde{b}+\tilde{m}-\tilde{d}\right). \quad \text{(Capital Requirement)}$$

$$\begin{aligned}
\chi_t(s) &= \begin{cases} \chi_t^{+} s & if\ s \geq 0 \\ \chi_t^{-} s & if\ s < 0 \end{cases}, \\
\chi_t^{-} &= \Psi_t^{-}\left(\bar{\imath}_t^{f} - i_t^{ior}\right) + \left(1-\Psi_t^{-}\right)\left(i_t^{dw} - i_t^{ior}\right) \\
\chi_t^{+} &= \Psi_t^{+}\left(\bar{\imath}_t^{f} - i^{ior}\right).
\end{aligned}$$

Central Bank Policies: The Fed

- Sets quantity of reserves M_t^{Fed}, loan purchases B_{t+1}^{FED} and corridor rates i^{dw}, i^{ior}
- Taxes/transfers to balance budget

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- Taxes/transfers to balance budget
- Fed budget constraint:

$$M_t^{Fed}(1+i_t^{ior}) + B_{t+1}^{Fed} + W_{t+1}^{Fed} = M_{t+1}^{Fed} + B_t^{Fed}(1+i_t^b) + W_t^{Fed}(1+i_t^{dw}) + P_t T_t.$$

- Stationary equilibrium: constant nominal balance sheet

Closing the Model

- Loan Market Clears

$$\frac{B^d_{t+1}}{P_t} = \Theta^b_t \left(\frac{1+i^b_{t+1}}{1+\pi_{t+1}}\right)^{\epsilon}, \epsilon < 0, \Theta^b_t > 0,$$

- Deposit Market Clears

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- Microfoundation in the paper:
  - Loan demand with WK constraint
  - Deposit supply: household problem
  - Frictions translate into labor wedge

Market Clearing

$$\int_j b_{t+1}^j + B_{t+1}^{Fed} = B_{t+1}^d \qquad \text{(Loans markets clearing)}$$

$$\int_j d_t^j = D_{t+1}^S \qquad \text{(Deposits market clearing)}$$

$$\int_j m_{t+1}^j = M_{t+1}^{Fed} \qquad \text{(Reserves market clearing)}$$

$$\int_j f_t^j = 0 \qquad \text{(Interbank markets clearing)}$$

$$\int_j w_t^j = W_{t+1}^{Fed} \qquad \text{(Discount window market clearing)}$$

Characterization

One Value Function and a Single State

$$e_t \equiv \frac{b_t(1+i_t^b) + m_t(1+i_t^{ior}) - d_t\ (1+i_t^d) - \left(1+\bar{i}_t^f\right) f_t - \left(1+i_t^{dw}\right) w_t - T_t}{P_t}.$$

One Value Function and a Single State

$$V_t(e) = \max_{\left\{c,\tilde{m},\tilde{b},\tilde{d}\right\}\geq 0} u(c) + \beta\mathbb{E}_t\left[V_{t+1}(e')\right],$$

$$e = \frac{\tilde{b}+\tilde{m}-\tilde{d}}{P_t} + c, \qquad \text{(Budget Constraint)}$$

$$e' = \left((1+i^{ior}_{t+1})\tilde{m} + \left(1+i^{b}_{t+1}\right)\tilde{b} - \left(1+i^{d}_{t+1}\right)\tilde{d} + \chi_{t+1}\left(s\right)\right)\frac{(1-\tau_{t+1})}{P_{t+1}}, \qquad \text{(Evolution of Equity)}$$

$$s = \tilde{m} + \frac{\omega_t\tilde{d}'\left(1+i^{d}_{t+1}\right)}{1+i^{IOR}_{t+1}} - \rho\tilde{d}'\left(1+\omega\right) \qquad \text{(Reserve Balance)}$$

$$\tilde{d} \leq \kappa\left(\tilde{b}+\tilde{m}-\tilde{d}\right). \qquad \text{(Capital Requirement)}$$

