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Market failures in market-based finance

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ABSTRACT

We build a three-period model to investigate market failures in the market-based financial system. Institutional investors (IIs), such as insurance companies and pension funds, have liabilities offering guaranteed returns and operate under a risk-sensitive solvency constraint. They seek to allocate funds to asset managers (AMs) that provide diversification when investing in risky assets. At the interim date, AMs that run investment funds face investor redemptions and liquidate risky assets and/or deplete cash holdings, if available. Dealer banks can purchase risky assets, thus providing market liquidity. The latter ultimately determines equilibrium allocations. In the competitive equilibrium, AMs suffer from a pecuniary externality and hold inefficiently low amounts of cash. Asset fire sales increase the overall cost of meeting redemptions and depress risk-adjusted returns delivered by AMs to IIs, forcing the latter to de-risk. We show that a macroprudential approach to (i) the liquidity regulation of AMs and (ii) the solvency regulation of IIs can improve upon the competitive equilibrium allocations.

JEL classification: D62, G01, G23, G38.

Keywords: Market-based finance; regulation; investment funds; insurance companies and pension funds; market liquidity.

Non technical summary

The market-based financial system is growing rapidly. The Financial Stability Board estimates that roughly half of global financial assets are held by nonbank financial intermediaries worldwide. This also reflects structural developments, some of which may improve the diversification of funding sources for real economy borrowers. However, the new environment comes with new financial stability risks. Key questions are related to possible heightened pro-cyclicality. The growth of asset managers has introduced greater liquidity and maturity transformation in several markets, including traditionally less liquid ones such as corporate bond markets. Funds indeed have progressively decreased their holdings of highly liquid assets, moving into less liquid assets. Fund shares can often be redeemed on very short notice and asset managers become net absorber of market liquidity in times of stress, as highlighted during the Covid-19 crisis in March 2020. These developments come at times when insurance companies and pension funds are less able to buy risky assets in market drawdowns and stabilise asset prices. Indeed, faced with a low-yield environment and widening asset-liability mismatches, these institutional investors have progressively moved into more risky segments themselves. They do so by investing in more risky assets and increasing their allocation of funds to asset managers. Additional concerns are related to the fact that dealer banks' supply of market liquidity in certain segments have declined since the global financial crisis. The resilience of the market-based financial intermediation system is under severe scrutiny and policymakers are discussing possible macroprudential regulatory tools for nonbanks to limit financial stability risks.

The baseline model has three dates, two assets (cash and a risky asset) and three relevant types of agents. Institutional investors must deliver guaranteed returns on legacy contracts with their clients (e.g. defined-benefit pensions) and operate under a risk-sensitive solvency regulation. They look for diversification when investing in risky assets and allocate a fraction of their endowment to asset managers. The latter face a redemption shock at the interim date and can either deplete cash (if any) and/or liquidate risky assets to dealer banks. Market liquidity provision by dealers is costly, as it requires balance sheet space, and limited. We derive competitive equilibrium allocations. We show that when the supply of market liquidity is scarce, asset managers suffer from a pecuniary externality, fail to internalise the effect of asset sales on equilibrium prices and hold a suboptimal amount of cash. This drives up the overall cost of meeting redemptions and depresses the returns that asset managers deliver to institutional investors, forcing the latter to de-risk ex-ante. In the model, regulatory minimum cash buffers for asset managers are an effective macroprudential tools. More specifically, a planner would choose an optimal cash buffer that let asset managers internalise the equilibrium effect of asset sales. The policy measure reduces the overall cost of meeting redemptions and implements a socially optimal allocation. A lower cost of meeting redemptions also means that asset managers can deliver better risk-adjusted returns to institutional investors, thereby relaxing the solvency constraints.

We extend the model and allow institutional investors to purchase risky assets at the interim date, alongside bankers. This requires the former to hold cash at the interim date and have balance sheet capacity, i.e. their solvency constraint should not be binding. In the competitive equilibrium individual institutional investors take on too much risk ex-ante and are then unable to exploit profitable market opportunities when asset managers must liquidate risky assets. We show that a macroprudential approach to the solvency regulation can implement a socially optimal allocation. The regulator would set a solvency constraint at the initial date that is tight enough so that institutional investors are induced to hold enough cash (i.e. risk-taking or balance sheet capacity) to purchase risky assets at the interim date. The optimal regulatory constraint is such that the additional demand for risky assets coming from institutional investors pushes the clearing price up to its efficient level. In this case, the overall cost for asset managers of meeting redemptions decreases and returns that asset managers deliver to institutional investors increase.

Although very stylised, the model captures relevant features of the post-crisis global financial system: the shift towards market-based finance, the increasing relevance of asset managers that allocate a larger fraction of global capital, the popularity of investment fund shares in the portfolios of insurance companies and pension funds. The model connects these developments in a parsimonious way and offers a perspective on some policy-relevant questions. Our insights can inform the ongoing broader debate on the regulation of nonbanks, such as ex-ante liquidity management tools for investment funds and macroprudential capital measures for insurers.

1 Introduction

The market-based financial system is growing rapidly. The Financial Stability Board estimates that roughly half of global financial assets are held by nonbank financial intermediaries worldwide. This also reflects structural developments, some of which may improve the diversification of funding sources for real economy borrowers. However, the new environment comes with new financial stability risks. Key questions are related to possible heightened pro-cyclicality. The growth of asset managers has introduced greater liquidity and maturity transformation in several markets, including traditionally less liquid ones such as corporate bond markets. Funds indeed have progressively decreased their holdings of highly liquid assets, moving into less liquid assets (Figure 1).

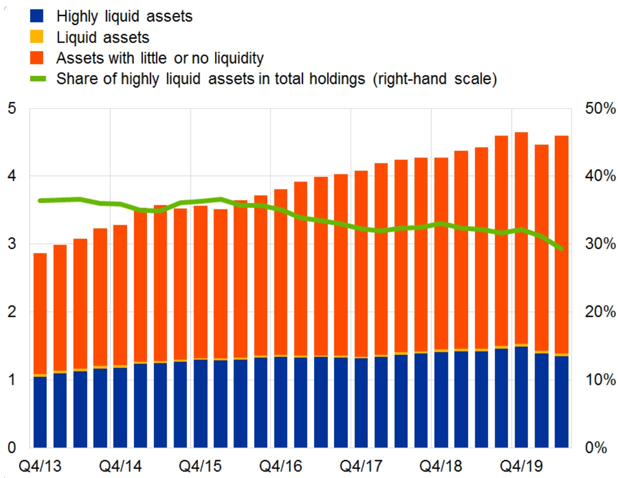

Figure 1: Assets holdings of euro area investment funds, by liquidity of the asset. Notes: The chart includes all types of investment funds domiciled in the euro area, except money market funds. Sources: ECB Securities Holdings Statistics and ECB calculations.

Fund shares can often be redeemed on very short notice. When hit by large-scale redemption requests, asset managers become net absorber of market liquidity, as seen during the Covid-19 crisis in March 2020. On the other hand, insurance companies and pension funds seem less able to buy risky assets in market drawdowns and stabilise asset prices. Indeed, faced with a low-yield environment and widening asset-liability mismatches, these institutional investors have progressively moved into more risky segments themselves. They do so also by increasing their allocation of funds to asset managers (Figure 2). Finally, dealer banks' supply of market liquidity in certain segments have declined since the global financial crisis.[1] Taken together, these developments create concerns on the resilience of the market-based financial intermediation system. Policymakers are discussing macroprudential regulatory tools for nonbanks to limit financial stability risks.

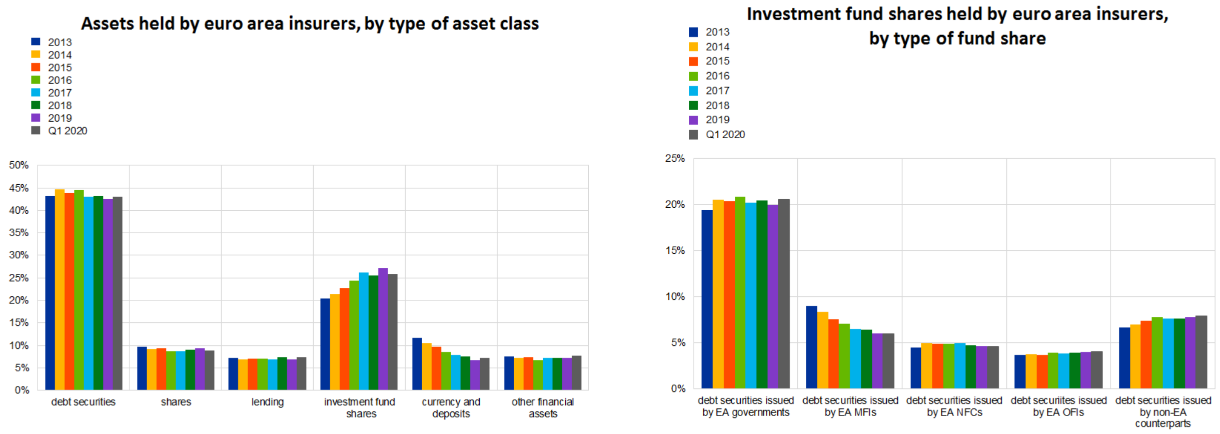

Figure 2: Figures show percentage of total assets. Source: ECB euro area accounts and ECB calculations (left-hand panel); ECB insurance corporation balance sheet data and ECB calculations (right-hand panel).

