Money and Banking in a New Keynesian Model

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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
  - disconnect between policy rate & short rate

- **Central bank chooses reserve supply**
  - scarce reserves (‘corridor system’): policy targets fed funds rate, fixes reserve rate, adjusts reserves to implement target
  - abundant reserves (‘floor system’): policy targets reserve rate
Banking with scarce reserves ("corridor system")

- higher policy rate $i^F$ is tax on banks’ liquidity
Banking with abundant reserves ("floor system")

- Higher policy rate $i^M$ does not change banks' cost of liquidity.
Implications

- **Standard NK model**
  - interest rate is all that matters, plumbing & quantities not important

- **NK model with banks**
  - disconnect between policy rate & short rate
    - affects transmission of policy
    - plumbing and quantities matter
  - stronger pass-through from policy rate to short rate in corridor system
    - corridor system: tighter policy is tax on liquidity
  - nominal assets held by banks important for output & inflation
  - less scope for multiple equilibria, even without Taylor principle

- **Plan for talk:**
  - Transmission in minimal model with disconnect (no banks)
  - Introduce banks
Minimal model with short rate disconnect (no banks)

- **Representative household**
  - utility separable in labor + CES bundle of consumption & money
  - $\sigma = \text{IES for bundles}, \eta = \text{interest elasticity of money demand}$
  - 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 $i_t^D = \text{interest rate on money}$
  - lump sum taxes adjust to satisfy budget constraint

- **Market clearing:** goods, money, labor
  - $i_t^S = \text{short rate in household SDF adjusts endogenously}$
  - familiar special case: NK model with money growth rule & peg $i_t^D = 0$
**Linear dynamics**

- Steady state with zero inflation
- Standard NK Phillips curve & Euler equation

\[
\Delta \hat{p}_t = \beta \Delta \hat{p}_{t+1} + \lambda \left( \varphi + \frac{1}{\sigma} \right) \hat{y}_t
\]

\[
\hat{y}_t = \hat{y}_{t+1} - \sigma \left( i_t^S - \Delta \hat{p}_{t+1} - \delta \right)
\]

- Households’ choose money holdings to equalize expected returns

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

- Structure of difference equation
  - Standard model: block recursive, solve for \((\hat{p}_t, \hat{y}_t)\) given policy rate \(i_t^S\)
  - CBDC model: solve for \((\hat{p}_t, \hat{y}_t, i_t^S)\) given policy tools \(i_t^D\) and \(\hat{d}_t\)
  - state variable \(\hat{p}_t\) with initial condition \(\hat{p}_0\)
Monetary policy

- Standard model: short rate $i^S_t = \text{policy rate}$

- Transmission of interest rate policy
  
  | policy rate | $\rightarrow$ | real return $\rightarrow$ | output, inflation |

- Money supplied elastically to implement $i^S_t$, fix $i^D_t = 0$
Monetary policy

- CBDC model: convenience yield is endogenous wedge

\[ i_t^S - \delta = i_t^D - r^D + \frac{\delta - r^D}{\eta} (\hat{p}_t + \hat{y}_t - \hat{d}_t) \]

- Transmission of interest rate policy

  \[ \text{policy rate} \quad + \quad \text{real return on savings} \quad - \quad \text{output, inflation} \]

  \[ + \uparrow \quad + \downarrow \quad + \uparrow \quad + \downarrow \]

  \[ \text{convenience yield} \quad + \quad \text{spending, velocity} \quad \leftarrow \]

  \[ \Rightarrow \text{convenience yield dampens effect} \]

- Money supply = independent policy instrument
Local determinacy with interest rate peg

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

```
low output ————> high real rate ————> Phillips curve

low demand ————> low inflation ————> interest rate peg

Euler eqn
```

- Taylor principle: policy reacts aggressively to low inflation
Local determinacy with interest rate peg

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

```
  low output          Phillips curve
    ↗               ↘
  ↓          low demand
    ↗        low convenience yield
      ↓      low inflation
    ↗    low real rate
      ↓
  Euler eqn

interest rate peg
```

- CBDC model: endogenous convenience yield as a stabilizing force
  - works like Taylor principle: lower rate if lower inflation, output
  - strength depends on preferences, technology, policy
Conditions for local determinacy

- Policy: interest rate & money supply
  - exogenous path for $i_t^D$ or Taylor rule $i_t^D = r^D + \phi \pi \Delta \hat{p}_t + v_t$
  - compare three scenarios for money supply rule

1. Exogenous path for money supply
   - always local determinacy: convenience yield responds strongly to $\pi$

2. Exogenous path for real balances: $D_t = P_t G_t$
   - local determinacy iff $\frac{\delta - r^D}{\eta} > \frac{\lambda (\phi + 1/\sigma)}{1 - \beta} (1 - \phi \pi)$
   - less scope for multiple equilibria if
     * money demand less elastic (low $\eta$) $\rightarrow$ conv. yield responds more to $y$
     * flatter NK Phillips curve, e.g. prices more sticky, lower $\lambda$
     * more aggressive inflation response: higher $\phi \pi$

3. Nominal rigidities in money supply: $D_t = \mu D_{t-1} + P_t G$, $\mu < 1$
   - local determinacy if $\mu$ sufficiently large
   - predetermined nominal money $\rightarrow$ convenience yield responds more
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
    → reduce consumption, increase leisure/decrease labor
    → 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 $i_t^D$ → higher cost
  - CBDC model: higher $i_t^D$ + imperfect pass-through → 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

