Banks, Liquidity Management and Monetary Policy

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This Paper

★ A micro-founded dynamic quantitative model of banks' liquidity management and monetary policy

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

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- ★ Credit channel of monetary policy

Model Overview

1. Bank individual decision problem:
   - Loan issuances, liquid assets, deposit creation, retain earnings
   - Subject to capital requirements, liquidity requirements
   - ★ Demand for excess reserves

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★ Tractability

Application

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- Five Hypothesis

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  5. Interest on Excess Reserves (Feldstein, Hall)

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)
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- Continuum of banks with idiosyncratic liquidity shocks
- **Utility function:** Concave utility U over dividends c_t, $u(c) = \frac{c^{1-\sigma}}{1-\sigma}$

Banks' Balance Sheet

- Liabilities:
  - d_t demand deposits
- Assets:
  - m_t liquid assets (central bank reserves, T-bills)
  - b_t loans
- Interbank market loans f_t and discount-window loans w_t
- All assets/liabilities denominated in nominal terms

Banks' Problem (Lending Stage)

- Budget constraint

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

- P_t price of goods in terms of reserves

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- P_t price of goods in terms of reserves
- Capital requirement constraint

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

Banks' Problem (Balancing Stage)

- Idiosyncratic withdrawal shock $\omega \in (-1, \infty], \omega \sim F_t(\omega), \quad \mathbb{E}(\omega) = 0$
- Borrow in interbank market f to satisfy res. req. (or $m_{t+1} \geq 0$)

$$
\begin{aligned}
d^j_{t+1} &= \tilde{d}^j_{t+1} + \omega_t \tilde{d}^j_{t+1} \\
m^j_{t+1} &= \tilde{m}^j_{t+1} + \omega^j_t \tilde{d}^j_{t+1} \left(\frac{1 + i^d_{t+1}}{1 + i^{ior}_{t+1}} \right) + f^j_{t+1} + w^j_{t+1}, \\
m^j_{t+1} &\geq \rho d^j_{t+1}
\end{aligned}
$$

$$
s^j \equiv \underbrace{\tilde{m}^j_{t+1} - \omega \tilde{d}^j_{t+1}}_{\text{Reserves left}} - \underbrace{\rho \tilde{d}^j_{t+1}(1 - \omega)}_{\text{Deposits left}}
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Interbank Market

- "Dollar to dollar" matching (OTC markets of Atkeson et al. 2014)
- N rounds of matching
- Matching function for dollars in surplus (S^+) and deficit (S^-)
- Terminal outside options are discount window rates and interest on reserves
- Nash Bargaining
- See paper for analytical results for Fed funds rate and matching probabilities

Liquidity Cost Function χ_t

- Wedge in return to excess reserves and reserves deficits:
- Marginal Benefit of excess reserves:

$$\chi_t^+ = \gamma^+ \bar{\imath}_t^f + (1-\gamma^+) i^{ior}$$

- Marginal cost of reserve deficits:

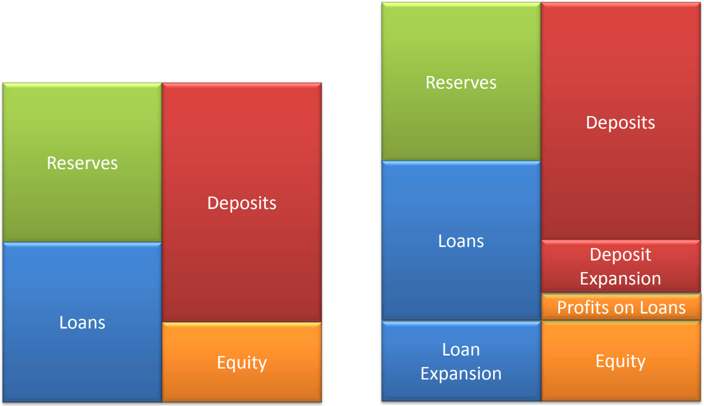
$$\chi_t^- = \gamma^- \bar{\imath}_t^f + \left(1-\gamma^-\right) i_t^{dw}.$$

- Liquidity Cost Function:

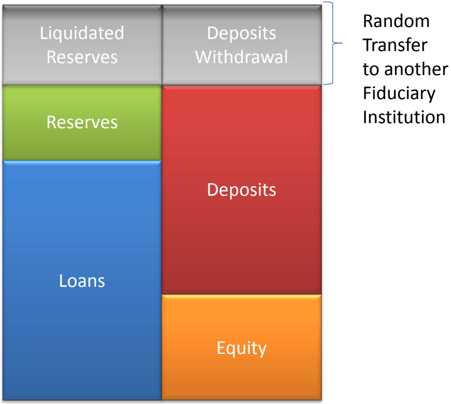
$$\chi(s) = \begin{cases} \chi_t^+ s \text{ if } \ s > 0 \\ \chi_t^- s \quad \text{if } \ s \leq 0 \end{cases}$$

Balance Sheet

Expansion of Lending



Withdrawal Risk



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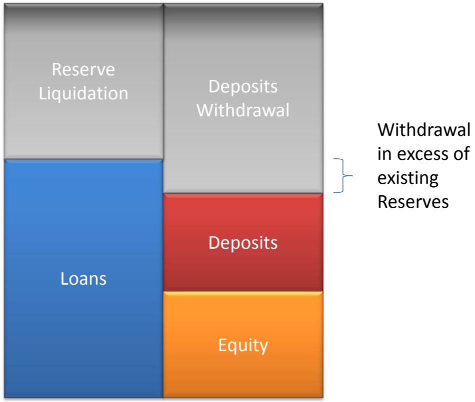

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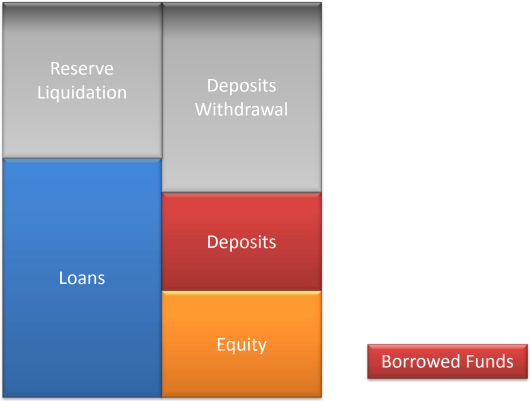

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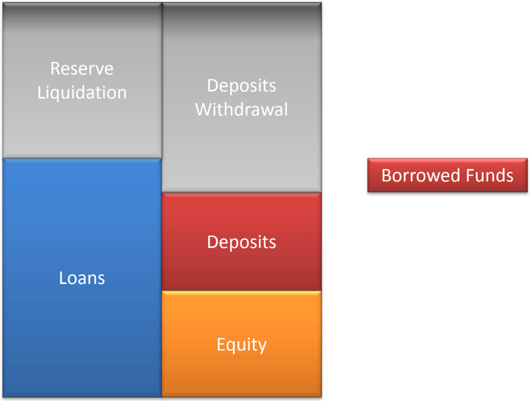

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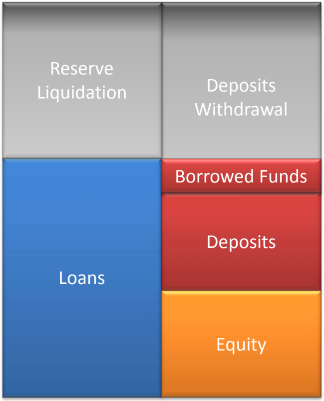

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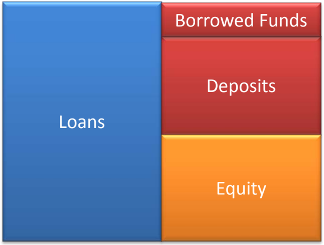

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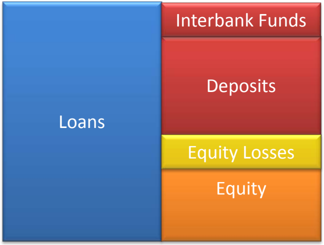

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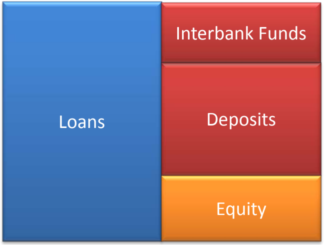