The aim of the paper is threefold. First, it builds a micro-founded model to frame key interactions among key players of the market-based financial system and pin down relevant market failures. Second, the paper addresses questions on the scope for a macroprudential approach to the liquidity regulation of asset managers and the solvency regulation of institutional investors. We show that both policies can relax inefficiencies related to those market failures. Finally, the model aims to provide a theoretical underpinning for the growing literature on system-wide stress analysis.

The baseline model described in Section 2 has three dates $t = 0, 1, 2$, two types of financial assets (cash and risky assets), and three relevant types of agents (see Figure 3 for the timeline of events). Cash is riskless and also used as liquidity. Each unit invested at $t = 0$ in risky assets returns $\tilde{q} \sim U[q - Z, q + Z]$ at $t = 2$, where Z is the fundamental risk. Institutional investors have equity e_{II}, have received $1 - e_{II}$ from households before $t = 0$ under the promise to repay at least $\delta = R(1 - e_{II})$. This assumption captures legacy, long-term contracts with guaranteed returns between households and institutional investors, such as defined-benefit pensions. We assume institutional investors operate under a risk-sensitive

[1] See Committee on the Global Financial System (2016).

solvency constraint, reflecting Solvency II-type of regulation of insurance companies. For this reason, they look for diversification when investing in risky assets and instead of purchasing the assets directly they seek to allocate a fraction $a \in [0, 1]$ of their endowment to asset managers, who are assumed to deliver diversification. More specifically, when risky assets are managed by asset managers the fundamental risk drops to $z \in (0, Z)$. Asset managers receive 1 and a from households and institutional investors, respectively, and invest y_0 in cash and the remaining amount in risky assets. Asset managers maximise the expected value of their portfolio at $t = 2$. At the interim date, a deterministic fraction x of households redeem and asset managers deplete cash (if any) and liquidate y_1 risky assets to pay the net asset value of the fund to redeeming households. On the other side of the market for risky assets there are bankers. More specifically, we assume assets in liquidation are confronted with a downward sloped demand curve for risky assets $i(p)$, where p is the equilibrium price of risky assets at $t = 1$.

Section 3 shows that when the supply of market liquidity is scarce - low $i(p)$ - individual asset managers suffer from a pecuniary externality. They fail to internalise the effect of asset sales on equilibrium prices and hold too little cash. This drives up the overall cost of meeting redemptions and depresses the returns that asset managers deliver to institutional investors. This makes the solvency constraint tighter and poorly capitalised institutional investors (high δ) are forced to allocate less to asset managers and instead hold some cash.

Section 4.1 discusses how a regulatory minimum cash buffer for asset managers can restore efficiency. More specifically, we show that a planner would choose an optimal cash buffer $y_0^{LIQ} > 0$ that makes asset managers internalise the equilibrium effect of sales. The policy reduces the overall cost of meeting redemptions and implements a socially optimal allocation. A lower cost of meeting redemptions also means that asset managers can deliver better risk-adjusted returns to institutional investors, thereby relaxing the solvency constraints and boosting allocation a from institutional investors to asset managers in cases where the former, in the competitive equilibrium, are constrained (i.e. $a < 1$). This regulatory minimum cash buffer is macroprudential in nature, as it is designed to address a system-wide externality.

Section 4.2 extends the baseline model of Section 2 and allows institutional investors to purchase risky assets at the interim date, alongside bankers. This requires the former to have cash and balance sheet capacity at $t = 1$. In this setup we test the ability of a planner/regulator to impose a countercyclical solvency requirement on institutional investors, as an alternative policy to the liquidity regulation described in Section 4.1. We first show that in the competitive equilibrium institutional investors hold inefficiently low cash at $t = 1$ and are unable to exploit profitable market opportunities at the interim date. More specifically, individual institutional investors fail to internalise the effects of their risk-taking a at $t = 0$ on equilibrium prices at $t = 1$. We show that a macroprudential approach to the solvency regulation of institutional investors can implement a socially optimal allocation. More specifically, the regulator would set a solvency constraint at $t = 0$ that is tight enough so that institutional investors are forced to hold enough cash (i.e. balance sheet capacity) to purchase risky assets at $t = 1$. The optimal regulatory constraint is such that the additional demand for risky assets coming from institutional investors pushes the clearing price up to πq, which is the efficient level. This reduces the overall cost for asset managers of meeting redemptions and shifts rightwards the probability distribution of the returns that asset managers deliver to institutional investors. Overall, the model captures the fundamental difference between the micro- and the macro-prudential approach to the regulation of non-banks.

Relationship with the literature. Our work is related to various strands of literature. We adapt the concept of pecuniary externalities to the market-based financial system. As in Bianchi (2011) and Lorenzoni (2008), agents do not internalize the price effects of their decisions and over-borrow. Our individual asset managers and/or institutional investors take on too much risk ex-ante, which eventually results in inefficiently low equilibrium prices. In a similar spirit, Davila and Korinek (2017) develop a general framework to analyse efficiency in economies with financial frictions, pecuniary externalities and fire sales.[2] Pecuniary externalities can also lead to inefficient risk-sharing or imperfect intertemporal smoothing in versions of the Diamond and Dybvig (1983) model when agents are allowed to re-trade.[3] As in our model, financial intermediaries choose illiquid portfolio ex-ante to generate higher returns, counting on market liquidity ex-post. This brings about excessively high liquidity mismatch and inefficiently low market prices ex post. Our paper contributes to the literature on open-ended investment funds and associated risks to financial stability.[4] Chernenko and Sunderam (2016) suggest that investment funds' cash holdings do not fully mitigate the price impact externality created by the fund liquidity transformation. Similarly to our model, a planner chooses a higher cash buffer and improve upon the market equilibrium. In other terms, a regulatory minimum liquidity requirement can correct for the pecuniary ex-

[2] See also Shleifer and Vishny (1992), Stein (2012), Greenwood et al. (2015), Brunnermeier and Pedersen (2008).

[3] See Farhi et al. (2009) and Grochulski (2013)

[4] See Feroli et al. (2014), Morris et al. (2017), Zeng (2017), Chen et al. (2010), Goldstein et al. (2017).

ternality. Kilenthong and Townsend (2011) argue that the market structure can also correct the pecuniary externality, when access to ex-post markets depends on the portfolio liquidity of market participants. One of the key assumptions of our model is that asset managers deliver diversification to their clients, e.g. better risk-return combinations. Lewrick and Schanz (2017) consider a framework similar to Diamond and Dybvig (1983) and assume that the investment in fund shares has lower volatility than the one in the underlying long-term assets. This attracts risk-averse households that seek to invest in fund shares despite lower expected returns.

Our second market failure is rooted in the existence of legacy, long-term contracts between households and institutional investors. An emerging literature is focusing on the role of institutional investors, including their risk-taking in good times and their possible pro-cyclical behaviour in times of market stress. Czech and Roberts-Sklar (2017) and Becker and Ivashina (2015) provide empirical evidence that insurance companies reach for yield. Ellul et al. (2018) focus on the impact of financial guarantees embedded in insurance contracts on financial stability and reach for yield. Douglas et al. (2017), Douglas and Roberts-Sklar (2018) and Fache Rousová and Giuzio (2019) study the response of insurance companies and pension funds to different shocks, highlighting the potential for pro-cyclical behaviour. Our model provides micro-foundations to a macroprudential approach to solvency regulation of these institutions.

Finally, our work is related to the literature on system-wide stress analysis. Baranova et al. (2017) build a representative agent model in which broker-dealers and hedge funds supply liquidity in corporate bond markets. They assess the degree to which redemptions and subsequent sales of assets by open-ended investment funds could have a destabilising effect on market prices. Aikman et al. (2019) and di Iasio et al. (2020) represent an evolution of the fund-dealer model. They have a larger set of representative agents, which correspond to key financial sectors. Agents interact in asset, repo (funding), and derivatives markets and face a range of solvency and liquidity constraints on their behaviour. Looking forward, one aim of our paper is to provide micro-foundations to these quantitative analyses.

2 The model

There are three dates, $t = 0, 1, 2$. The economy is populated by insurance companies and pension funds (shortly, institutional investors, IIs), asset managers (AMs), bankers and households (HHs). Figure 3 shows the timeline of relevant events.

