A Model of Interacting Banks and Money Market Funds

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Introduction

- Motivation
  - MMFs and banks
    * compete in attracting investors' demand for money-like assets
    * interact in primary and secondary markets for short-term securities
  - Despite increasing policy attention, few models have considered MMFs & banks interacting in a market equilibrium setup
- Goals
  - Constructing a model where bank deposits and MMF shares coexist
  - Exploring rationale for such a coexistence & identifying potential sources of inefficiency
- Current version is a very first attempt in this direction

Current modeling features

1. Firms self-insure against liquidity shocks by holding cash-like assets
   - Deposits promise fixed conversion value
   - MMF shares are redeemable at (potentially fluctuating) market value

2. Some frictions erode the liquidity convenience yield of cash-like assets
   - Deposits
     - Currently: idiosyncratic convertibility risk (operational risk? temporary suspension due to liquidity problems?)
     - Other: regulatory burden, imperfect competition, solvency risk
   - MMFs: accommodate redemptions with sales in secondary markets subject to frictions (due diligence costs, congestion,...)

$$\text{Redemptions} \Rightarrow \text{asset sales} \Rightarrow \text{price declines}$$

3. MMFs invest in banks' commercial paper (CP), bank assets are liquid & MMF share pricing avoids 1st mover advantages

   Elements in 3) help close the model in a simple manner:

   - MMFs could invest in other non-fully liquid assets (e.g. Treasury bonds) insofar as they are sold to in a frictional secondary market

   - Liquidity of bank assets may reflect banks' access to lending facilities where less liquid asset can be posted as collateral

     (Banks' idiosyncratic liquidity risk might reflect temporary lack of access to relevant lending facilities)

   - Marked-to-market pricing of shares redeemed at interim date prevent 1st mover advantages

     (1st mover advantages would make things worse ex post but also reduce size of the MMF sector ex ante)

Agents' balance sheets at initial date

Banks

Bank assets a_0^b	Deposits $p_0^D d_0^b$
	Commercial paper $p_0^{CP} cp_0^b$

Firms

Deposits $p_0^D d_0^f$	Net worth e_0^f
MMFs shares m_0^f	

MMFs

Commercial paper $p_0^{CP} cp_0^m$	Shares m_0^f

[At interim date, some firms receive an investment opportunity & in an aggregate illiquidity state (ω=1) all firms need a minimum of liquid deposits up to terminal date (*dash for cash*)]

Uses & sources of funds (or balance sheets) at interim date

Firm i (uses & sources of funds)

Illiquid deposits εd_0^f	Illiquid deposits εd_0^f
Deposits $p_1^D(\omega)d_1^f(s_i^f)$	Past liquid deposits $(1-\varepsilon)\, d_0^f$
MMFs shares $q_1(\omega)m_1^f(s_i^f)$	Past MMFs shares $q_1(\omega)m_0^f$
Investment in project $k_1^f(s_i^f)$	

Liquid bank j (uses & sources of funds)

Assets $a_1^b(s_j^b)$	Past assets $(1+r_0)\, a_0^b$
CP $p_1^{CP}(\omega)\,(1+\lambda\,(\omega))\, t_1^b(s_j^b)$	Net deposit funding $p_1^D(\omega)d_1^b(s_j^b) - d_0^b$

MMFs

CP $p_1^{CP}(\omega)\,(cp_0^m - t_1^m\,(\omega))$	Shares $q_1(\omega)\int m_1^f(s_i^f)di$

[Secondary trade in commercial paper is $t_1^m\,(\omega) = \int t_1^b(s_j^b)dj$]

Main insights from the analysis

- Firms optimize aware of risk of fluctuations in MMF redemption values but neglect pecuniary externality (via secondary market frictions)

  $\uparrow$ agg. holdings of MMF shares $\rightarrow$ $\uparrow$ asset sales $\rightarrow$ $\uparrow$ price declines
  (in bad states)