Homogeneity and Portfolio Separation

(i) The value function V satisfies

$$V_t(e) = v_t e^{1-\gamma},$$

(ii) Certainty-equivalent of banks's equity return

$$\Omega_t \equiv \max_{\{\bar{b},\bar{m},\bar{d}\}\geq 0} \left\{ \mathbb{E}_\omega \left[R_t^b \bar{b} + \ R_t^m \bar{m} - \ \ R_t^d \bar{d} + \chi(\bar{m}, \bar{d}, \omega) \right]^{1-\gamma} \right\}^{\frac{1}{1-\gamma}},$$

$$\bar{b} + \bar{m} - \bar{d} = 1,$$

$$\bar{d} \leq \kappa \left(\bar{b} + \bar{m} - \bar{d} \right).$$

(iii) Consumption-equity ratio $\bar{c}_t$, and v_t are given by

$$\bar{c}_t \ = \frac{1}{1 + [\beta(1-\gamma) v_{t+1} \Omega_t{}^{1-\gamma}]^{1/\gamma}}.$$

$$v_t = \frac{1}{1-\gamma} \left[1 + \left(\beta(1-\gamma) \Omega_t^{1-\gamma} v_{t+1} \right)^{\frac{1}{\gamma}} \right]^\gamma.$$

(iv) Policy functions are linear in equity

$$\tilde{b}_{t+1}(e_t) = P_t \bar{b}_t (1 - \bar{c}_t) e_t,$$

$$\tilde{d}_{t+1}(e_t) = P_t \bar{d}_t \ (1 - \bar{c}_t) e_t.$$

$$\tilde{m}_{t+1}(e_t) = P_t \bar{m}_t (1 - \bar{c}_t) e_t,$$

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$$\tilde{m}_{t+1}(e_t) = P_t \bar{m}_t (1 - \bar{c}_t) e_t, \qquad \Rightarrow \text{Quantity Theory Eq.} \int_j P_t \bar{m}_t (1 - \bar{c}_t \;) e_t = M_{t+1}^{Fed}$$

Liquidity Premium

$$\underbrace{R^b - R^m}_{\text{Liquidity Premium}} \quad = \quad \underbrace{\mathbb{E}_\omega \left[\frac{\partial \chi \left(\bar{d}, \bar{m}, \omega \right)}{\partial \bar{m}} \right]}_{\text{Interbank market return}} + \underbrace{\mathbb{E}_\omega \frac{\mathbb{COV}_\omega \left[\left(R^e \right)^{-\gamma}, \frac{\partial \chi \left(\bar{d}, \bar{m}, \omega \right)}{\partial \bar{m}} \right]}{\mathbb{E}_\omega \left[\left(R^e \right)^{-\gamma} \right]}}_{\text{Liquidity risk premium}} .$$

Liquidity Premium

$$\underbrace{R^b - R^m}_{\text{Liquidity Premium}} = \underbrace{\mathbb{E}_\omega \left[\frac{\partial \chi\left(\bar{d}, \bar{m}, \omega\right)}{\partial \bar{m}} \right]}_{\text{Interbank market return}} + \underbrace{\mathbb{E}_\omega \frac{\mathbb{COV}_\omega \left[\left(R^e\right)^{-\gamma}, \frac{\partial \chi\left(\bar{d}, \bar{m}, \omega\right)}{\partial \bar{m}} \right]}{\mathbb{E}_\omega \left[\left(R^e\right)^{-\gamma} \right]}}_{\text{Liquidity risk premium}}.$$

- Role of Search Frictions: Walrasian limit (no kink) $\frac{\partial \chi\left(\bar{d}, \bar{m}, \omega\right)}{\partial \bar{m}}$ constant

Liquidity Premium

$$\underbrace{R^b - R^m}_{\text{Liquidity Premium}} = \underbrace{\mathbb{E}_{\omega}\left[\frac{\partial \chi\left(\bar{d}, \bar{m}, \omega\right)}{\partial \bar{m}}\right]}_{\text{Interbank market return}} .$$

- Role of Search Frictions: Walrasian limit (no kink) $\frac{\partial \chi\left(\bar{d}, \bar{m}, \omega\right)}{\partial \bar{m}}$ constant
  - No effects from ω vol
  - Only aggregate scarcity matters
  - More unstable $\bar{i}^f$