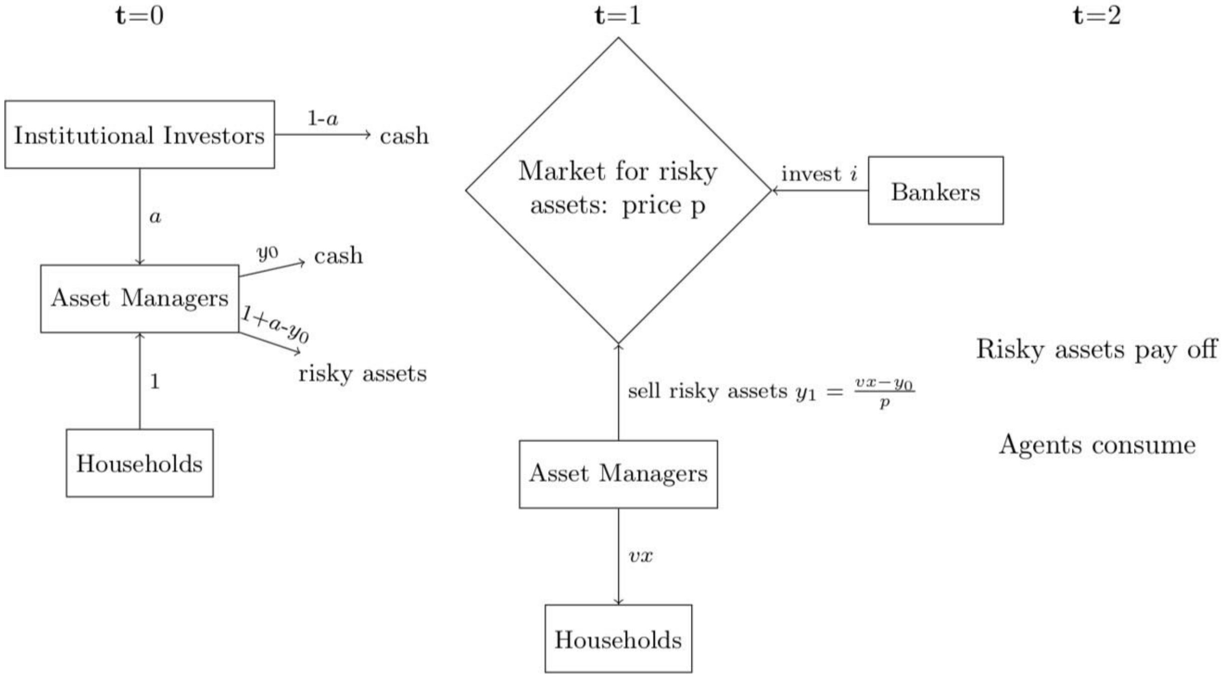

Figure 3: Timeline of relevant events in the model. At $t = 0$ IIs and AMs make their portfolio allocations: IIs choose the allocation a to AMs and AMs choose cash holdings y_0. At $t = 1$ bankers lever up their equity e, borrow $i - e$ and invest i in risky assets. At the same time, AMs liquidate $y_1 \equiv \frac{vx-y_0}{p} \geq 0$. The market clears at price p.

There are two investment technologies (assets). A safe assets, cash, that at $t+1$ returns one unit for each unit invested at t. The risky asset is such that each unit of cash invested at date $t = 0$ returns a random amount $\tilde{q}_Z \sim U[q - Z, q + Z]$, with $0 < Z < 1 < q$, at the final date. We assume that when the asset is managed by the AM, the risk of the asset decreases to $z < Z$. In the next sections we describe the problem of the agents.

2.1 Asset managers

Asset managers receive 1 and a from households and institutional investors, respectively. At time $t = 0$, the AM seeks to hold y_0 cash and invests the remaining $1 + a - y_0$ in risky assets. At $t = 1$ a fraction $x \in [0, 1]$ of HHs redeem and the AM pays back the NAV of the fund at $t = 1$. If cash is too low to meet redemptions, the AM sells y_1 risky assets. The NAV of the fund at $t = 1$ before redemptions are met is[5]

$$v \equiv \frac{1}{1+a}[y_0 + py_1 + q(1 + a - y_0 - y_1)]. \tag{1}$$

where p is the equilibrium price of risky assets at $t = 1$. The manager chooses y_0 and y_1 to maximise the expected value of her portfolio at $t = 2$:

$$u_{AM}(y) = q\,(1 + a - y_0 - y_1) \tag{2}$$

Holding cash and liquidating assets are both costly as $q \geq \max(1, p)$. The manager chooses y_0 and y_1 such that $y_0 + py_1 = vx$, so that

$$y_1 = \frac{vx - y_0}{p} \geq 0 \tag{3}$$

Proposition 1 *For a given a, u_{AM} is decreasing in y_0.*

Proof. See Appendix A. ■

2.2 Bankers

The banking system is made up of a continuum of unit mass of identical bankers. Each banker runs a bank and is endowed with cash on hand I at $t = 1$. We assume bankers demand $i(p) = I/p$ risky asset at $t = 1$, where $p \in (1, \pi q]$. The parameter $\pi < 1$ reflects balance sheet costs and other frictions that make the banker a second best user of the risky asset.

Assumption 1 $I > \underline{I} \equiv \frac{2qx}{(q-1)x+2}$.

Assumption 1 guarantees that $p > 1$ in equilibrium so that it is optimal for asset managers to rely, at least to the extent possible, upon market liquidity provided by bankers to meet redemptions. Indeed, whenever $p < 1$, asset managers would prefer to meet redemptions with cash only.

2.3 Institutional investors

There is a unit mass of identical institutional investors. They enter $t = 0$ with equity $e_{II} > 0$ (cash on hand), and $1 - e_{II}$ received from households in the previous period and must decide

[5] Since $y_0 + y_1 \leq \frac{qx}{1+\frac{x}{1+a}(q-1)}$, we have $v > 1$.

how to invest their total endowment 1. Relevantly, their liabilities are expressed in a fixed nominal amount in the sense that they committed to repay $\delta \equiv R(1-e_{II})$ to households at $t=2$, where R is the guaranteed return and $\delta < 1$. This feature permits to model one key driver of institutional investors' behavior over recent years, namely the widespread reach for yield driven by the gap between current market returns and returns promised to investors in the past.

We assume institutional investors operate under a VaR-like constraint such that the probability to fail to repaying the debt is lower than a specific positive value γ. The constraint captures risk-sensitive capital regulation, e.g. Solvency II for insurance companies, or a market-induced constraint on risk-taking. At $t=0$ institutional investors allocate a fraction $a \in [0,1]$ to asset managers and at $t=2$ receive back the NAV v_2 of the fund:

$$\tilde{v}_2 \equiv \frac{\tilde{q}_z(1+a-y_0-y_1)}{1+a-x}. \tag{4}$$

Institutional investors maximise expected utility:

$$\mathsf{E}u_{II}(a,\tilde{q}_z) = a\mathsf{E}(\tilde{v}_2) + 1 - a - \delta \tag{5}$$

where $\tilde{q}_z \sim U[q-z, q+z]$, under a solvency (VaR-like) constraint:

$$\mathsf{P}\{a\tilde{v}_2 + 1 - a < \delta\} \leq \gamma \tag{6}$$

Condition 6 states that the probability of default (left-hand side) must be lower than γ. The following result can be established by standard calculations.

Lemma 1 *The optimal allocation of IIs is*

$$\begin{cases} a = 1 \ \textit{if}\ \delta \leq \bar{\delta} \\ a(z) < 1 \ \textit{otherwise} \end{cases}$$

where $\bar{\delta} \equiv \frac{2-y_0-y_1}{2-x}\left[q - z(1-2\gamma)\right]$ *and* $a(z)$ *is strictly positive and decreasing in the relevant set of parameters.*

Discussion. The utility u_{II} is increasing in a, as $\mathsf{E}(v_2) > 1$ in equilibrium. However, the solvency constraint becomes binding for high values of δ. In that case, IIs must reduce their allocation to asset managers to de-risk. Interestingly, the threshold $\bar{\delta}$ is decreasing in the overall cost $y_0 + y_1$ of meeting redemptions.

Assumption 2 $\delta \leq \bar{\delta} \equiv \frac{q-z(1-2\gamma)}{1-x/2}\left[1 - \frac{x}{2\pi+(1-\pi)x}\right]$.

Assumption 2 guarantees that in the socially optimal equilibrium (see below), IIs can effectively allocate their whole endowment to AMs.

3 Competitive equilibrium allocations

At $t = 1$ the market for risky assets opens. Asset managers sell $y_1(p)$ and the banker buys up to $i(p)$ risky assets at the endogenous price p. The market clearing condition is then

$$y_1(p) = i(p) \tag{7}$$

We characterize equilibrium allocations in two sub-cases: abundant and scarce market liquidity.