- Price level: A sharp decline in the percentage deviations from SS within the first quarter, followed by a gradual recovery.
- Output: A steady increase in the percentage deviations from SS over the first four quarters.
- Money: A sharp and steady increase in the percentage deviations from SS over the first four quarters.
- Inflation: A gradual increase in the percentage changes p.a. from the first to the fourth quarter.
- Policy rate: A gradual decrease in the percentage changes p.a. from the first to the fourth quarter.
- iS - iD: The difference between the standard and another variable, showing a decreasing trend over the first four quarters.
IRFs to 25 bp monetary policy shock: standard vs CBDC

- **Price level**
  - Standard: Decrease by around -0.1% after 4 quarters.
  - CBDC: Decrease by around -0.1% after 4 quarters.

- **Output**
  - Standard: Increase by around 0.6% after 4 quarters.
  - CBDC: Increase by around 0.6% after 4 quarters.

- **Money**
  - Standard: No change.
  - CBDC: Increase by around 0.6% after 4 quarters.

- **Inflation**
  - Standard: Increase by around 0.6% after 4 quarters.
  - CBDC: Increase by around 0.6% after 4 quarters.

- **Policy rate**
  - Standard: Decrease by around -0.1% after 4 quarters.
  - CBDC: Decrease by around -0.1% after 4 quarters.

- **i^S - i^D**
  - Standard: Decrease by around -0.1% after 4 quarters.
  - CBDC: No change.
IRFs to 25 bp monetary policy shock: standard vs CBDC

**Price Level**
- % deviations from SS
- 0 4 8 12 16 20 quarters
- -0.1 to 0

**Output**
- % deviations from SS
- 0 4 8 12 16 20 quarters
- 0

**Money**
- % deviations from SS
- 0 4 8 12 16 20 quarters
- 0

**Inflation**
- % p.a.
- 0 4 8 12 16 20 quarters
- -0.3 to 0

**Policy Rate**
- % p.a.
- 0 4 8 12 16 20 quarters
- 0 to 0.6

**i^S - i^D**
- % p.a.
- 0 4 8 12 16 20 quarters
- 0
NK Model with Banks

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

\[ i^M, i^F \]

Reserves
Reserve Demand
Reserve Supply
Banking sector

- **Balance sheet**

<table>
<thead>
<tr>
<th>Assets</th>
<th>Liabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>$M$</td>
<td>Reserves</td>
</tr>
<tr>
<td>$A$</td>
<td>Other assets</td>
</tr>
<tr>
<td>Money</td>
<td>$D$</td>
</tr>
<tr>
<td>Equity</td>
<td></td>
</tr>
</tbody>
</table>

- Shareholders maximize present value of cash flows

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

$$+ A_{t-1} \left(1 + i_{t-1}^A\right) - A_t$$

- Costless adjustment of equity

- Leverage constraint: $D_t \leq \ell (M_t + \rho A_t)$
  - $\rho < 1$ 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 $i_t^S$
  - $\gamma_t = \text{multiplier on leverage constraint}$
- Optimal portfolio choice: assets valued as collateral
  \[
  i_t^S = i_t^M + \ell \gamma_t \left(1 + i_t^S\right)
  \]
  \[
  i_t^S = i_t^A + \rho \ell \gamma_t \left(1 + i_t^S\right)
  \]
- Optimal money creation: money requires leverage cost
  \[
  i_t^S = i_t^D + \gamma_t \left(1 + i_t^S\right)
  \]
⇒ 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

\[ D_t = \left( \int (D^i_t)^{1-\frac{1}{\eta_b}} \right)^{\frac{1}{1-\frac{1}{\eta_b}}} \]

- \( \eta_b = \) elasticity of substitution between bank accounts

\[ i^S_t - i^D_t = \frac{\eta_b}{\eta_b - 1} \ell \left( i^S_t - i^M_t \right) \]

⇒ Constant markup over marginal cost
Equilibrium with abundant reserves

- Government: floor system with abundant 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
  - path or rule for exogenous supply of nominal assets $A_t$
  - stands in for borrowing by firms or against housing
  - nominal rigidity in $A_t$ could be due to long term debt

- Characterizing equilibrium
  - NK Phillips curve & Euler equation unchanged
Dynamics with abundant reserves

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

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

  - 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 $\lambda D_t$ 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 $i^F_t$, 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 abundance
  - government selects type of equilibrium
Dynamics with scarce reserves

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

\[ i_t^S - \delta = i_t^F - r^M + \frac{\delta - r^M}{\eta} (\hat{\rho}_t + \hat{y}_t - \hat{d}_t) \]

- Inside money in reserveless limit: share of reserves in bank assets \( \rightarrow 0 \)

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

\[ \varepsilon = \text{function of bank technology parameters} \]

\[ \Rightarrow \text{Works like CBDC model with more elastic money supply} \]

- Numerical example to compare floor & corridor system
IRFs to monetary policy shock

- Price level
- Output
- Money
- Inflation
- Policy rate
- Spreads

- % deviations from SS
- % p.a.
- % p.a.
- % p.a.
- % p.a.

- 0 4 quarters
- 0 4 quarters
- 0 4 quarters
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