- Even without 1st mover advantages, competitive equilibrium features inefficiency: excessive channeling of savings to MMFs

- Pigouvian tax on investment in MMFs can restore constrained efficiency

Remarks on the inefficiency (and the setup more generally) ($\times$)

– Problem is not MMFs per se but their assets' illiquid secondary market (problem might be worse if firms directly invested in those assets)

– Rationale for banks' CP issuance is to provide liquidity to its holders via "market liquidity"... but banks neglect the pecuniary externality associated with secondary market trade

– Policy implications would be different if MMFs had access to central bank liquidity or other mitigants of the underlying trading frictions

Related literature ($\times$)

- Banks & non-banks: Plantin'15; Gertler-Kiyotaki-Prestipino'16; Moreira-Savov'17; Begenau-Landvoigt'18; Bengui-Bianchi'18; Ordoñez'18; Martinez-Miera & Repullo'19; Jeanne-Korinek'20 [here: not just in parallel but closely interacting]

- Non-bank provision of safe assets: Gennaioli-Shleifer-Vishny'13; Ferrante'18; Segura-Villacorta'20 [here: traditional precautionary preference for cash-like features]

- Financial fragility in the mutual fund sector: Chen-Goldstein-Jiang'10; Cipriani-Martin-McCabe-Parigi'14; Goldstein-Jiang-Ng'17; Cipriani-La Spada'20; Voellmy'21; Jin-Kacperczyk-Kahraman-Suntheim'22; policy papers [here: ex ante & ex post stages + no 1st-mover advantages]

- Other: pecuniary externalities (Lorenzoni'08, Dávila-Korinek'17); effects of bank regulation on liquidity provision (Cimon-Garriott'19; Saar-Sun-Yang-Zhu'20; d'Avernas-Vandeweyer'20; Breckenfelder-Ivashina'21); trading restrictions & deposit optimality (Jacklin'87); CB interventions (Falato-Goldstein-Hortacsu'21; Breckenfelder-Hoerova'23)

Outline of the presentation

- Some model details
- Equilibrium conditions
- Equilibrium analysis
- Efficiency properties
- Conclusions and way forward

Some model details Three dates $t = 0, 1, 2$

- Measure-one continua of risk-neutral firms, banks & MMFs
- Firms and banks are competitive expected terminal net worth maximizers

Firms invest initial net worth e_0^f in deposits d_0^f & MMFs m_0^f

At interim date:

- Scalable project w/ returns $A > 1 + r_1$ (idiosyncratic pr. π)
- Need liquid deposits$\geq \theta e_0^f$ until t=2 (aggregate pr. γ)
- Assets held from $t = 0$ are their only source of funds

Banks Indexed by j, aimed to maximize expected terminal value

- Issue at discount one-period deposits d_0^b & two-period CP cp_0^b
- Invest $a_0^b = p_0^D d_0^b + p_0^{CP}\ cp_0^b$ at safe short-term rate r_0
- At $t = 1$, fraction ϵ of illiquid banks (δ_j=1) roll-over positions, while liquid banks (δ_j=0) rebalance assets & liabilities

Liquid bank j (uses and sources of funds)

Assets $a_1^b(s_j^b)$ (with return r_1)	Past assets $(1 + r_0)\, a_0^b$
CP $p_1^{CP}(\omega)\, (1 + \lambda\, (\omega))\, t_1^b(s_j^b)$	Net deposit funding $p_1^D(\omega) d_1^b(s_j^b)$–$d_0^b$

- Buying CP $t_1^b(s_j^b)$ in secondary market involves unit cost

$$\lambda(\omega) = \frac{v}{e_0^f} \int t_1^b(s_j^b) dj \tag{1}$$

[due diligence, search cost in OTC market]

MMFs

- Invest m_0^f in bank CP: $cp_0^m = m_0^f / p_0^{CP}$

  [Initial price of MMF shares normalized to q_0^m=1]