3.1 Abundant market liquidity

We first characterize the equilibrium allocation when the supply of market liquidity is abundant. Bankers can absorb the largest possible sales of risky assets from AMs at the highest price $p = \pi q$. This happens when

$$I \geq \bar{I} \equiv \frac{2\pi q x}{(1-\pi)x + 2\pi}$$

Proposition 2 *When $I \geq \bar{I}$, the competitive equilibrium allocation is*

$$\begin{aligned}
&p = \pi q \\
&y_0 = 0 \quad \textit{and} \quad y_1 = \frac{x(1+a)}{\pi(1+a) + (1-\pi)x} \\
&i = \frac{I}{\pi q} = y_1 \\
&a = 1
\end{aligned}$$

Proof. When market liquidity is abundant, $p = \pi q$ for every amount of assets sold by AMs. From Proposition 1, AMs seek not hold cash and meet redemptions by liquidating $y_1 = \frac{x(1+a)}{\pi(1+a)+(1-\pi)x}$ assets. The investment of the banker that clears the market at $p = \pi q$ is $i = y_1$ (equation 7). From Lemma 1 and Assumption 2, it follows that $a = 1$. ■

Discussion. In our first case - abundant market liquidity - asset sales do not affect equilibrium prices. The supply of market liquidity is then large enough to prevent fire sales to emerge and externalities to have negative effects (see below). Under these conditions, AMs optimally hold no cash, while according to Assumption 2, IIs optimally allocate their whole endowment a to AMs. This is efficient, as IIs minimise their investment in cash (low yield technology).

3.2 Scarce market liquidity

Asset liquidation affects the market clearing price p when asset managers bid for a limited pool of market liquidity. We show that AMs still choose $y_0^{CE} = 0$, while they would be better off by holding some positive amount of cash (pecuniary externality, see Section 4).

Proposition 3 *When $I < \bar{I}$, the competitive equilibrium allocation is*

$$\begin{aligned} p^{CE} &= \frac{qsI}{qx - (1-s)I} \in (1, \pi q) \\ y_0^{CE} &= 0 \quad \textit{and} \quad y_1^{CE} = \frac{qx(1+a^{CE})}{(1+a^{CE})p^{CE} + x(q - p^{CE})} \\ i^{CE} &= y_1^{CE} \end{aligned}$$

and

$$\begin{cases} a^{CE} = 1 & \textit{if } \delta \leq \delta^{CE} \\ a^{CE} < 1 & \textit{if } \delta > \delta^{CE} \end{cases}$$

where $s = \frac{x}{1+a^{CE}}$ is the fraction of redemptions on the total portfolio managed by AMs and $\delta^{CE} = \frac{I}{qx}\left[q - z(1-2\gamma)\right]$.

Proof. From Proposition 1, if $p \geq 1$ the optimal choice of the asset manager is $y_0 = 0$. The expression for p^{CE} is derived from equation 7. Assumption 1 guarantees that $p \in (1, \pi q)$. With simple substitutions we obtain the value for y_1^{CE}. We get a^{CE} from Lemma 1 and simple substitutions. ■

4 Policy

In this section, we show that competitive equilibrium allocations are inefficient when market liquidity is scarce. This is due to a pecuniary externality in the cash buffer choice of AMs.

The model has several policy implications. First, liquidity regulation of AMs - i.e. regulatory minimum cash buffers - can solve the externality problem and implement a socially optimal allocation. Second, we consider solvency regulation of IIs, as captured by the solvency constraint (condition 6). When IIs allocate funds to AMs, solvency is also affected by the overall cost of meeting redemptions (see expression 4). We extend the model to the case of IIs purchasing risky assets at $t = 1$, alongside bankers. In principle, this additional demand drives up the clearing price p and reduces the overall cost of meeting redemptions. The probability distribution of the returns delivered by AMs to IIs shifts rightwards, accordingly. We show that a solvency regulation that accounts for this general equilibrium effect can fix or relax the externality problem. Both these policies - liquidity regulation of AMs and solvency regulation of IIs - are macroprudential in nature.

4.1 Liquidity regulation of asset managers

Section 3.2 demonstrates that AMs seek $y_0^{CE} = 0$ in the competitive equilibrium under scarce market liquidity. Proposition 4 shows that this choice is inefficient.

Proposition 4 *In the scarce liquidity region, if π is low enough*[6]*, a regulatory minimum cash buffer $y_0^{LIQ} > 0$ can implement a socially optimal allocation:*

$$
\begin{aligned}
&p^{LIQ} = \pi q \\
&y_0^{LIQ} = \frac{qx - \left(1 + \frac{x}{1+a}\frac{1-\pi}{\pi}\right) I}{1 + \frac{x}{1+a}(q-1)}, \; y_1^{LIQ} = \frac{I}{\pi q} \\
&\begin{cases} a^{LIQ} = 1 & \text{if } \delta \leq \delta^{LIQ} \\ a^{LIQ} < 1 & \text{if } \delta > \delta^{LIQ} \end{cases}
\end{aligned}
$$

where δ^{LIQ} is a decreasing function of I.[7]

Proof. See Appendix B. ■

Discussion. A pecuniary externality emerges in the competitive equilibrium. Individual asset managers disregard the general equilibrium effect of their cash choice and seek to hold too little cash. This drives up asset liquidation and the overall cost of meeting redemptions.

[6] The condition is that $\pi < \frac{1}{1+\frac{x}{1+a^{CE}}(q-1)}$. This sets a limit on disutility experienced by bankers due to a higher market price.

[7] More specifically $\delta^{LIQ} = \frac{1}{2-x}\left[2 - \frac{2qx}{2+x(q-1)} - \frac{(2-x)(1-\pi q)}{\pi q[2+x(q-1)]}I\right][q - z(1-2\gamma)]$.

The utility of AMs would increase if they hold cash y_0^{LIQ} such that the corresponding sales of assets y_1^{LIQ} required to meet redemptions is consistent with $p = \pi q$. We also show that y_0^{LIQ} implement a socially optimal allocation. The cash y_0^{LIQ} can be interpreted as a regulatory minimum cash buffer.

Regulatory minimum cash buffers reduce the cost of meeting redemptions and improves the fund's NAV distribution v_2^{LIQ}. More specifically, $v_2(y_0^{LIQ}, y_1^{LIQ})$ stochastically dominates $v_2(y_0^{CE}, y_1^{CE})$, as expressed in equation 4. This ultimately affects the expected utility and the solvency constraint of IIs (see expressions 5 and 6).

Result 1 $\delta^{LIQ} \geq \delta^{CE}$.

Discussion. Result 1 states that the liquidity regulation of AMs helps IIs with lower capital e_{II} and/or higher guaranteed returns R to boost their allocation a to AMs. The inefficiently high cost of meeting redemptions adversely affects the solvency constraint of IIs and, ultimately, their allocation to AMs. The stochastic dominance of $v_2^{LIQ}(y_0^{LIQ})$ over $v_2(y_0^{CE})$ implies that $a^{LIQ} > a^{CE}$ for IIs with weaker balance sheets. Regulatory minimum cash buffers guarantee that the cash is held by those that do face liquidity risk (AMs) and relatively less by those that do not (IIs).

4.2 Solvency regulation of institutional investors

This section extends our baseline model to the case where IIs can purchase risky assets at $t = 1$ (see Figure 4). IIs would need to have cash and balance sheet space, i.e. their solvency constraint should not be binding at $t = 1$. However, these two conditions may conflict. Indeed, at $t = 0$ IIs choose $a < 1$ if and only if the solvency constraint is binding (see Lemma 1).

We first show that when in the competitive equilibrium IIs have cash at $t = 1$, purchasing $d > 0$ risky assets would increase their utility (Proposition 5). The mechanism operates via a higher equilibrium price that reduces the overall cost of meeting redemptions and increases the net asset value of investment fund shares IIs hold. Ultimately, purchases will improve the risk-adjusted return of the IIs' portfolio.