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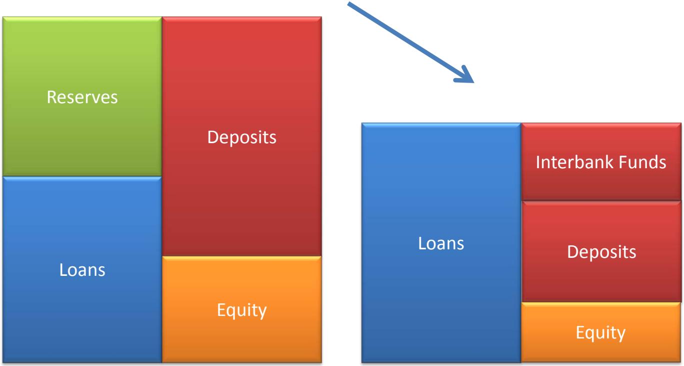

Value Function - Lending Stage

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

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

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

Value Function - Balancing Stage

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

$$
\begin{aligned}
& f = \psi_t^- s \text{ and } w_{t+1} = \left(1-\psi_t^-\right) s \text{ for } s < 0 \\
& f = \psi_t^+ s \text{ and } w_{t+1} = 0 \text{ for } s > 0.
\end{aligned} \tag{2}
$$

One Value Function

Define

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

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

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

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

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

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

Closing the Model

- Loan Market Clears

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

- Deposit Market Clears (today perfectly elastic supply)

$$\frac{D^S_{t+1}}{P_t} = \Theta^d_t \left(\frac{1}{(1+i^d_{t+1})} \frac{P_t}{P_{t+1}} \right)^{\zeta}, \varsigma > 0, \Theta^d_t > 0,$$

Central Bank Policies: The Fed

- Sets quantity of reserves M_t^{Fed}
- Buys loans B_{t+1}^{FED}, place deposits D_{t+1}^{FED}
- Discount window and interest on reserve rates i^{dw}, i^{ior}
- Fed budget constraint:

$$
\begin{aligned}
& M_t^{Fed}(1+i_t^{ior}) + D_{t+1}^{Fed} + \; B_{t+1}^{Fed} + W_{t+1}^{Fed} ... \\
= \quad & M_{t+1}^{Fed} + D_t^{Fed}(1+i_t^d) + B_t^{Fed}(1+i_t^b) + W_t^{Fed}(1+i_t^{dw}) + P_t T_t.
\end{aligned}
$$

- Stationary equilibrium: constant nominal growth of balance sheet
- Impulse responses: focus on fixed nominal balance sheet or keep constant inflation (today)

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\end{aligned}
$$

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Market Clearing

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

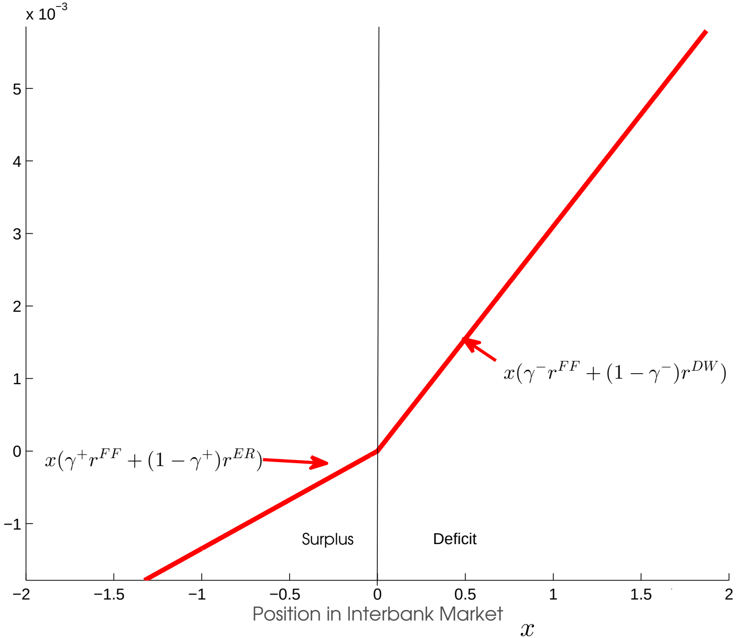
$$\int_j d_t^j - D_{t+1}^{Fed} = D_{t+1}^S \qquad \text{(Deposits market clearing)}$$

