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Risk-taking by asset managers and bank regulation*

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Abstract

A beneficial effect of bank regulation may play out through the asset management sector. When asset managers count on a central bank to support market liquidity in a systemic event, they take on fire-sale risk that is excessive from a social perspective. However, the extent of risk-taking today also incorporates the spread that bank dealers would charge for absorbing fire sales tomorrow. If regulation constrains banks' balance-sheet space, the expected spread would be higher, reining in excesses in asset managers' risk-taking and ultimately raising welfare.

JEL Classification: G21, G23, G28, D62

Keywords: Endogenous risk-taking, Investment funds, Liquidity injections, Bank regulation

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1 Introduction

The asset management sector has grown in size as well as in importance for financial stability (Schnabel, 2020). In the face of redemptions by investors, asset managers need to sell parts of their portfolios and rely on dealers – mostly banks – to deploy their balance sheets for absorbing these sales (Blackrock, 2020; O'Hara and Zhou, 2022). A recurrent argument is that strong liquidity mismatches at asset managers' investment funds often lead to fire sales and that reduced balance sheet capacity of dealer banks exacerbates the ensuing market stress (see e.g. Falato et al. (2021) for corporate bond funds, Li et al. (2021b) for municipal bond funds, and Financial Stability Board (2021) and Bouveret (2021) for money market funds (MMFs)). Both regulatory and internal risk-management factors have been studied as drivers of this capacity reduction (Andersen et al., 2019; Saar et al., 2020; Committee on the Global Financial System, 2014, 2017b).

We challenge the notion that bank regulation necessarily contributes to asset managers' destabilising behaviour, arguing instead that it could alleviate excessive fire-sale risk in the asset management sector. As a driver of fire-sale risk-taking, we consider central bank liquidity backstops, such as those deployed in 2008-9 and in the spring of 2020. While such backstops mitigate the severity of systemic events by limiting private losses, they can clash with other policy objectives (Hauser, 2021), hinder policy making by generating "liquidity dependence" in the financial system (Acharya et al., 2022), and may lead to resource misallocation (Yang and Zhu, 2021). It is the combination of limiting private losses and generating social costs that makes liquidity backstops a natural driver of the excessive risk-taking by asset managers that Coval and Stafford (2007), Kacperczyk and Schnabl (2013) and Carney (2018) refer to. But since liquidity backstops are never guaranteed *ex ante*, asset managers still need to take into account their dependence on dealers' balance-sheet space for the absorption of potential fire sales. This is why bank regulation can perform a beneficial *cross-sectoral* function. By imposing an *ex ante* floor on the cost of dealers' balance-sheet space, bank regulation can discipline asset managers' risk-taking.

To formally underpin this reasoning, we model the interaction between bank dealers and asset managers in the event of large redemptions. Dealers face inventory risk, are risk averse (as in

Foucault et al. (2013)) and differ in terms of their capitalisation. A regulatory leverage-ratio requirement may be binding for the low-capital dealers but is not for the high-capital ones.[1] In turn, the risk-neutral asset managers invest while anticipating possible redemptions that necessitate fire sales. They differ in their exposure to redemption shocks. The weaker are dealers' willingness and capacity to absorb fire sales, the more they impair market liquidity by raising the spread they charge asset managers.[2] This *willingness* depends on the state of the world, which materialises after asset managers have made their investments. If redemptions take place in the "bad" state, characterised by weaker asset fundamentals (i.e. a lower risk-adjusted return) relative to the "good" state, dealers' are willing to absorb smaller fire sales at a given price. The dealer sector's *capacity* to absorb fire sales declines as regulation becomes stricter. Ultimately, asset managers' fire-sale costs depend on dealers' financial constraints, as in Shleifer and Vishny (1997, 2011) and Gromb and Vayanos (2002). While we also model a feedback loop between fire-sale costs and constraints, our focus is on how they influence asset managers' risk-taking.

In the baseline model, the private equilibrium attains the social optimum. Individual asset managers do not internalise their impact on the spread, which reduces the welfare of their sector. But this externality generates a transfer to the dealer sector, resulting in a zero net effect on social welfare. In this context, a binding regulatory constraint – which caps the amount of fire-sale volume that dealers absorb – drives the private equilibrium away from the social optimum.