Satiation Case

- Satiation: Loans and reserves perfect substitutes if

  (i) The Fed pays interest on reserves such that $i_t^{ior} = i_t^b$

  (ii) The Fed pays interest on reserves such that $i_t^{ior} = i_t^D$, and $\kappa = \infty$

  (iii) The Fed eliminates corridor $i_t^{dw} = i_t^{ior}$

Limits of Monetary Policy

- Long-run neutrality
- Fisher-equation
- Spread minimum

Model Application

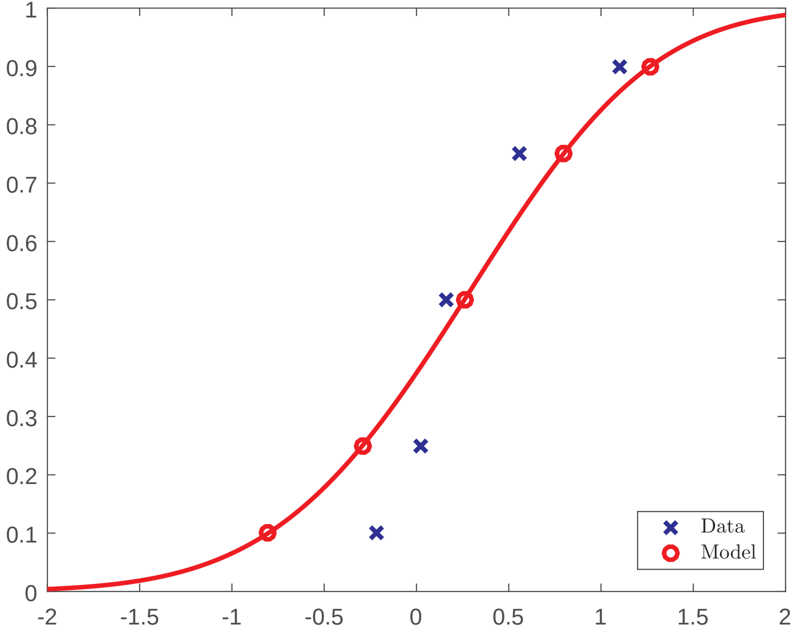
Model Application

- What caused contraction in lending and liquidity hoarding?
- Five Hypothesis
  1. Equity Losses
  2. Capital Requirements
  3. Precautionary Holdings
     - Shock to efficiency parameter λ
     - Higher volatility ω
  4. Weak Loan Demand
     - Shock to Θ_b
  5. Central Bank Policy
     - Interest on reserves i^{ior}
     - OMA (swap of agency securities/loans for reserves)
- Approach:
  - Calibrate steady state to pre-crisis
  - Compute impulse responses to different shocks
  - In the paper
    - Feed shocks $\lambda_t, F_\omega, \Theta_b$ to match evolution of (i) Volume interbank market, (ii) DW, (iii) Loans

Calibration Strategy for Stationary Equilibrium

- Steady state: 2006
- Variables set independently:
    - Regulatory parameters κ, ρ
    - Elasticities ϵ, ζ
    - Policy rates and inflation: i^{IOR}, i^{DW}
    - Risk aversion equal one
- Variables set to match targets:
    - η to match mean excess rserves
    - β to match dividend rate
    - Efficiency parameter λ to match DW loans
    - Volatility ω to minimize distance between model and empirical distribution of excess reserves