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

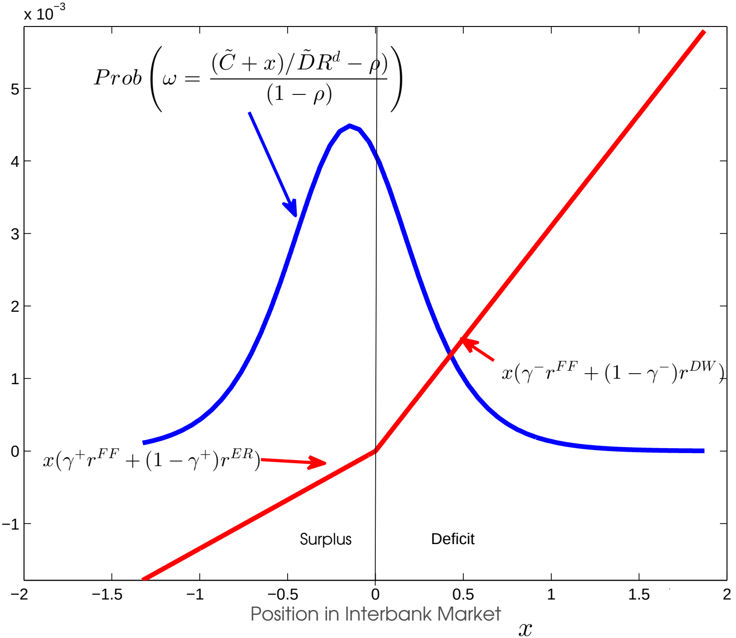
$$\int_j f_t^j = 0 \qquad \text{(Interbank markets clearing)}$$