We depart from the baseline by introducing a central bank that has the option to inject liquidity in order to absorb fire sales (Li et al., 2021a). We represent the central bank liquidity injection as a direct purchase of fire-sale assets from asset managers and derive that it renders bank regulation inconsequential. We believe that this captures parsimoniously salient features of recent liquidity assistance schemes – such as the Money Market Mutual Fund Liquidity Facility (MMLF) and the

[1]While risk-based or liquidity requirements could also affect banks' interaction with MMFs, we focus on the leverage ratio requirement for two reasons. First, it featured prominently in studies of this interaction (see e,g,. Breckenfelder and Ivashina, 2021). Second, by being largely insensitive to risk perceptions, leverage ratio regulation is the most likely one to bind if banks need to absorb fire sales of low-risk assets (such as those that money market funds invest in) in an otherwise benign environment. As we will see below, it is important for our analysis to focus on regulation that will bind in the absence of crisis management measures, such as liquidity injections. For analyses of the impact of other types of bank regulation, see Kisin and Manela (2016); Goel et al. (2020); Kara and Ozsoy (2020); Anderson et al. (2023).

[2]Herein, market liquidity is the ease of trading an asset without a discount (Brunnermeier and Pedersen (2009)).

bond purchase programmes by the ECB and the Federal Reserve (Claessens and Lewrick, 2021) in March 2020 – which typically used banks' balance sheets as conduits to restore market calm while simultaneously relaxing regulation (Li et al., 2021a).[3] Since liquidity injections are rare, we zoom in on parameter configurations for which the central bank steps in only in the bad state. The injection occurs because it is socially optimal *ex post*, but the anticipation of it leads asset managers to take on excessive risk relative to what would have been chosen by a planner who takes into account the social cost of the injection. When this cost is high enough, the *ex ante* welfare is lower in equilibrium than in the baseline setting, implying that the central bank is trapped in a classic time-inconsistency problem (à la Kydland and Prescott (1977)). Importantly, even if the social cost of liquidity injections is sufficiently low to imply that this policy option brings social value also *ex ante*, asset managers' risk-taking is still excessive and a social planner would still wish to rein it in. We argue that bank regulation provides a means for this.

In the departure from the baseline model, bank regulation is consequential only in the absence of liquidity injection, i.e. in the good state. When this state materialises, regulation binds for low-capital dealers, necessitating that high-capital ones assume more risk. To do so, these dealers charge asset managers a higher spread – i.e. market liquidity deteriorates. That said, the anticipation of higher costs induces asset managers to reduce their risk-taking before the state materialises. In other words, regulation plays a disciplining role across sectors. We find that, because the potential for a liquidity backstop makes asset managers' risk-taking excessive from a social perspective, the disciplining effect of the regulatory constraint improves welfare. Moreover, the unique optimal constraint is tighter when the central bank's liquidity provision is costlier.

For the policy implications of our model to be relevant in practice, bank regulation should make a difference for asset managers. Indeed, this seems to be the case for open-ended bond funds, as bank regulation has tightened liquidity conditions on corporate bond markets (Adrian et al., 2017; Bessembinder et al., 2018). To complement these studies, we focus on MMFs, motivated by three reasons why they provide a relevant environment for testing the implications of our model. First, MMFs depend on dealers' balance sheet space in times of stress. Even if MMFs can meet their

[3] On March 19, 2020, U.S. authorities issued a rule allowing banks to neutralise the effects of purchasing assets through the MMLF program on risk-based and leveraged capital ratios. See Federal Reserve Board (2020).

liquidity needs in tranquil times by not rolling over some of their, mostly short-term, holdings, large and abrupt redemptions force MMFs to fire sale part of their portfolio and thus make them dependent on dealers' absorption capacity (Blackrock, 2020; Financial Stability Board, 2021; International Organization of Securities Commissions, 2020). Second, at times of extreme stress, MMFs have benefited from central bank liquidity backstops, such as the MMLF. MMFs' risk-taking would thus reflect the perceived likelihood that large redemptions will occur in a systemic event that triggers public support, even if such support is not guaranteed *ex ante*. Third, given the dominance of short-term assets in their portfolios, MMFs can be expected to respond to a change in the regulatory environment within a narrow time frame around the start date of the change. With this motivation, we study whether the introduction of the Basel III leverage ratio requirement reduced the risk-taking by the managers of US MMFs.