Distribution of Excess Reserves



US Financial Crisis

(a) Liquidity Ratio

(b) Log Loans

(c) Liquidity Premium

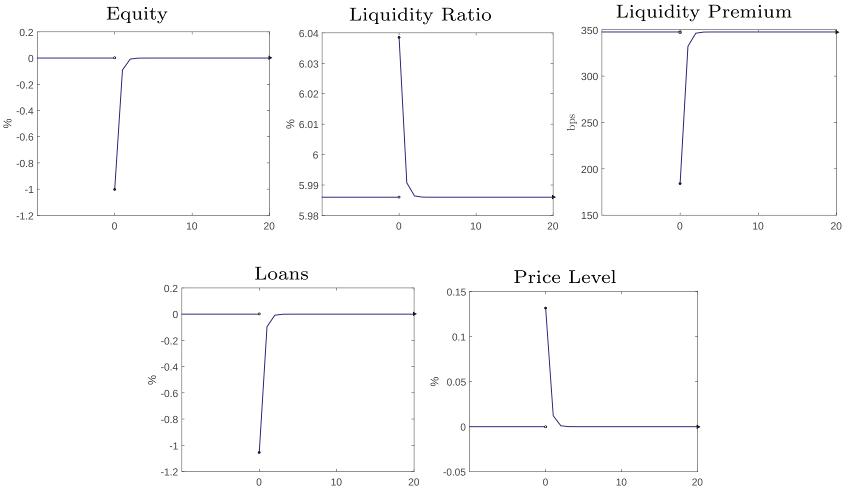
(d) DW Loans

(e) Loan Officers Tightening

(f) Interest on Reserves

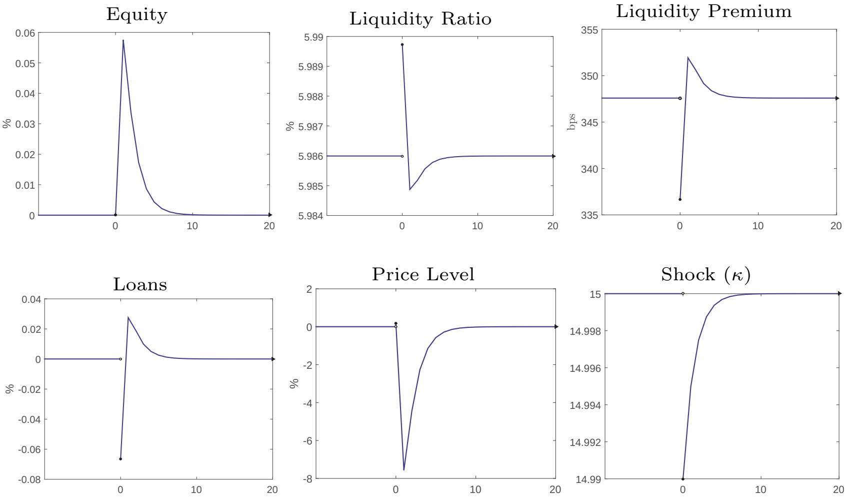
(g) Deposits

Equity Loss

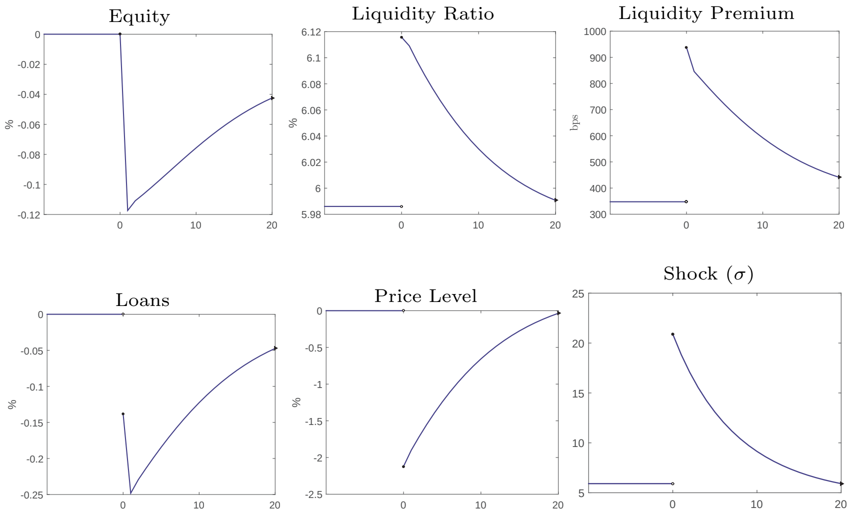


Equity
Liquidity Ratio
Liquidity Premium
Loans
Price Level
%
bps
0
10
20
0.2
-0.2
-0.4
-0.6
-0.8
-1
-1.2
6.04
6.03
6.02
6.01
6
5.99
5.98
350
300
250
200
150
0.15
0.1
0.05
-0.05