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

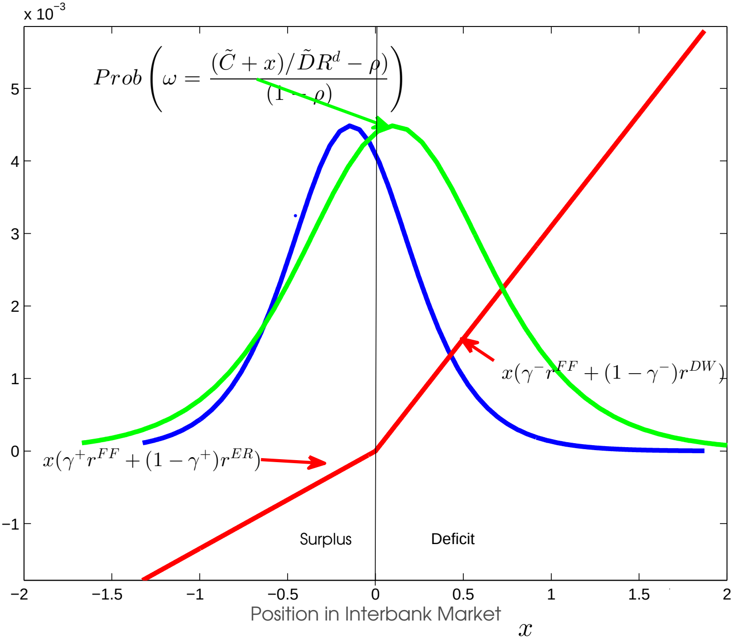
Liquidity Cost



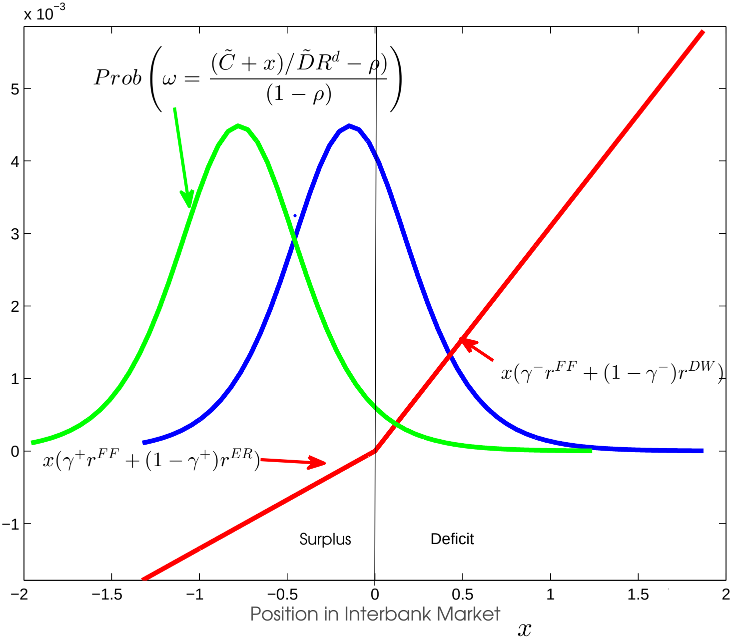
Liquidity Management



↑ Deposits


x 10^-3
5
4
3
2
1
0
−1
$Prob\left(\omega = \frac{(\tilde{C}+x)/\tilde{D}R^d - \rho)}{(1-\rho)}\right)$
$x(\gamma^- r^{FF} + (1-\gamma^-) r^{DW})$
$x(\gamma^+ r^{FF} + (1-\gamma^+) r^{ER})$
Surplus
Deficit
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
Position in Interbank Market
x

↑ Reserves



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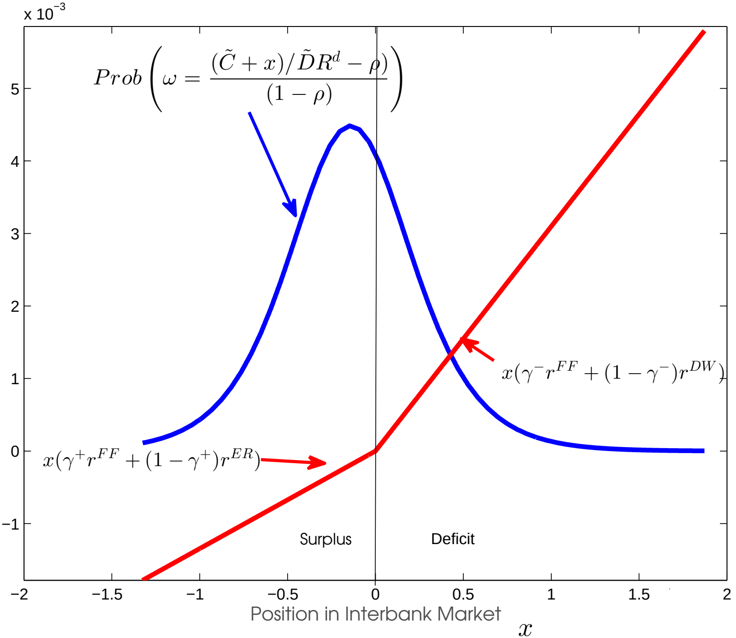
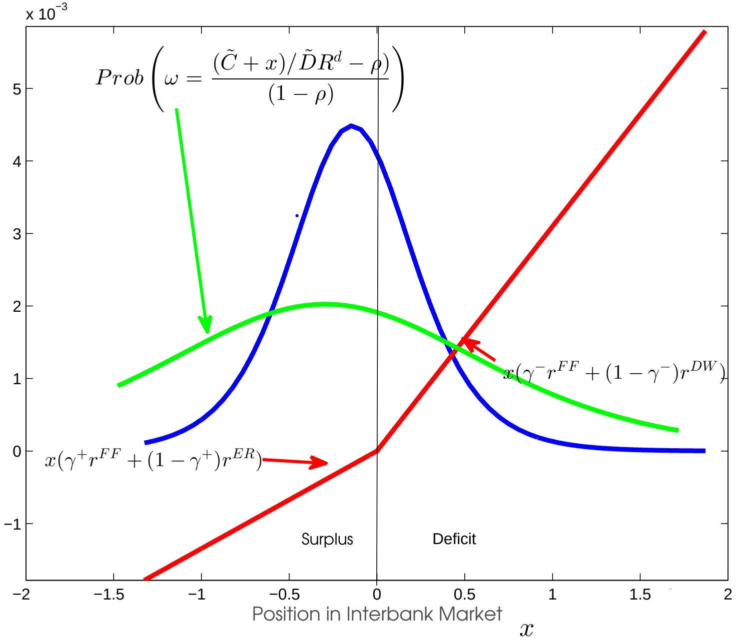
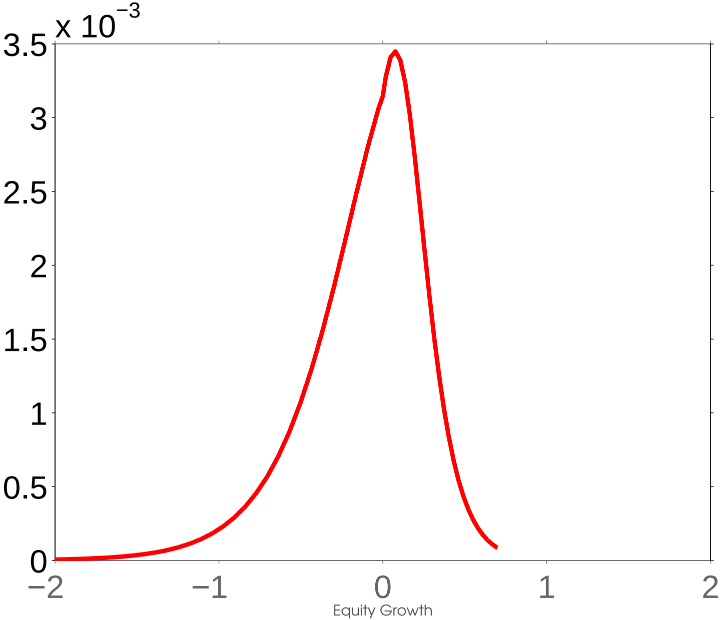
Liquidity Management