Data on US MMFs provide evidence consistent with the cross-sector disciplining effect of bank regulation. We study two measures of MMFs' liquidity risk-taking. One is the "risky asset share" (RAS) – or the share of commercial paper and certificates of deposits in MMFs' portfolios.[4] The second is the weighted average maturity (WAM) in these portfolios, a standard measure of risk taking (Di Maggio and Kacperczyk, 2017). A higher WAM implies a higher probability to sell assets in the face of redemptions, as opposed to cashing in maturing securities. We find that, in the wake of the implementation of the bank leverage ratio requirement in January 2018, MMFs reduced their risk-taking according to each measure.[5] This reduction was more pronounced among funds that held riskier asset portfolios and thus faced higher fire-sale risk. The findings cannot be explained by other potential drivers such as changes in the relative prices of alternative investment instruments, issuance volumes and year-end effects that control for funding demand, as well as various fund characteristics and fixed effects that absorb market-wide variation.

We contribute to the literature on the market-making capacity of dealer banks. Papers in this literature have looked into the corporate bond (e.g. Fender and Lewrick, 2015; Bao et al., 2018;

[4]Items not in the RAS' numerator but included in portfolios (the denominator) largely comprise highly liquid US Treasuries or repurchase agreements (repos) collateralised with such securities.

[5]We find no such effects in January 2015 when the leverage *disclosure* requirement came into force. This is in line with the short term nature of the assets that MMFs invest in, which suggests that adjustments to MMF portfolios and related strategies should occur very close to the implementation date.

Breckenfelder and Ivashina, 2021; Anderson et al., 2023) and foreign exchange markets (e.g. Du et al., 2018; Avdjiev et al., 2019). The focus has been on how the increased cost of dealers' balance sheets worsens liquidity shortages (e.g. Cimon and Garriott, 2019; Andersen et al., 2019; Saar et al., 2020), which can adversely affect asset managers (Li et al., 2021b; Jiang et al., 2022). We complement this liquidity channel with a disciplining channel that originates in the bank-dealer sector. Namely, instead of treating asset managers' risk-taking as exogenous, we consider a setting in which higher dealer balance sheet costs discourage asset managers from loading on fire-sale risk. We derive conditions under which the disciplining channel underpins a socially beneficial outcome and find empirical support for the existence of this channel.

A second contribution of our paper is to provide a tractable model for studying the impact of bank regulation on the investment fund sector in the presence of central bank liquidity injections. Although there is a growing empirical literature on such emergency assistance – e.g. Crosignani et al. (2020) and Li et al. (2021a) – its link with bank regulation and the attendant normative implications have not been studied. We address this gap by building on the fire-sales framework of Shleifer and Vishny (1997, 2011) and Gromb and Vayanos (2002). We find that, since liquidity backstops underpin excessive risk-taking, they bring to the fore the often neglected disciplining impact of bank regulation on the asset management sector. In addition, we derive that banks' regulatory constraints and liquidity backstops interact with each other *across* states of the world. Being consequential in some states, bank regulation reins in asset managers' risk-taking, which is excessive because liquidity backstops are anticipated to affect market outcomes in *other* states. Thus, the joint effect of the two policy measures on welfare stems from their interaction in shaping asset managers' expectations.

Roadmap. Section 2 presents the baseline model of the interaction between asset managers and dealers in the face of redemptions. We then discuss salient features of central bank liquidity assistance and use them to motivate our departure from the baseline in Section 3. In each version of the model we examine if risk-taking is excessive from a social perspective and the impact of bank regulation on welfare. Section 4 provides empirical evidence that bank regulation affects asset managers' risk-taking. Section 5 concludes.