Proposition 5 *In the competitive equilibrium, for a given cash holding $1-a > 0$, the utility of IIs is increasing in asset purchases d. IIs invest $D = \min\{\pi q y_1^{CE}(\pi q) - I, 1-a\}$ in asset purchases ($d = \frac{D}{p}$).*

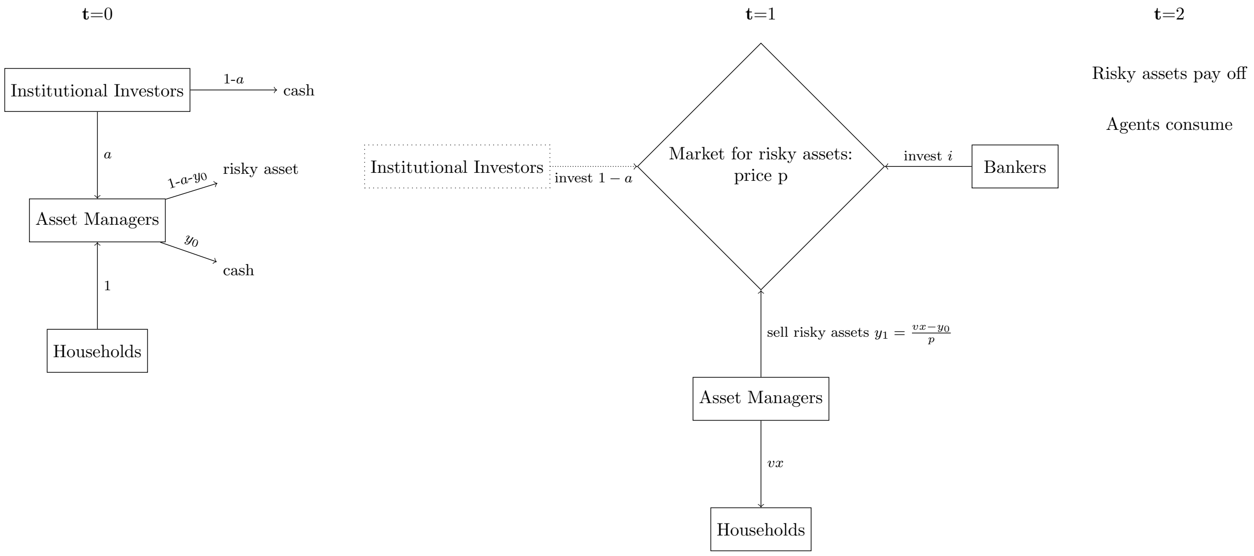

Figure 4: Timeline of relevant events when Institutional Investors purchase risky assets at $t = 1$.

Proof. See Appendix C. ■

Discussion. When $1 - a$ is large enough, IIs and bankers invest in asset purchases $D = \pi q y_1^{CE}(\pi q)$ and I, respectively, and the clearing price is $p = \pi q$. When instead IIs do not hold enough cash, the equilibrium price is $p < \pi q$. IIs indeed may fail to internalise this general equilibrium effect and hold no or too little cash at $t = 0$.

This market failure calls for a macroprudential approach to the solvency regulation of IIs. Consider a social planner that can set γ at $t = 0$ such that the resulting cash holding $1 - a$ is sufficient to buy assets at $t = 1$ and increase the price up to $p = \pi q$.

Proposition 6 *In the scarce liquidity region, a socially optimal allocation with macroprudential solvency regulation of IIs is*

$$
\begin{aligned}
p^{SOL} &= \pi q \\
y_0^{SOL} &= 0, y_1^{SOL} = \frac{qx}{(1 - \frac{x}{1+a^{SOL}})\pi q + \frac{qx}{1+a^{SOL}}} \\
a^{SOL} &= 1 - \pi q y_1^{SOL} + I
\end{aligned}
$$

Proof. See Appendix D. ■

Discussion. Consider the competitive equilibrium of Section 3.2 where AMs hold no cash and the cost of meeting redemptions is inefficiently high. A planner can set γ such that the corresponding solvency constraint induces IIs to hold cash $1 - a^{SOL}$. At $t = 1$, AMs liquidate assets y_1^{SOL}, while IIs and bankers invest $1 - a^{SOL}$ and I, respectively. The total demand for assets is high enough to sustain a price $p = \pi q$. This approach to solvency regulation is macroprudential in both a cross-section and time dimension (Borio, 2003). In a cross-section dimension, as it accounts for the general equilibrium effects of purchases from individual IIs. Additional demand for assets liquidated by AMs shifts rightwards the probability distribution of returns that AMs deliver to IIs and ultimately reduce balance sheet risks for IIs. As shown in Appendix C, the probability of default of IIs at $t = 1$ - accounting for purchases d - is not higher than γ, as set at $t = 0$. The approach is macroprudential in a time dimension as relatively tighter regulation at $t = 0$ guarantees that IIs have enough buying power at $t = 1$ to make counter-cyclical investment and stabilise the market when the supply of market liquidity from bankers is scarce.

Corollary 1 *In the scarce liquidity region, a socially optimal allocation with macroprudential solvency regulation of IIs can be decentralised (see Proposition 6).*

Proof. See Appendix E. ■

Discussion. In Corollary 1, individual institutional investors do internalize ex-ante the general equilibrium effect of purchasing risky assets at the interim date. It shows that they would be better off by holding enough cash to purchase liquidated assets and push the clearing price up to πq.

4.3 Liquidity regulation of AMs vs solvency regulation of IIs

Allocations under liquidity regulation of AMs and solvency regulation of IIs are different. In this section we compare the welfare properties of the two allocations.

Proposition 7 *From a social welfare viewpoint, solvency regulation of IIs is superior to the liquidity regulation of AMs when market liquidity supplied by bankers is not too scarce, i.e. when $I > \tilde{I}(a^{SOL})$.*

Proof. See Appendix F. ■

Discussion. Welfare results and emerging equilibrium allocations crucially depend on market liquidity. When liquidity is abundant, i.e. $I \geq \bar{I}$, the competitive equilibrium is efficient (see Section 3.1). In the scarce market liquidity region - $I < \bar{I}$ - two policies can implement efficiency. These two policies can be ranked in terms of total welfare. For $I \in [\tilde{I}(a^{SOL}), \bar{I})$, the regulator should seek to impose a solvency regulation on institutional investors, namely a relatively tighter solvency constraint at $t = 0$ so that institutional investors have enough buying power at $t = 1$ to support equilibrium prices $p = \pi q$. For $I < \tilde{I}(a^{SOL})$ instead, market liquidity supplied by bankers is so scarce that allowing institutional investors to buy the dip is not the efficient mechanism. This is because a very tight solvency constraint at $t = 0$ means a very low allocation to asset managers that, in the model, are experts in investing in the risky and most productive assets. In that case, the regulator prefers to impose a minimum cash buffer on asset managers and reduce the demand for market liquidity at $t = 1$. Both policies imply higher cash holdings at $t = 0$, as compared to the competitive equilibrium. However, they are fundamentally different. Cash holdings of institutional investors imposed by solvency regulation are safe assets that create a sufficient headroom that would in turn allow investors to take on more risk at $t = 1$. The friction that creates scope for these cash holdings is the interaction between fixed guaranteed returns promised by institutional investors in the past (δ) and the need for the regulator to preserve the stability of these intermediaries (solvency regulation). Cash holdings of asset managers instead play the role of a liquidity buffer. In the model, they structurally reduce the residual demand of asset managers for market liquidity, i.e. the amount of risky assets that must be sold to meet redemptions. The friction that motivates this regulatory intervention is the liquidity mismatch in asset managers who invest in partially illiquid assets while issuing shares that are redeemable on demand.

5 Conclusion

Although very stylised, the model captures relevant features of the post-crisis global financial system: the shift towards market-based finance, the increasing relevance of asset managers that allocate a larger fraction of global capital, the popularity of investment fund shares in the portfolios of insurance companies and pension funds. The model connects these developments in a parsimonious way and offers a perspective on some policy-relevant questions. Behaviours and constraints of different agents populating this system may give rise to market failures. Asset managers can fail to internalise equilibrium effects of fire sales and hold inefficiently low cash buffers. This increases the overall cost of meeting redemptions and also adversely affect institutional investors that hold investment fund shares. We show that regulatory minimum cash buffers can be an effective macroprudential tool and mitigate the market failure mentioned above. Furthermore, insurance companies and pension funds can fail to internalise the effects of their ex-ante risk taking in decreasing their ex-post risk-taking capacity which, in times of stress, determines their buying power of assets liquidated by asset managers hit by redemption shocks. We show that a macroprudential approach to the solvency regulation of insurance companies and pension funds would allow the latter to purchase risky assets in times of stress and reduce the overall costs of fire sales. These insights can inform the ongoing broader debate on the regulation of nonbank financial institutions.