↑ Withdrawal Risk



Equity Growth



Proposition (Homogeneity and Portfolio Separation)

(i) The value function $V_t(b, m, d)$ satisfies

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

(ii) where $v\,(\cdot)$ satisfies

$$\begin{aligned}
&\Omega_t \equiv \max_{\{\bar{b},\bar{m},\bar{d}\}\geq 0} \left\{\mathbb{E}_\omega\left[R_t^b\bar{b} + \ R_t^m\bar{m} - \quad R_t^d\bar{d} + \chi(\bar{m},\bar{d},\omega)\right]^{1-\gamma}\right\}^{\frac{1}{1-\gamma}}\,, \\
&\bar{b} + \bar{m} - \bar{d} = 1, \\
&\bar{d} \leq \kappa\left(\bar{b} + \bar{m} - \bar{d}\right).
\end{aligned}$$

(iii)

$$\begin{aligned}
\tilde{b}'_{t+1}(e_t) &= P_t\bar{b}_t(1-\bar{c}\ )e_t, \\
\tilde{m}_{t+1}(e_t) &= P_t\bar{m}_t(1-\bar{c}\ )e_t, \\
\tilde{d}_{t+1}(e_t) &= P_t\bar{d}_t\ (1-\bar{c})e_t.
\end{aligned}$$

(iv) $\bar{c}_t, v_t$ are given by

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

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

Liquidity Premium

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

$$\underbrace{R^b - R^d}_{\text{External finance premium}} = \underbrace{\frac{\mathbb{E}_\omega \left[\left(R^e_\omega\right)^{-\gamma} \cdot \frac{\partial \chi\left(\bar{d}, \bar{m}, \omega\right)}{\partial \bar{d}} \right]}{\mathbb{E}_\omega \left[\left(R^e\right)^{-\gamma} \right]}}_{\text{Deposit Liquidity Cost}} + \underbrace{\frac{\mu}{\mathbb{E}_\omega \left[\left(R^e_\omega\right)^{-\gamma} \right]}}_{\text{Collateral term}}$$

Liquidity Premium

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

$$\underbrace{R^b - R^d}_{\text{External finance premium}} = \underbrace{\frac{\mathbb{E}_\omega\left[\left(R^e_\omega\right)^{-\gamma}\cdot\frac{\partial\chi\left(\bar{d},\bar{m},\omega\right)}{\partial\bar{d}}\right]}{\mathbb{E}_\omega\left[\left(R^e\right)^{-\gamma}\right]}}_{\text{Deposit Liquidity Cost}} + \underbrace{\frac{\mu}{\mathbb{E}_\omega\left[\left(R^e_\omega\right)^{-\gamma}\right]}}_{\text{Collateral term}}$$

Banks are satiated with reserves 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 sets the discount window rate to $i_t^{dw} = 0$

Quantitative Exercise

Calibration Strategy

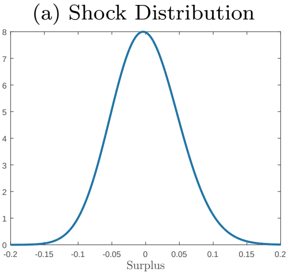
- F_t approximated with a logistic distribution
  - Cross-sectional distribution of deposits growth rates (Call Reports)