2 Baseline model

The financial system evolves over three periods – $t = 0, 1, 2$ – and in one of two states. It features two sets of atomistic agents – asset managers and dealers – and two assets – one risk-free and one risky.[6] Asset managers are the only active agents in period $t = 0$, when they decide how much to invest in each of the assets. Two *independent* events materialise at the beginning of period $t = 1$: (i) redemption requests for some asset managers and (ii) the state of the economy, which determines the statistical properties of the risky asset's return at $t = 2$. Those asset managers that receive redemption requests sell their risky asset to dealers. The risky asset's return has a higher expected level and a lower volatility in the "good" (g) state, which materialises with probability π, than in the "bad" (b) state, of probability $(1 - \pi)$. The return on the risky asset materialises at $t = 2$.

To focus parsimoniously on the interaction between asset managers (as sellers in an illiquid market, under redemption pressure) and bank dealers (as market-makers buying that asset), we make the following modeling choices. First, we keep ultimate investors – and any strategic motives that they may have for redemptions – in the background, taking redemption intensity as given.[7] Second, we assume that dealers competitively absorb asset managers' sales. Even though real-life asset managers typically have a relationship with only one dealer at a time, we contend that the drive to maintain this relationship would lead to some competition among dealers. Third, we focus only on states of the world in which there are redemption-driven fire-sales (i.e. stress times), with the expected intensity of these sales varying across asset managers – consistent with actual experience (Avalos and Xia (2021)). The model's implications would not change if we introduced states without redemptions and assumed that they occur with a known probability.

The building blocks of the baseline model are inspired by Shleifer and Vishny (1997, 2011) and Gromb and Vayanos (2002).[8] Despite similarities, the asset managers in our model differ in

[6]Since we consider only one type of risky asset, our model is silent with regards to funds' strategic fire-sale behaviour, such as prioritising the sale of the more liquid assets when facing redemption pressures (Claessens and Lewrick, 2021; Ma et al., 2022).

[7]We do not model redemption dynamics in this paper. Given that, in deriving the impact of bank dealers' regulatory constraints, the literature has treated asset managers' fire sales as exogenous. Our contribution is to endogenise asset managers' exposure to redemption risk and thus the volume of their fire sales. We leave the joint modelling of redemption dynamics and asset managers' exposure to redemption risk to future research.

[8]The noise traders/fragmented investors and arbitrageurs in these models appear respectively as asset managers

important ways from the noise traders in Shleifer and Vishny (1997) and fragmented investors in Gromb and Vayanos (2002). In these papers, arbitrage opportunities arise from misperceptions of risky asset values or from market fragmentation. To zoom in on incentives for risk-taking, we do not introduce arbitrage opportunities in our model and consider asset managers as players in a single market, having accurate information about the expected intensity of their redemption shock.

2.1 Assets

The risk-free asset is worth 1 at any t and in each state, consistent with a zero risk-free interest rate.

The price of the risky asset evolves over time. It is 1 at $t = 0$. It is at the level that clears the market at $t = 1$: $R_{1,g}$ or $R_{1,b}$, in the good or bad state, respectively. Finally, it is exogenous and stochastic at $t = 2$, $\tilde{R}_2$, with state-contingent mean and volatility: $R_{2,g} > R_{2,b}$ and $\sigma_g < \sigma_b$, respectively. These imply state-contingent spreads: $s_g \equiv R_{2,g} - R_{1,g}$ and $s_b \equiv R_{2,b} - R_{1,b}$, which correspond to the fire-sale cost in Shleifer and Vishny (1997) and Gromb and Vayanos (2002).

2.2 Asset managers

The asset managers are of unit mass and are risk neutral.[9] Each one enters $t = 0$ with an endowment of one unit of the risk-free asset and cannot borrow. We denote them by i. When deciding whether to buy the risky asset at $t = 0$, asset manager i knows the expected level of her redemption-driven liquidation at $t = 1$. These expected levels are drawn independently across asset managers and uniformly from the unit line: $\varepsilon_i \sim U[0, 1]$. Denoting asset manager i's investment in the risky asset by $a_i \in [0, 1]$, her expected utility is:

$$\begin{aligned} U_i &= a_i (1 - \varepsilon_i) R_2 + a_i \varepsilon_i R_1 + (1 - a_i) \\ &= 1 + \underbrace{a_i (R_2 - 1)}_{\text{gain from investing}} - \underbrace{a_i \varepsilon_i s}_{\text{loss from liquidation}} \end{aligned} \tag{1}$$

and dealers in ours.