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Appendix A: Proof of Proposition 1

Proof. Substituting 3 into expression 1 we get:

$$v = \frac{p(1+a)}{p(1+a)+(q-p)x}\left[q - \frac{q(p-1)}{(1+a)p}y_0\right]$$

The utility function 2 can be rewritten as:

$$\begin{aligned} u_{AM}(y) &= q\left(1+a-y_0-\frac{vx-y_0}{p}\right) \\ &= q\left[1+a-\frac{xq(1+a)}{p(1+a)+(q-p)x}-\frac{(p-1)(1+a-x)}{p(1+a)+(q-p)x}y_0\right] \end{aligned}$$

The coefficient of y_0 is nonnegative, as $p > 1$ according to Assumption 1 (see Section 2.2). ■

Appendix B: Proof of Proposition 4

Proof. We first show that AMs are better off if they hold cash up to the point where the associated y_1 is such that the market clearing price is $\bar{p} = \pi q$. Let $u_{AM}(y^{CE})$ be the utility of AMs in the competitive equilibrium. Consider the following AM cash choice:

$$\bar{y}_0 = \bar{v}x - \bar{p}\bar{y}_1$$

where $\bar{y}_1 = y_1^{CE} - \epsilon$ are sales of assets, with $\epsilon > 0$. The utility of redeeming HHs is $\bar{v}x = \frac{qx+\frac{x}{1+\bar{a}}q(\bar{p}-1)\bar{y}_1}{1+\frac{x}{1+\bar{a}}(q-1)}$ and let $u_{AM}(\bar{y})$ be the utility of the asset manager when she holds $\bar{y}_0 = \bar{v}x - \bar{p}\bar{y}_1$. The corresponding market-clearing price is $\bar{p} \in (1, \pi q]$. We will show that[8]

$$u_{AM}(\bar{y}) + \bar{v}x > u_{AM}(y^{CE}) + vx \tag{8}$$

The utility of AMs and HHs in the competitive equilibrium is:

$$u_{AM}(y^{CE}) + vx = q\left[1+a^{CE}-y_1^{CE}\right] + \frac{p^{CE}qx}{p^{CE}+\frac{x}{1+a^{CE}}(q-p^{CE})}$$

[8]Note that $u_{AM} + vx$ is the early and late shareholders' utility. Similarly, one can show that $u_{AM}(\bar{y}) - u_{AM}(y^{CE}) > 0$.

and in the coordinated equilibrium (all asset managers hold cash $\bar{y}_0$) is

$$\begin{aligned} u_{AM}(\bar{y}) + \bar{v}x &= q\left[1 + \bar{a} - y_1(p=1,\bar{a}) + \left(1 - \frac{\frac{x}{1+\bar{a}}q}{1+\frac{x}{1+\bar{a}}(q-1)}\right)(\bar{p}-1)\bar{y}_1\right] \\ &+ v(p=1,\bar{a})x + \frac{\frac{x}{1+\bar{a}}q(\bar{p}-1)\bar{y}_1}{1+\frac{x}{1+\bar{a}}(q-1)}, \end{aligned}$$

where $y_1(p=1,\bar{a}) = \frac{qx}{1+\frac{x}{1+\bar{a}}(q-1)} = v(p=1,\bar{a})x$.

Plugging in the above formulas and reorganizing terms in the inequality (5) results in

$$\begin{aligned} q\left(a^{CE} - \bar{a}\right) + q\left(y_1(p=1,\bar{a}) - y_1(p^{CE},a^{CE})\right) + \left(v(p^{CE},a^{CE}) - v(p=1,\bar{a})\right)x \\ < \frac{q}{1+\frac{x}{1+\bar{a}}(q-1)}(\bar{p}-1)\bar{y}_1, \end{aligned}$$

and by the market clearing condition we get

$$\begin{aligned} q\left(a^{CE} - \bar{a}\right) + q\left(y_1(p=1,\bar{a}) - y_1(p^{CE},a^{CE})\right) + \left(v(p^{CE},a^{CE}) - v(p=1,\bar{a})\right)x \\ < \frac{q}{1+\frac{x}{1+\bar{a}}(q-1)}\left((p^{CE}-1)y_1(p^{CE},a^{CE}) + \epsilon\right) \end{aligned}$$

We can rewrite it as

$$\begin{aligned} q\left(a^{CE} - \bar{a}\right) + (q-x)\left(y_1(p=1,\bar{a}) - y_1(p=1,a^{CE})\right) \\ +q\left(y_1(p=1,a^{CE}) - y_1(p^{CE},a^{CE})\right) + \left(v(p^{CE},a^{CE}) - v(p=1,a^{CE})\right)x \\ < \frac{q}{1+\frac{x}{1+\bar{a}}(q-1)}\left((p^{CE}-1)y_1(p^{CE},a^{CE}) + \epsilon\right) \end{aligned} \tag{9}$$

Since $\bar{a}$ is an increasing function of ϵ (by formulas in section 2.1 and the implicit function theorem) or $\bar{a} \equiv 1$, the left-hand side of (9) is a decreasing function of ϵ or $q\left(a^{CE} - \bar{a}\right) + (q-x)\left(y_1(p=1,\bar{a}) - y_1(p=1,a^{CE})\right) \leq 0$, and the right-hand side of (9) is an increasing function of ϵ. Both the right and left-hand sides of (9) are increasing functions of the price $p^{CE} \in [1, \pi q)$. Notice that

$$\begin{aligned} q\left(y_1(p=1,a^{CE}) - y_1(p^{CE},a^{CE})\right) + \left(v(p^{CE},a^{CE}) - v(p=1,a^{CE})\right)x \\ = \frac{q}{1+\frac{x}{1+a^{CE}}(q-1)}\left((p^{CE}-1)y_1(p^{CE},a^{CE})\right), \end{aligned} \tag{10}$$

i.e., for $\epsilon = 0$, (9) holds with equality. By the properties of right and left-hand sides of (9), the inequality (9) (and hence the inequality (5)) holds.

Since both utility functions of AMs and HHs in the coordinated equilibrium are increasing in ϵ, the price in the coordinated market equilibrium is $\bar{p} = \pi q$.

To show that (y^*, p^*) is a socially optimal allocation we need to analyze how the utility of bankers changes. In the competitive equilibrium bankers get

$$\left(\frac{\pi q}{p^{CE}} - 1\right) I$$

and in the coordinated equilibrium (all asset managers hold cash $\bar{y}_0$)

$$\left(\frac{\pi q}{\bar{p}} - 1\right) I$$

One can show that

$$\left(\frac{\pi q}{p^{CE}} - 1\right) I - \left(\frac{\pi q}{\bar{p}} - 1\right) I = \pi q \epsilon$$

We also need to take into account the change in the IIs' utility on top of the change in the NAV of the fund at $t = 2$, i.e., $a^{CE} - \bar{a}$.

In order to prove that the coordinated allocation $(\bar{y}, \bar{p})$ is a Pareto improvement, we need to show that

$$\begin{aligned}
&(q-1)\left(a^{CE} - \bar{a}\right) + (q - x)\left(y_1(p = 1, \bar{a}) - y_1(p = 1, a^{CE})\right) \\
+q&\left(y_1(p = 1, a^{CE}) - y_1(p^{CE}, a^{CE})\right) + \left(v(p^{CE}, a^{CE}) - v(p = 1, a^{CE})\right) x + \pi q \epsilon \\
&< \frac{q}{1 + \frac{x}{1+\bar{a}}(q-1)} \left((p^{CE} - 1) y_1(p^{CE}, a^{CE}) + \epsilon\right)
\end{aligned} \tag{11}$$

holds for all $\epsilon > 0$, given $p^{CE} \in [1, \pi q)$.

By (10), we can rewrite (11) as

$$\begin{aligned}
&(q-1)\left(a^{CE} - \bar{a}\right) + (q - x)\left(y_1(p = 1, \bar{a}) - y_1(p = 1, a^{CE})\right) \\
&\quad + \frac{q}{1 + \frac{x}{1+a^{CE}}(q-1)} (p^{CE} - 1) y_1(p^{CE}, a^{CE}) + \pi q \epsilon \\
&\quad < \frac{q}{1 + \frac{x}{1+\bar{a}}(q-1)} \left((p^{CE} - 1) y_1(p^{CE}, a^{CE}) + \epsilon\right)
\end{aligned} \tag{12}$$

It is easy to notice that

$$\frac{q}{1+\frac{x}{1+a^{CE}}(q-1)}(p^{CE}-1)y_1(p^{CE},a^{CE}) \leq \frac{q}{1+\frac{x}{1+\bar{a}}(q-1)}(p^{CE}-1)y_1(p^{CE},a^{CE})$$

and similarly as before

$$(q-1)\left(a^{CE}-\bar{a}\right)+(q-x)\left(y_1(p=1,\bar{a})-y_1(p=1,a^{CE})\right) \leq 0$$

Therefore, if $\pi < \frac{1}{1+\frac{x}{1+\bar{a}}(q-1)}$, the coordinated allocation $(\bar{y},\bar{p})$ (and also (y^*,p^*)) gives a Pareto improvement.

Finally, the socially optimal cash buffer is $y_0^* = v(p^*)x - I$. By the market clearing condition $y_1^* = \frac{I}{\pi q}$ and by substituting for the NAV we get

$$y_0^* = \frac{qx - I\left(1+\frac{x}{1+a}\frac{1-\pi}{\pi}\right)}{1+\frac{x}{1+a}(q-1)}$$

■

Appendix C: Proof of Proposition 5

Proof. For now let's assume $1-a>0$ so that IIs can invest in risky assets at $t=1$. IIs choose their demand d for risky assets or, equivalently, the market price, which is a solution to the following maximisation problem

$$\max_{p^{CE}\leq p\leq \pi q} a\mathsf{E}\left(\frac{\tilde{q}_z\left(1+a-y_1^{CE}(p)\right)}{1+a-x}\right)+d(p)(q-p)+1-a-\delta \tag{13}$$

under a solvency constraint

$$\mathsf{P}\left\{a\frac{\tilde{q}_z\left[1+a-y_1^{CE}(p)\right]}{1+a-x}+d(p)(\tilde{q}_Z-p)+1-a<\delta\right\} \leq \gamma \tag{14}$$

where $p^{CE}\leq p\leq \pi q$, $d(p)\leq y_1^{CE}(p)-i(p) = \frac{qx}{p+\frac{x}{1+a}(q-p)} - \frac{I}{p}$ and $d(p)\leq 1-a$.