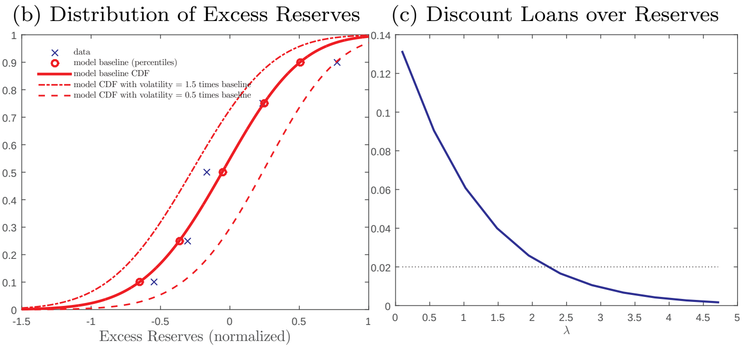
    ▸ distribution

- Loan-demand elasticity $= 1.8$
  - Bassett, Chosak, Driscoll, and Zakrajsek (2013)

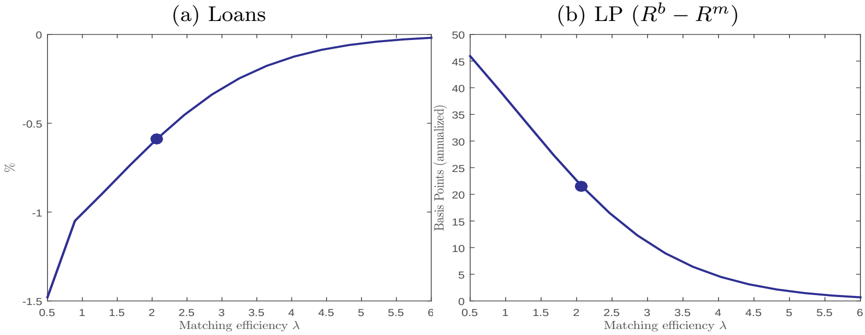
Calibration

	Value	Source/Target
Capital requirement	$\kappa = 10$	Regulatory parameter
Discount factor	$\beta = 0.993$	Dividend ratio = 8 %
Risk aversion	$\gamma = 1$	Constant dividend-equity ratio
Reserve requirement	$\rho = 0.1$	Regulatory parameter
Deposit supply intercept	$\Theta^d = 9.6$	Annual deposit rate = 1%
Loan demand intercept	$\Theta^b = 10.4$	Unit steady state equity
Discount window rate (annual)	$i^{dw} = 6\%$	2006 value
Interest on reserves (annual)	$i^{ior} = 0\%$	2006 value
Bargaining parameter	$\eta = 0.5$	Baseline value
Inflation	$g = 2\%$	Long-run inflation target
Matching friction	$\lambda = 2.1$	DW loans to reserves $W/M = 2$
Volatility	$\sigma = 0.04$	Reserve-balance distribution
Elasticities	$\zeta = -\epsilon = 25$	Bank credit response to policy rate

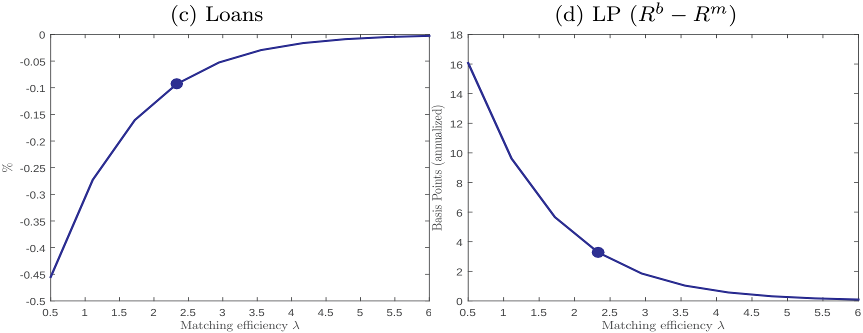

(a) Shock Distribution
8
7
6
5
4
3
2
1
0
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Surplus


(b) Distribution of Excess Reserves
data
model baseline (percentiles)
model baseline CDF
model CDF with volatility = 1.5 times baseline
model CDF with volatility = 0.5 times baseline
Excess Reserves (normalized)
(c) Discount Loans over Reserves
λ

Effects of DW shock (1% increase in i^f)



Effects of Vol shock (3 times increase)



Quantitative Application

- Why are banks not lending when holding so many reserves?