[9] Equivalently, they maximise the utility of risk-neutral investors. Flat fees, paid by investors to asset managers, would be inconsequential in our setup.

where $R_t \equiv \pi R_{t,g} + (1-\pi) R_{t,b}$, for $t \in \{1,2\}$, and $s \equiv \pi s_g + (1-\pi) s_b$ denote the expected levels of the risky-asset prices and the spread from the standpoint of period $t = 0$. From this point on, when the context rules out ambiguity, we refer to the risky asset as "the asset".

Being risk neutral, asset managers are either fully invested in the asset or not at all:

$$\begin{aligned} a_i &= 1 \text{ if } R_2 - 1 < \varepsilon_i s, \\ a_i &= 0 \text{ otherwise.} \end{aligned} \tag{2}$$

Since R_2 is exogenous and an individual asset manager takes s as given, expression (2) implies that there is a threshold $\hat{\varepsilon} \in [0,1]$, such that asset managers i with $\varepsilon_i < \hat{\varepsilon}$ invest in the asset and the rest do not. Aggregate investment is equal to $\int_0^{\hat{\varepsilon}} d\varepsilon_i = \hat{\varepsilon}$ and the corresponding liquidation volume to:

$$y = \int_0^{\hat{\varepsilon}} \varepsilon_i d\varepsilon_i = \frac{\hat{\varepsilon}^2}{2} \tag{3}$$

2.3 Dealers

The dealers are also of measure one and act only at $t = 1$, as buyers of asset mangers' fire sales. Being competitive, they take the market-clearing spread s_x as given in each state $x \in \{g, b\}$. The dealers differ with respect to their capital endowment: those with low capital, k^l, are of mass β and those with high capital, k^h, of mass $1-\beta$, where $k^l < k^h$. A dealer $j \in \{l, h\}$ finances his purchase of the asset $y_x^j R_{1,x}$ with the fixed capital endowment and by issuing debt, equal to $y_x^j R_{1,x} - k^j$, at the risk-free rate.[10] Dealers make markets, bridging the gap between the time when asset managers need to liquidate their asset holdings ($t = 1$) and the time when the asset's return materialises ($t = 2$). Thus, they face inventory risk (see e.g., Garman, 1976; Foucault et al., 2013).

The dealers are risk-averse, facing mean-variance utility and are subject to a regulatory con-

[10]We abstract from how investment in the risky asset affects dealers' credit-worthiness and ultimately their funding cost. We could justify this by modelling the risky-asset returns on a finite support and postulating sufficiently high risk aversion on dealers' part that guarantees their positive net worth in each state at $t = 2$. Our preference is to abstain from such an elaboration since it would not be central to the analysis of asset managers' exposure to fire-sale risk, as opposed to dealers' exposure to fundamental risk. This approach is consistent with that adopted in the market microstructure literature (see Madhavan (2000) for a detailed survey).

straint on the amount of the asset that they can purchase. Each one chooses y^j to maximise the following utility (net of the additive constant k^j):

$$U_x^j = \underbrace{s_x y_x^j}_{\text{gain from the spread}} - \underbrace{\frac{\rho}{2}\sigma_x^2 \left(y_x^j\right)^2}_{\text{disutility from uncertainty}} \equiv s_x y_x^j - \frac{c_x}{2}\left(y_x^j\right)^2 \tag{4}$$

$$\text{subject to: } y_x^j \leq \frac{k^j}{\lambda R_{1,x}} \equiv \frac{\omega^j}{R_{1,x}} \equiv \frac{\omega^j}{R_{2,x} - s_x}, \text{ where } \rho > 0,\ x \in \{g, b\},\ j \in \{l, h\} \text{ and } \lambda \in [0, 1]. \tag{5}$$

In this expression: $c_x \equiv \rho\sigma_x^2$ is the (effective) state-contingent riskiness of the asset (which could alternatively stem from a risk-based constraint on the dealers (Danıelsson et al., 2004)), λ denotes the leverage ratio requirement, capping the ratio of equity k^j in total assets $y_x^j R_{1,x}$. We treat $\omega^j \equiv k^j/(\lambda R_{1,x})$ as the (effective) regulatory parameter for dealer j.