The utility function 13 and the solvency constraint 14 are augmented with the extra term $d(p)(q-p)$ that captures asset purchases. The term $d(p)(\tilde{q}_Z-p)$ in the constraint 14 is computed at the market clearing price p, i.e. the solvency regulation considers the general equilibrium effect of asset purchases. When $d > 0$ the equilibrium price is higher than p^{CE}.

Notice that $d\left(p^{CE}\right)\left[q-(1-2\gamma)Z-p^{CE}\right]=0$ and, since $\delta < \bar{\delta}$, we have $q-(1-2\gamma)z < 1$ (see Section 2.3). The utility function of IIs investors is strictly increasing in d.

We can rewrite the solvency constraint as

$$\delta-1+a-(q-(1-2\gamma)z)\frac{a\left(1+a-y_1^{CE}(p)\right)}{1+a-x} \leq d(p)\left(q-(1-2\gamma)Z-p\right) \tag{15}$$

Both sides of the inequality (15) are decreasing in $p \in [p^{CE}, \pi q]$.

Since $a < 1$, the solvency constraint at $t = 0$ is binding, i.e. a satisfies

$$\delta-1+a-(q-(1-2\gamma)z)\frac{a\left(1+a-y_1^{CE}(p^{CE})\right)}{1+a-x}=0$$

which implies that for $p = p^{CE}$ the solvency constraint (14) is always satisfied. Define $p_Z \in [p^{CE}, \pi q]$ as the highest price for which the solvency constraint (15) is satisfied. Notice that p_Z is decreasing in Z, for Z small enough we have $p_Z = \pi q$.[9]

Suppose now that the cash at hand of institutional investors is higher that $p^{CE}y_1^{CE}(p^{CE})$ (i.e.,$1-a > p^{CE}y_1^{CE}(p^{CE})$). Then institutional investors would be the only buyers and their utility is

$$a\mathsf{E}\left(\frac{\tilde{q}_z(1+a-y_1^{CE}(p))}{1+a-x}\right)+y_1^{CE}(p)(q-p)+1-a-\delta \tag{16}$$

The utility is decreasing in p and institutional investors will never push the market price above $p = \pi q$.

As a result, the optimal choice of the institutional investor is $D = \min\{p_Z\left(y_1^{CE}(p_Z)-\frac{I}{p_Z}\right), 1-a\}$, and the corresponding market clearing price, p, if IIs are allowed to trade at $t = 1$, is such that

$$py_1^{CE}(p) = I + D$$

The price of the risky asset will go up, i.e., $p \geq p^{CE}$, which benefits both asset managers and shareholders (see also the proof of Proposition 4). ■

[9] $Z \leq \frac{q-\pi q}{1-2\gamma}-\frac{1}{(1-2\gamma)d(\pi q)}\left(\delta-1+a-(q-(1-2\gamma)z)\frac{a\left(1+a-y_1^{CE}(\pi q)\right)}{1+a-x}\right)$ the solvency constraint (15) is satified for all $p \in [p^{CE}, \pi q]$. For plausible parameter values we have $1 \leq -\frac{1}{(1-2\gamma)d(\pi q)}\left(\delta-1+a-(q-(1-2\gamma)z)\,a\right)$ which implies that the solvency constraint (15) is satified for all $p \in [p^{CE}, \pi q]$, i.e., $p_Z = \pi q$ always.

Appendix D: Proof of Proposition 6

Proof. We will first show that for reasonable risk of the asset, Z, the solvency constraint of IIs is still satisfied if IIs engage in trade at the interim date.

From the $t = 0$ solvency constraint

$$\mathsf{P}_0 = \mathsf{P}\{a\frac{\tilde{q}_z(1 + a - y_1^{CE}(p^{CE}))}{1 + a - x} + 1 - a < \delta\} \leq \gamma$$

we get the feasible allocation a to asset managers and the cash holdings of IIs $(1 - a)$. With simple algebra, the probability of default at $t = 0$ is

$$\mathsf{P}_0 = \frac{1}{2z}\left(\frac{1}{a\frac{1+a-y_1^{CE}(p^{CE})}{1+a-x}}(\delta - 1 + a) - (q - z)\right)$$

The solvency constraint $t = 1$ is

$$\mathsf{P}_1 = \mathsf{P}\{a\frac{\tilde{q}_z\left(1 + a - y_1^{CE}(\pi q)\right)}{1 + a - x} + d(\pi q)(\tilde{q}_Z - \pi q) + 1 - a < \delta\} \leq \gamma$$

and includes the asset purchase d calculated at the first best price πq. After substitutions we get:

$$\mathsf{P}_1 = \frac{1}{2\left(a\frac{1+a-y_1^{CE}(\pi q)}{1+a-x}z + d(\pi q)Z\right)} \times$$
$$\left[\delta - 1 + a + d(\pi q)\left(Z - q(1 - \pi)\right) - a\frac{1 + a - y_1^{CE}(\pi q)}{1 + a - x}(q - z)\right].$$

The optimal purchases are $d(\pi q) = \frac{1-a}{\pi q}$. For plausible parameter values we have $\mathsf{P}_1 \leq \mathsf{P}_0$ - see the ratio:

$$\frac{\mathsf{P}_1}{\mathsf{P}_0} = \frac{2a\frac{1+a-y_1^{CE}(p^{CE})}{1+a-x}z}{2\left(a\frac{1+a-y_1^{CE}(\pi q)}{1+a-x}z + d(\pi q)Z\right)}\frac{\delta - 1 + a + d(\pi q)\left(Z - q(1 - \pi)\right) - a\frac{1+a-y_1^{CE}(\pi q)}{1+a-x}(q - z)}{\delta - 1 + a - a\frac{1+a-y_1^{CE}(p^{CE})}{1+a-x}(q - z)}$$

The first term is of course smaller than one. The second term

$$\frac{\delta - 1 + a + d(\pi q)\left(Z - q(1-\pi)\right) - a\frac{1+a-y_1^{CE}(\pi q)}{1+a-x}(q-z)}{\delta - 1 + a - a\frac{1+a-y_1^{CE}(p^{CE})}{1+a-x}(q-z)}$$

is smaller than one if

$$\frac{Z - q(1-\pi)}{q-z} \leq \frac{1}{d(\pi q)} \frac{a}{1+a-x}\left(y_1^{CE}(p^{CE}) - y_1^{CE}(\pi q)\right)$$

which is satisfied if the risk of the asset Z is reasonable.

We will now show that it is socially optimal to increase the cash holdings of IIs till $\bar{p} = \pi q$. We assume that at $t = 1$ IIs buy risky assets for $1-a$ if there is no trade restriction. Suppose IIs choose $\bar{a} = a - \epsilon$ instead of a in the first period ($\epsilon > 0$). We denote by $\bar{p}$ the corresponding price, i.e., a market-clearing price if IIs buy assets for $1 - \bar{a}$ at $t = 1$. We will show that this change gives a Pareto improvement, i.e.,

$$(\bar{u}_{AM} + \bar{u}_B + \bar{v}x + d(\bar{p})(q - \bar{p}) - \bar{a}) - (u_{AM} + u_B + vx + d(p)(q-p) - a) > 0$$

$$\begin{aligned} &q(1+\bar{a} - y_1^{CE}(\bar{p},\bar{a})) + (\frac{\pi q}{\bar{p}} - 1)I + \bar{p}y_1^{CE}(\bar{p},\bar{a}) + \left(y_1^{CE}(\bar{p},\bar{a}) - \frac{I}{\bar{p}}\right)(q-\bar{p}) - \bar{a} \\ &- \left(q(1+a-y_1^{CE}(\tilde{p},a)) + (\frac{\pi q}{\tilde{p}} - 1)I + \tilde{p}y_1^{CE}(\tilde{p},a) + \left(y_1^{CE}(\tilde{p},a) - \frac{I}{\tilde{p}}\right)(q-\tilde{p}) - a\right) > 0 \end{aligned}$$

$$(\frac{1}{\tilde{p}} - \frac{1}{\bar{p}})qI(1-\pi) - (q-1)\epsilon > 0$$

or

$$(\frac{1}{\tilde{p}} - \frac{1}{\bar{p}})qI(1-\pi) > (q-1)\epsilon$$

We have

$$(\frac{1}{\tilde{p}} - \frac{1}{\bar{p}})qI(1-\pi) \geq (\bar{p} - \tilde{p})\frac{I(1-\pi)}{\pi p} > (q-1)\epsilon$$

and since $\bar{p} = p(\epsilon)$ is strongly increasing in ϵ the inequality holds.

$$(\frac{1}{\tilde{p}} - \frac{1}{\bar{p}})qI(1-\pi) = \frac{\bar{p}-\tilde{p}}{\tilde{p}\bar{p}}qI(1-\pi) \approx \frac{qI(1-\pi)}{I - qx\left(\frac{p}{p+\frac{x}{1+a}(q-p)}\right)^2(1-\frac{x}{1+a})}\epsilon$$

■

Appendix E: Proof of Corollary 1

Proof. Suppose at the initial date, IIs know that they will be able to buy assets at the interim date.