Capital Requirements

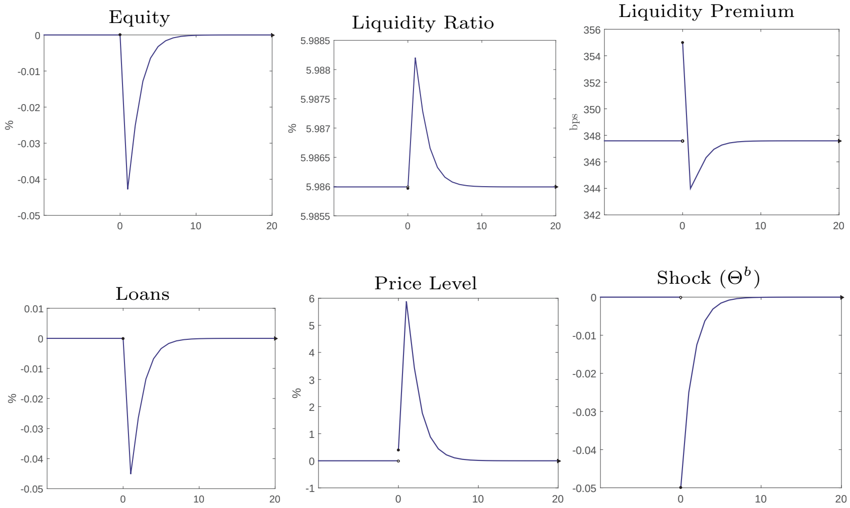


Volatility



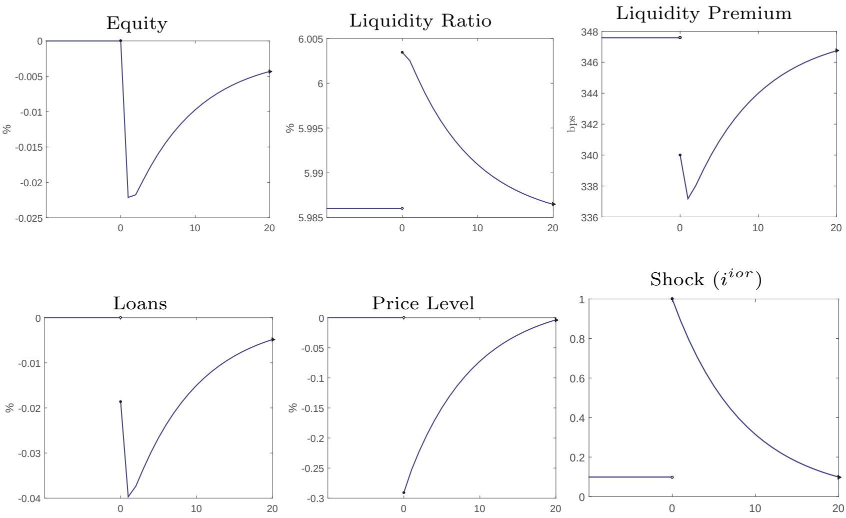
Equity
%
Liquidity Ratio
%
Liquidity Premium
bps
Loans
%
Price Level
%
Shock (σ)