We integrate regulation in the model in the following way. First, we assume that $\omega^h > 1/2$ so that – by (2) and $\hat{\varepsilon} < 1$, which imply $R_{1,x} < 1$, and (3) – the regulatory constraint *never* binds for high-capital dealers. Second, to study the equilibrium in the total absence of regulation, we will also assume that ω^l is similarly high; and to study the impact of regulation, we will let ω^l be low enough. Since the regulatory parameter matters only for low-capital dealers, we will lighten the exposition by removing the l superscript and referring simply to ω. We will use "binding constraint (or regulation)" as a shorthand for "constraint that binds for low-capital dealers".

Ultimately, dealers' utility-maximising purchase schedules are:

$$\begin{aligned} y_x^h &= \frac{s_x}{c_x} \\ y_x^l &= \min\left\{\frac{s_x}{c_x}, \frac{\omega}{R_{2,x} - s_x}\right\}, \text{ for } x \in \{g, b\}, \end{aligned} \tag{6}$$

and market clearing requires that dealers absorb the liquidation volume, y:

$$y = \beta y_x^l + (1 - \beta)\, y_x^h \text{ for } x \in \{g, b\}. \tag{7}$$

Expressions (6) and (7) imply that $y_x^h = y_x^l = y$ when the constraint does not bind in state x and that a constraint is binding in state x if $\frac{\omega}{R_{2,x}-s_x} < y$.

2.4 Equilibrium and welfare

In this subsection, we derive the equilibrium and welfare, using the timeline and information sets summarised in Figure 1. There is uncertainty at $t = 0$, as regards the state and *individual* asset managers' obligation to liquidate at $t = 1$, and at $t \in \{0, 1\}$, as regards the asset's exogenous return.

Table 3 in Appendix A.1 reports the notation used in the model.

2.4.1 Equilibrium without bank regulation

When regulation is inconsequential, the baseline setup takes on its most stripped-down form. By asset managers' and dealers' decision rules (2) and (6), as well as the market-clearing condition (7), the threshold expectation $\hat{\varepsilon}$, the state-contingent spread s_x, and the expected spread, $s = \pi s_g + (1-\pi)s_b$, are given by:

$$\hat{\varepsilon}s = R_2 - 1 \tag{8}$$

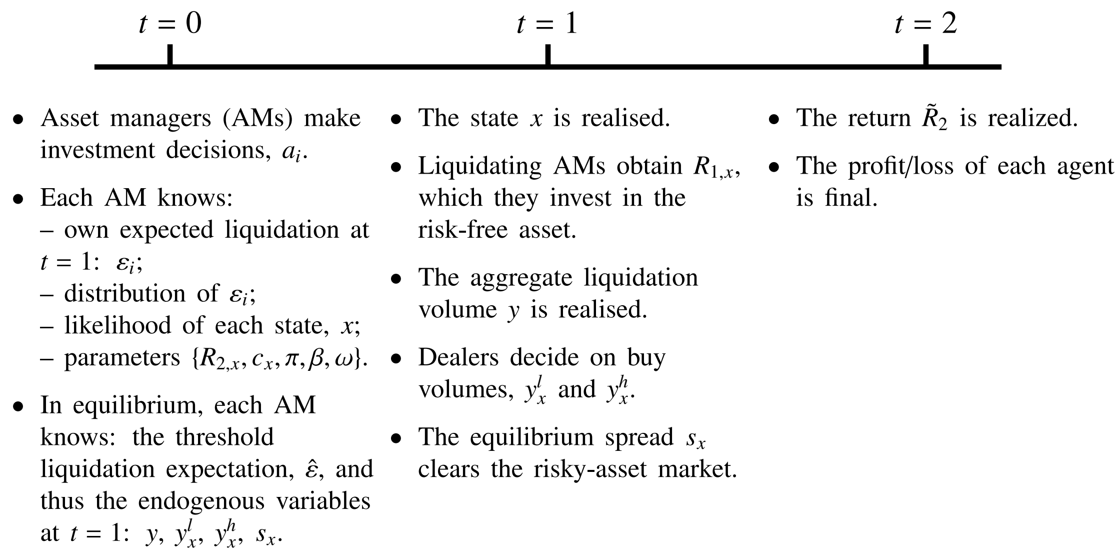
$$s_x = c_x\frac{\hat{\varepsilon}^2}{2} \text{ for } x \in \{g, b\} \text{ and } s = c\frac{\hat{\varepsilon}^2}{2}, \tag{9}$$