- Accommodate potential net redemptions $m_0^f - \int m_1^f(s_i^f)di$ at t=1 with CP sales:

$$p_1^{CP}(\omega)\, t_1^m(\omega) = q_1(\omega) \left(m_0^f - \int m_1^f(s_i^f)\, di \right) \tag{2}$$

- Redemption at floating net asset value avoids 1st mover advantage:

$$q_1(\omega) = \frac{\text{floating NAV}}{m_0^f} = \frac{p_1^{CP}(\omega)\, cp_0^m}{m_0^f} = \frac{p_1^{CP}(\omega)}{p_0^{CP}}$$

[$\Rightarrow q_2(\omega) = \frac{\text{value of residual CP}}{\text{outstanding shares}} = \frac{1}{p_0^{CP}}$ independently of redemptions!]

Issues to discuss

- Characterization of interior competitive equilibrium
- Efficiency properties
- Pigouvian implementation of constrained efficient allocation

Guess & verify optimal firm behavior at interim date

1. Firms **with an investment project** choose maximum project scale given frozen deposits & minimal liquid deposits in ω=1:

$$d_1^f(s_i^f) = \omega\theta e_0^f, \quad m_1^f(s_i^f) = 0 \tag{3}$$
$$k_1^f(s_i^f) = (1-\varepsilon)\, d_0^f + q(\omega) m_0^f - p_1^D(\omega)\, \omega\theta e_0^f \geq 0 \tag{4}$$

$$\text{Optimality requires } A \geq \max\left\{\frac{1}{p_1^D(0)}, \frac{1}{p_1^D(1)}, \frac{q_2(0)}{q_1(0)}, \frac{q_2(1)}{q_1(1)}\right\} \tag{5}$$

2. Firms **w/o investment project in ω=1** choose minimal liquid deposits (implying minimal MMFs redemption at aggregate level):

$$d_1^f(s_i^f) = \theta e_0^f, \quad k_1^f(s_i^f) = 0 \tag{6}$$
$$m_1^f(s_i^f) = \frac{q_1(1)\, m_0^f + (1-\varepsilon)\, d_0^f - p_1^D(1)\, \theta e_0^f}{q_1(1)} \geq 0 \tag{7}$$

$$\text{Optimality requires } \frac{q_2(1)}{q_1(1)} \geq \frac{1}{p_1^D(1)}$$

3. Firms **w/o investment project in ω=0** choose any combination $\left(d_1^f(s_i^f), m_1^f(s_i^f)\right)$ satisfying:

$$p_1^D\left(0\right)d_1^f(s_i^f) = \left(1-\varepsilon\right)d_0^f + q_1\left(0\right)\left(m_0^f - m_1^f(s_i^f)\right) \tag{8}$$

(allowing accommodation of liquidity shock w/o sales of CP)

$$\text{Optimality requires } \frac{q_2(0)}{q_1(0)} = \frac{1}{p_1^D(0)} \tag{9}$$

Equilibrium at the initial date

Firms at t=0 Allocate initial funds across deposits & MMFs shares

$$\max_{\{d_0^f, m_0^f\}} \quad \mathbb{E}_0\left[V_1^f\left(d_0^f, m_0^f; s_i^f\right)\right] \qquad \text{[linear objective]} \tag{10}$$

$$\text{s.t.:} \qquad p_0^D d_0^f + m_0^f = e_0^f \tag{11}$$

$$d_0^f, m_0^f \geq 0 \qquad \text{[linear constraints]} \tag{12}$$

L1 Firms' **indifference** at t=0 requires

$$\frac{1}{p_0^D}\left\{(1-\epsilon)\left[\pi A + (1-\pi)\left(\frac{1-\gamma}{p_1^D(0)} + \frac{\gamma q_2(1)}{q_1(1)}\right)\right] + \epsilon\left(\frac{1-\gamma}{p_1^D(0)} + \frac{\gamma}{p_1^D(1)}\right)\right\} =$$

$$\pi A\left[(1-\gamma)\, q_1(0) + \gamma q_1(1)\right] + (1-\pi)\left[(1-\gamma) q_2(0) + \gamma q_2(1)\right] \tag{13}$$