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- Five Hypotheses:
  1. Equity Losses
  2. Tighter Capital Requirements
  3. Precautionary Motive (Interbank Market Shutdown)
  4. Weaker Loan Demand
  5. Interest on Reserves

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- *Approach*
  - First: Transitional Dynamics after individual shocks
  - Second: Fit calibrated sequences of shocks

Identification

(a) Interbank Market Shocks

(b) Volatility and Loan Demand

(c) Matching and Loan Demand

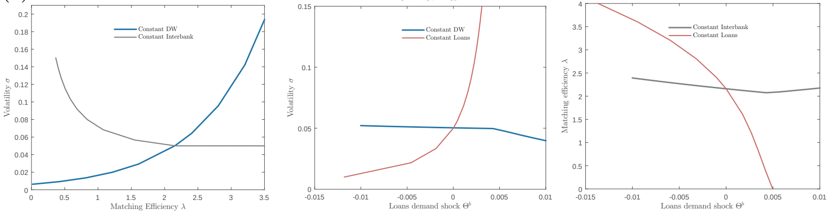


Figure: Identification for Quantitative Application

(f) Credit Shocks

(e) Volatility Shocks

(f) Matching Shocks

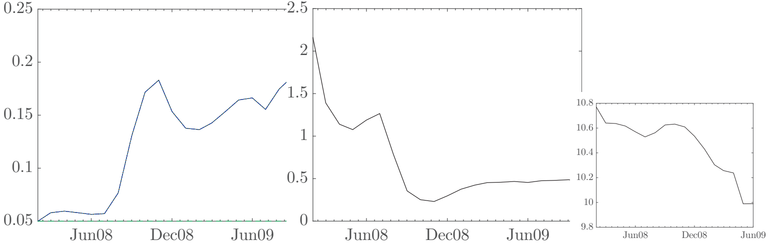
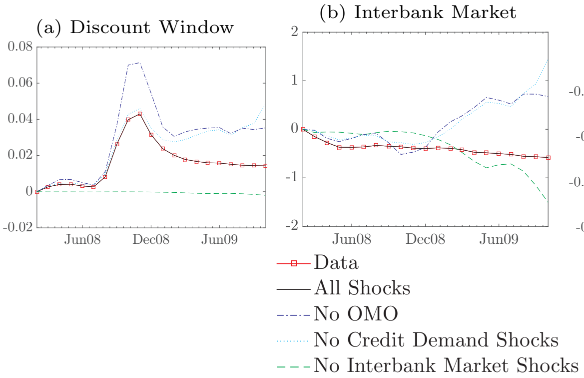
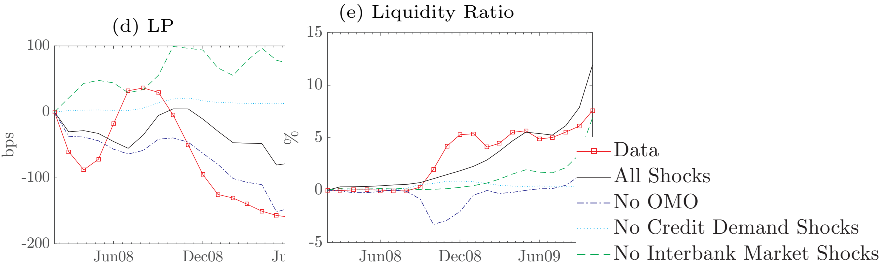


Figure: All Experiments


(a) Discount Window
0.08
0.06
0.04
0.02
0
-0.02
Jun08
Dec08
Jun09
(b) Interbank Market
2
1
0
-1
-2
Jun08
Dec08
Jun09
(c) Credit Data
0
-0.05
-0.1
-0.15
-0.2
Jun08
Dec08
Jun09
Data
All Shocks
No OMO
No Credit Demand Shocks
No Interbank Market Shocks



(d) LP
100
0
-100
-200
bps
Jun08
Dec08
(e) Liquidity Ratio
15
10
5
0
-5
%
Jun08
Dec08
Jun09
Data
All Shocks
No OMO
No Credit Demand Shocks
No Interbank Market Shocks