Loan Demand

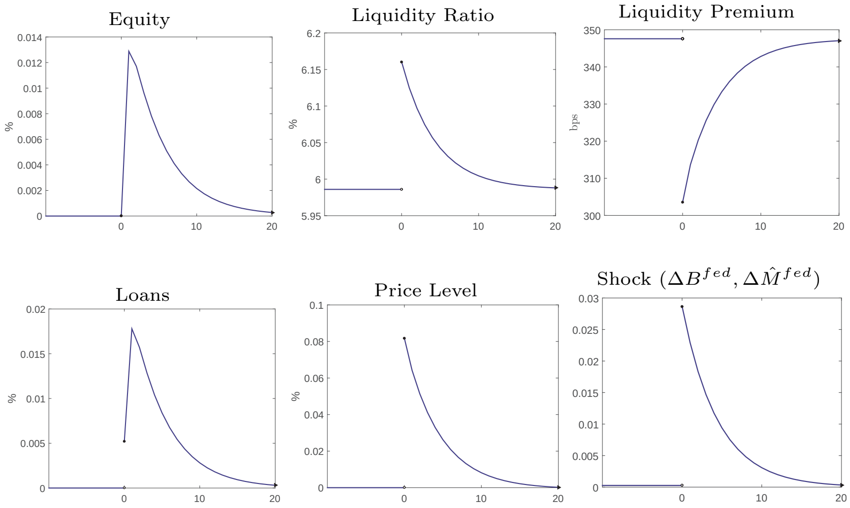


Equity
Liquidity Ratio
Liquidity Premium
Loans
Price Level
Shock (Θ^b)
%
bps

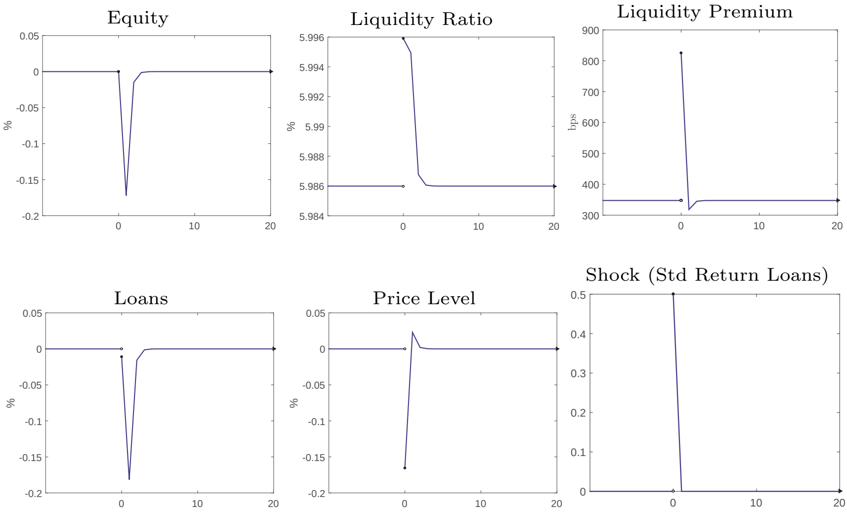
Interest on Reserves



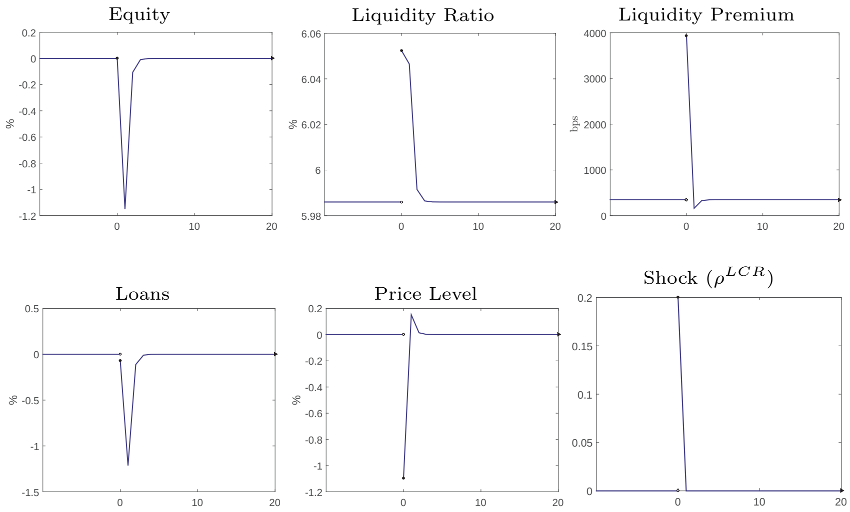
CB's Loan Purchases



Default Risk



Liquidity Coverage Ratio



Conclusions

- Dynamic macroeconomic model of banks liquidity management
- Transmission of monetary policy through banking system
- Application to financial crisis
  - Precautionary motive played important early role
  - Persistence of drop in credit points to demand shocks
- Research ahead/applications:
  - Floor vs. corridor system
  - Interaction between liquidity and capital regulation
  - Size and composition of Fed's balance sheet
  - Fire sales, LCR, macroprudential policy