We know that IIs will not spend more than

$$\min\left(py_1(p) - I, 1-a\right)$$

on the risky asset at the interim date, and $py_1(p) = I + dp$ by the market clearing condition. We have

$$\min\left(py_1(p) - I, 1-a\right) = \min\left(dp, 1-a\right)$$

Since $dp(d)$ is increasing in d, and IIs'utility function is strictly increasing in d, IIs will spend all the cash at hand at the interim date, i.e., they will buy risky assets for $1-a$.

The IIs' maximisation problem becomes

$$\max_{a\in[0,1]} a\mathsf{E}\left(\frac{\tilde{q}_z\left(1+a-y_1^{CE}(a)\right)}{1+a-x}\right) + \frac{1-a}{p(a)}(q-p(a)) + 1 - a - \delta \tag{17}$$

under a solvency constraint:

$$\mathsf{P}\{a\frac{\tilde{q}_z\left(1+a-y_1^{CE}(a)\right)}{1+a-x} + \frac{1-a}{p(a)}(\tilde{q}_Z - p(a)) + 1 - a < \delta\} \leq \gamma \tag{18}$$

where $y_1^{CE}(a) = \frac{qx}{p(a)+\frac{x}{1+a}(q-p(a))}$, and

$$p(a) = \frac{(I+1-a)\frac{qx}{1+a}}{qx - (I+1-a)(1-\frac{x}{1+a})}$$

which is a strongly decreasing function.

IIs' utility function

$$
\begin{aligned}
& a\mathsf{E}\left(\frac{\tilde{q}_z\left(1+a-y_1^{CE}(a)\right)}{1+a-x}\right)+\frac{1-a}{p(a)}(q-p(a))+1-a-\delta \\
& =a\frac{q\left(1+a-y_1^{CE}(a)\right)}{1+a-x}+d(a)q-(1-a)+1-a-\delta \\
& =aq\frac{1+a-y_1^{CE}(a)}{1+a-x}+d(a)q-\delta
\end{aligned}
$$

is decreasing in a:

$f_1(a)=\frac{1+a-y_1^{CE}(a)}{1+a-x}$ is decreasing in a for a close to one since for $\bar{a}$ such that $p(\bar{a})=q$ we have $f_1'(\bar{a})=-\frac{1}{1+\bar{a}-x}(y_1^{CE}(\bar{a}))_a'<0$

$f_2(a)=d(a)=\frac{1-a}{p(a)}$ is decreasing in a for a close to one since we have $f_1'(a=1)=-p(a)<0$.

We conclude that IIs will buy assets at the interim date till $p=\pi q$ if the solvency constraint is satisfied.

We will now show that for reasonable values of the risk of the asset, Z, the solvency constraint of IIs is still satisfied if IIs engage in trade at the interim date.

The solvency constraint of uniformed IIs at $t=0$ is

$$
\mathsf{P}\{a\frac{\tilde{q}_z(1+a-y_1^{CE}(p^{CE}(a),a))}{1+a-x}+1-a<\delta\}\leq\gamma
$$

where $p^{CE}(a)=\frac{I\frac{qx}{1+a}}{qx-I(1-\frac{x}{1+a})}$.

$$
\mathsf{P}^U=\mathsf{P}\{a\frac{\tilde{q}_z(1+a-y_1^{CE}(p^{CE}(a),a))}{1+a-x}+1-a<\delta\}=\frac{1}{2z}\left(\frac{1}{a\frac{1+a-y_1^{CE}(p^{CE}(a),a)}{1+a-x}}(\delta-1+a)-(q-z)\right)
$$

The solvency constraint of informed IIs at $t=0$ is

$$
\mathsf{P}\{a\frac{\tilde{q}_z\left(1+a-y_1^{CE}(p(a),a)\right)}{1+a-x}+d(a)(\tilde{q}_Z-p(a))+1-a<\delta\}\leq\gamma
$$

where $p(a)=\frac{(I+1-a)\frac{qx}{1+a}}{qx-(I+1-a)(1-\frac{x}{1+a})}\leq p^{CE}(a)$.

$$\mathsf{P}^I = \mathsf{P}\{a\frac{\tilde{q}_z\left(1+a-y_1^{CE}(p(a),a)\right)}{1+a-x} + d(a)(\tilde{q}_Z - p(a)) + 1 - a < \delta\}$$
$$= \frac{1}{2\left(a\frac{1+a-y_1^{CE}(p(a),a)}{1+a-x}z + d(a)Z\right)}\left(\delta - 1 + a + d(a)\left(p(a) - (q-Z)\right) - a\frac{1+a-y_1^{CE}(p(a),a)}{1+a-x}(q-z)\right)$$

where $d(a) = \frac{1-a}{p(a)}$

For plausible parameter values we have $\mathsf{P}_1 \leq \mathsf{P}_0$ - see the ratio:

$$\frac{\mathsf{P}_1}{\mathsf{P}_0} = \frac{2a\frac{1+a-y_1^{CE}(p^{CE}(a),a)}{1+a-x}z}{2\left(a\frac{1+a-y_1^{CE}(p(a),a)}{1+a-x}z + d(a)Z\right)} \frac{\delta - 1 + a + d(a)\left(p(a) - (q-Z)\right) - a\frac{1+a-y_1^{CE}(p(a),a)}{1+a-x}(q-z)}{\delta - 1 + a - a\frac{1+a-y_1^{CE}(p^{CE}(a),a)}{1+a-x}(q-z)}$$

The first term is of course smaller than one. The second term

$$\frac{\delta - 1 + a + d(a)\left(p(a) - (q-Z)\right) - a\frac{1+a-y_1^{CE}(p(a),a)}{1+a-x}(q-z)}{\delta - 1 + a - a\frac{1+a-y_1^{CE}(p^{CE}(a),a)}{1+a-x}(q-z)}$$

is smaller than one if

$$\frac{p(a) - (q-Z)}{q-z} \leq \frac{1}{d(a)}\frac{a}{1+a-x}\left(y_1^{CE}(p^{CE}(a),a) - y_1^{CE}(p(a),a)\right)$$

since $d(a) = \frac{1-a}{p(a)}$ the inequality is satisfied for plausible parameter values. If the risk $z \leq Z < 1$ big enough (around one) the inequality does not hold. ■

Appendix F: Proof of Proposition 7

Proof. The difference between total welfare of the allocations under liquidity and solvency regulations , i.e. $U^{SOL} - U^{LIQ}$, is:

$$U^{SOL} - U^{LIQ} = (q-1)\left(\frac{1}{2}y_1^{CE}(p=1, a=1)\epsilon^{LIQ} - \epsilon^{SOL}\right)$$

where $\epsilon^{LIQ} = I(\frac{1}{p^{CE}} - \frac{1}{\pi q})$ and $\epsilon^{SOL} = \pi q y_1^{SOL} - I$.

From a social welfare viewpoint, solvency regulation is superior, i.e. $U^{SOL} > U^{LIQ}$, when[10]

$$I > \frac{2\left(\pi q y_1^{SOL} - y_1^{CE}(p=1,a=1)\right)}{2-(\frac{1}{\pi q}+\frac{2-x}{qx})y_1^{CE}(p=1,a=1)} = \frac{\pi q x}{\pi + \frac{x}{1+a^{SOL}}(1-\pi)} \frac{\pi q - \frac{2}{1+a^{SOL}} + \frac{1-a^{SOL}}{1+a^{SOL}}\pi}{\pi q - 1} =: \tilde{I}(a^{SOL})$$

■

[10]Note that

$$\tilde{I}(a^{SOL}) < \frac{2\left(\pi q y_1^{CE}(p=\pi q,a=1) - y_1^{CE}(p=1,a=1)\right)}{2-(\frac{1}{\pi q}+\frac{2-x}{qx})y_1^{CE}(p=1,a=1)} = \frac{2\pi q x}{2\pi + (1-\pi)x} = \bar{I}$$

For plausible parameter values $\underline{I}(a=1) \leq \tilde{I}(a^{SOL})$.

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