[E(R_bank deposits) = E(R_MMFs shares); notice elements in $q_t(\omega)$]

Equilibrium analysis

Banks' optimization & MMFs pricing rules determine most prices; indifference condition in L1 determines unique candidate value of $\lambda(1)$

L2+L3 Conjectured equilibrium involves

$$p_1^{CP}(1) = \frac{1}{(1+r_1)(1+\lambda(1))}, \quad q_1(1) = \frac{1+r_0}{1+\lambda(1)}; \tag{14}$$

and $\lambda(1) = \lambda^*$ defined by

$$\epsilon\left\{\pi[A-(1+r_1)] + (1-\pi)\gamma\lambda^*(1+r_1)\right\} = \gamma\left\{\pi\frac{\lambda^* A}{1+\lambda^*} + (1-\pi)\lambda^*(1+r_1)\right\} \tag{15}$$

[E(losses due to deposit illiquidity)=E(losses due to MMF price decline if ω=1)]

Other prices are trivially connected to short-term rates r_0 & r_1

Additional details $(\times)$

P1 Determinants of the price discount in $\omega = 1$

$$\lambda^* = L(\underset{+}{\pi},\ \underset{+}{A},\ \underset{+}{\epsilon},\ \underset{-}{\gamma},\ \underset{0}{\theta},\ \underset{0}{r_0},\ \underset{-}{r_1},\ \underset{0}{v},\ \underset{0}{e_0^f}) \tag{16}$$

(Demand-side determined λ^*; increases with parameters that make deposits comparatively less attractive; most surprising one: probability and attractiveness of investment projects increase $\lambda^* \rightarrow$ "procyclical" attractiveness of MMFs)

L4 Remaining necessary and sufficient condition for optimality of firms' conjectured behavior under the prices obtained in L2 & L3:

$$\gamma \geq \frac{\pi\epsilon}{\pi\epsilon + (1-\epsilon)} \tag{17}$$

$$[\Pr(\text{illiquid state}) \geq F(\text{pr. receiving project, pr. deposit illiquidity})]$$

Equilibrium quantities

Firms' portfolio decisions at t=0 are determined as those compatible w/ market clearing at t=1 under the prices derived before

- Let $x_0^f \equiv m_0^f / e_0^f \in [0,1]$
- Market clearing under $\lambda(0)$**=**0 **requires** $t_1^m(0)=0 \Leftrightarrow x_0^f \le \bar{x}_0^f$ **(L5)**
- Market clearing under $\lambda(1)$**=**λ^* **requires** $\underset{+}{\Lambda(x_0^f)} = \lambda^* \Rightarrow$ unique x^*:

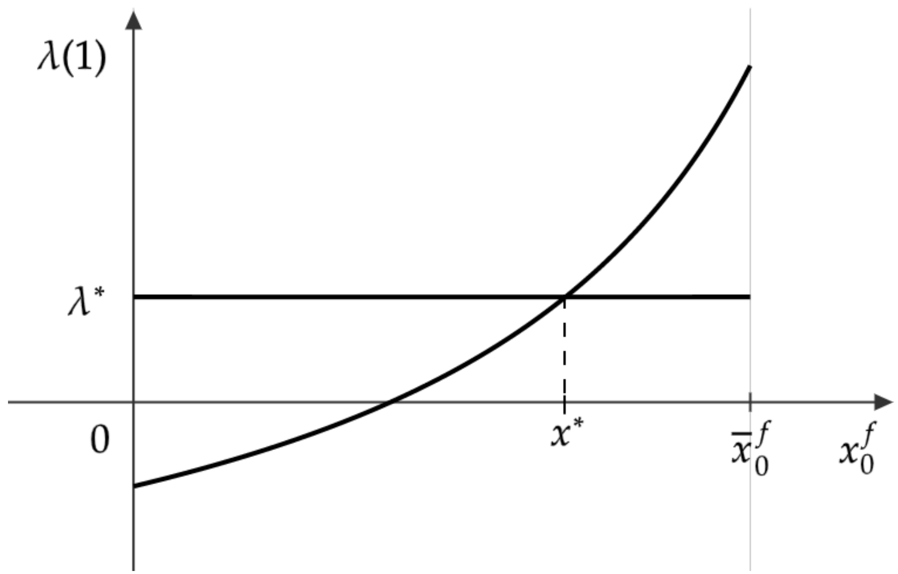

Fig. 2
[**P2** sets cond. for $x^* \in (0, \bar{x}_0^f]$

Additional results $(\times)$

P3 Determinants of x^*

	π	A	ϵ	γ	θ	r_0	r_1	v	e_0^f
Direct effect on x^*	–	0	–	0	-	$+$	$+$	–	0
Indirect effect via λ^*	$+$	$+$	$+$	-	0	0	-	0	0
Overall effect on x^*	?	$+$	?	–	–	$+$	?	–	0

[+ eff. A; – eff. illiquidity pr γ, liquidity needs θ & trading frictions v]

Other details (**P2**):

Under (17), the necessary and sufficient condition for $x^* \in (0, \bar{x}_0^f]$ is

$$\frac{\lambda^*}{1+\lambda^*}\frac{[\pi+(1-\pi)(1-\varepsilon)]+v(1-\pi)(1-\epsilon)(1+r_0)(1+r_1)\pi}{v(1-\pi)[\pi+(1-\pi)(1-\varepsilon)]} \leq \theta < (1-\epsilon)(1+r_0)(1+r_1) \quad (18)$$

Efficiency analysis

Frictions reminder:

i) Markets incompleteness ($\rightarrow$ self-insurance)

ii) Friction affecting convertibility of deposits at interim date

iii) Secondary market frictions (growing in aggregate selling pressure)

Narrow notion of constrained efficiency [as in, e.g., Davila-Korinek'17]:

- How would a social planner decide x_0^f ($\rightarrow x^{SP}$)?

  [Maximizing firms' value subject to all frictions; letting agents & markets operate freely otherwise]

- Assume firms' decisions at $t{=}1$ are qualitatively as in competitive equilibrium $\Rightarrow$ pricing, except for $\lambda(1)$, is as in competitive equilibrium

Constrained inefficiency of unregulated equilibrium

Social planner decides $x_0^f = x^{SP}$ aware of $\lambda(1) = \Lambda(x_0^f)$ & prices in L2

$$\begin{aligned} \max_{x_0^f \in [0,1]} \quad & \mathbb{E}_0 \left[V_1^f \left((1 - x_0^f) e_0^f / p_0^D, x_0^f e_0^f; s_i^f \right) \right] \\ \text{s.t.:} \quad & \lambda(1) = \Lambda(x_0^f) + \text{pricing conditions in L2} \end{aligned} \tag{19}$$

$$\text{FOC: } \frac{\partial \mathbb{E}_0 \left[V_1^f \left((1 - x_0^f) e_0^f / p_0^D, x_0^f e_0^f; s_i^f \right) \right]}{\partial x_0^f} + \frac{\partial \mathbb{E}_0 \left[V_1^f \left((1 - x_0^f) e_0^f / p_0^D, x_0^f e_0^f; s_i^f \right) \right]}{\partial \lambda(1)} \Lambda'(x_0^f) = 0 \tag{20}$$

[Evaluated at $x_0^f = x^*$, 1st term $=$0 (envelop theorem) & second term $<$0]

P4 Competitive equilibrium is not constrained efficient ($x^* \neq x^{SP}$); welfare can be increased by choosing $x_0^f < x^*$

Implementation of x^{SP} with a Pigouvian tax

Consider taxing m_0^f at rate τ & rebating revenue to firms at $t = 0$ with lump-sum transfer $L = \tau m_0^f$:

> **P5** Constrained efficient allocation w/ $x^{SP} < x^*$ can be implemented w/ some $\tau = \tau^{SP} > 0$

[Tax induces firms to internalize MgC of MMFs investment; reduces x_0^f while reducing $\lambda(1)$]

Conclusions and way forward

- Preliminary model with interacting banks & MMFs
- Even without 1st mover advantages, investment in MMFs is excessive due to pecuniary externality related to secondary market frictions
- Model is just a 1st step along several dimensions:
  - reduced-form nature of frictions affecting bank deposits
  - no microfoundations for secondary market frictions
  - banks are not (explicitly) involved in maturity transformation
- Way forward:
  - allowing banks to invest in long-term assets
  - relating secondary market frictions to quality of bank assets
  - allowing MMFs to invest in more liquid assets (or to have access to central bank liquidity)

Further discussion on policy issues ($\times$)

- Richer policy interventions (w/ taxes & subsidies not only at t=0) might improve on the constrained efficient allocation

  [But characterizing interventions bringing outcomes closer to 1st best is beyond our scope]

- We could examine specific policy proposals put forward after March 2020 (e.g. redemption fees or liquidity requirements)

$\longrightarrow$ Some of these might help while being generally inferior to taxing m_0^f

- $*$ Investment in MMFs is ex ante discouraged
- $*$ But at cost of worsening MMFs' "liquidity insurance" function

[If taxes are not viable, liquidity requirements at t =0 might be superior to interventions aimed to discourage x_0^f by penalizing redemptions]

THANK YOU!

SUPPLEMENTARY MATERIAL

Balance sheets at t=2

Firm i

Illiquid deposits $\varepsilon d_0^f / p_1^D(\omega)$	Net worth
Liquid deposits $d_1^f(s_i^f)$	
MMFs shares $q_2(\omega) m_1^f(s_i^f)$	
Real assets $A k_1^f(s_i^f)$	

Liquid bank j

Assets $(1 + r_1)\, a_1^b(s_j^b)$	Deposits $d_1^b(s_j^b)$
CP $t_1^b(s_j^b)$	CP cp_0^b
	Net worth (=0)

MMFs

CP $cp_0^m - t_1^m(\omega)$	Shares $q_2(\omega) \int m_1^f(s_i^f) di$

Definition of competitive equilibrium

- Allocation

$$\Big\{ \{d_0^f, m_0^f, d_0^b, cp_0^b, a_0^b, cp_0^m\}$$
$$\{d_1^f(s^f), m_1^f(s^f), k_1^f(s^f)\}_{s^f}, \{d_1^b(s^b), t_1^b(s^b), a_1^b(s^b)\}_{s^b}, \{t_1^m(\omega)\}_{\omega=0,1} \Big\}$$

- Prices

$$\{p_0^D, p_0^{CP}, \{p_1^D(\omega), p_1^{CP}(\omega)\}_{\omega=0,1}\}$$

such that agents optimize and markets clear

[We derive equilibrium conditions by backward induction; with conjectured firm behavior that is confirmed as optimal under equilibrium prices]

Remaining backward induction analysis: Final date (t=2)

Firm terminal net worth:

$$V_2^f(s_i^f) = \varepsilon \frac{d_0^f}{p_1^D(\omega)} + d_1^f(s_i^f) + q_2(\omega)\, m_1^f(s_i^f) + \psi_i A k_1^f(s_i^f) \tag{21}$$

Bank terminal net worth (trivial):

$$V_2^b(s_j^b) = (1+r_1)\, a_1^b(s_j^b) + t_1^b(s_j^b) - d_1^b(s_j^b) - cp_0^b \tag{22}$$

MMFs' balance sheet (trivial):

$$q_2(\omega) \int m_1^f(s_i) di = cp_0^m - t_1^m(\omega) \tag{23}$$

Firms at t=1

Continuation value results from maximization of expected final net worth

$$V_1^f(d_0^f, m_0^f; s_i^f) = \max_{\left\{d_1^f(s_i^f), m_1^f(s_i^f), k_1^f(s_i^f)\right\}} \left\{\frac{\varepsilon d_0^f}{p_1^D(\omega)} + d_1^f(s_i^f) + q_2(\omega)\, m_1^f(s_i^f) + \psi_i A k_1^f(s_i^f)\right\} \tag{24}$$

s.t.:
$$p_1^D(\omega)\, d_1^f(s_i^f) + k_1^f(s_i^f) = (1-\varepsilon)\, d_0^f + q_1(\omega)\left(m_0^f - m_1^f(s_i^f)\right) \tag{25}$$

$$d_1^f(s_i^f) \geq \omega\theta e_0^f \tag{26}$$

$$m_1^f(s_i^f), k_1^f(s_i^f) \geq 0 \tag{27}$$

[budget constraint; liquid deposits requirement in ω=1; non-negativity constraints]

Liquid banks at t=1

- Maximize continuation value:

$$V_1^b\left(d_0^b, cp_0^b; s_j^b\right) = \max_{\left\{a_1^b(s_j^b), d_1^b(s_j^b), t_1^b(s_j^b)\right\}} \left\{(1+r_1)\, a_1^b(s_j^b) + t_1^b(s_j^b) - d_1^b(s_j^b) - cp_0^b\right\} \quad (28)$$

subject to

$$a_1^b(s_j^b) + p_1^{CP}(\omega)\,(1+\lambda(\omega))\, t_1^b(s_j^b) = (1+r_0)\,(p_0^D d_0^b + p_0^{CP} cp_0^b) + (p_1^D(\omega)\, d_1^b(s_j^b) - d_0^b) \quad (29)$$

$$d_1^b(s_j^b) \geq 0 \quad (30)$$

- Having interior optimal $d_1^b(s_j^b)$ & $t_1^b(s_j^b)$ requires:

$$p_1^D(\omega) = \frac{1}{1+r_1} \quad (31)$$

$$p_1^{CP}(\omega) = \frac{1}{(1+r_1)(1+\lambda(\omega))} \quad (32)$$

[perfectly elastic supply of deposits + willingness to buy commercial paper]

MMFs at t=1

- Sell commercial paper $t_1^m(\omega)$ to accommodate net redemptions
- Under non-diluting pricing this implies

$$t_1^m(\omega) = \left(1 - \frac{\int m_1^f(s_i^f)\,di}{m_0^f}\right) cp_0^m \tag{33}$$

Market clearing at $t = 1$

Clearing markets for deposits and commercial paper requires

$$\int d_1^b(s_j^b)\,dj - \epsilon \frac{d_0^f}{p_1^D(\omega)} = \int d_1^f(s_i^f)\,di \tag{34}$$

$$\int t_1^b(s_j^b)\,dj = t_1^m(\omega) \tag{35}$$

Banks at t=0 (trivial)

Building on expression for continuation value in (28)-(30), the bank solves

$$\max_{\left\{d_0^b, cp^b\right\}} \quad \mathbb{E}_0\left[V_1^b\left(d_0^b, cp_0^b; s_j^b\right)\right] \tag{36}$$

$$\text{s.t.:} \qquad d_0^b, cp_0^b \geq 0 \tag{37}$$

Interior solutions require

$$p_0^D = \frac{1}{1+r_0} \text{ and} \tag{38}$$

$$p_0^{CP} = \frac{1}{\left(1+r_0\right)\left(1+r_1\right)} \tag{39}$$

[supply of deposits & CP are perfectly elastic at these prices]

MMFs at t=0 (trivial)

Balance sheet constraint:

$$m_0^f = p_0^{CP} cp_0^m \tag{40}$$

Market clearing at t=0 (trivial)

Clearing of deposit and commercial paper markets

$$d_0^b = d_0^f \tag{41}$$

$$cp_0^b = cp_0^m \tag{42}$$