where $c \equiv \pi c_g + (1-\pi)c_b$ stands for the expected riskiness of the asset. The solutions to these equations in terms of $\hat{\varepsilon}$ and s_x determine the investment volume $\hat{\varepsilon}$, the liquidation volume $y = y_x^j$ by (3) and (7) as well as asset managers' and dealers' welfare per (1) and (4), respectively.

Since equations (8) and (9) imply a one-to-one relationship between $\hat{\varepsilon}$ and each s_x, we can define the equilibrium as follows:

Definition 1. ***The equilibrium without bank regulation*** *is a threshold investment strategy. An asset manager invests in the asset if and only if she faces an expected liquidation intensity that is lower than the level of* $\hat{\varepsilon}$ *solving* (8) *and* (9)*.*

Figure 1: Timeline and information sets



We solve the equilibrium in terms of the asset's expected return, R_2, and riskiness, c:

$$\hat{\varepsilon} = \left(\frac{2(R_2 - 1)}{c}\right)^{\frac{1}{3}}, \tag{10}$$

$$s_x = \frac{c_x}{2}\left(\frac{2\,(R_2 - 1)}{c}\right)^{\frac{2}{3}} \text{ and } s = \left(\frac{c}{2}\right)^{\frac{1}{3}}(R_2 - 1)^{\frac{2}{3}} \tag{11}$$

Equation (10) implies that there is more investment in the asset, i.e. $\hat{\varepsilon}$ is higher, for a higher risk-adjusted return, $(R_2 - 1)/c$. Expression (11) reveals that – by raising the liquidation volume through a higher $\hat{\varepsilon}$ – a higher expected return $(R_2 - 1)$ raises each state-contingent spread s_x. In turn, the risk parameters, c_x and c, affect s_x through two distinct channels. First – for a given liquidation volume, $y = (2\,(R_2 - 1)/c)^{2/3}/2$, by (3) – higher state-contingent riskiness, c_x, leads dealers to demand greater compensation in the form of a higher spread s_x. Second, higher unconditional riskiness, c, leads asset managers to expect a higher spread in the event they need to engage in a fire sale. This results in smaller investment and liquidation volume, which lower the spread s_x in each state x. In expectation, the first channel dominates, implying that s increases in c.

We impose the following parameter restrictions. For an interior solution, $\hat{\varepsilon} \in (0, 1)$, we need:

$$\frac{R_2 - 1}{c} \in (0, 1/2) . \tag{12}$$

Thus, $R_2 > 1$, which ensures that a positive mass of asset managers invest in the asset. In addition, $R_{1,x} > 0$, or equivalently $R_{2,x} > s_x$, is necessary so that asset managers do not prefer to simply dispose of the asset in the face of liquidation, in any state x at $t = 1$. Hence, we require that:

$$R_{2,x} > \frac{c_x}{2} \left(\frac{2 (R_2 - 1)}{c} \right)^{\frac{2}{3}} . \tag{13}$$

Table 4 in Appendix A.2 summarises the parameter restrictions for the baseline model without bank regulation (first row) and subsequent variations of the model (second through last rows).

2.4.2 Equilibrium with bank regulation

To derive the equilibrium with bank regulation, distinguished with a superscript R, we work backwards from $t = 1$. At $t = 1$, the liquidation volume $\left(\hat{\varepsilon}^R\right)^2 /2$ is taken as given. If regulation binds in state x, a low-capital dealer purchases $\frac{\omega}{R_{2,x} - s_x^R}$ of the fire-sale volume – where s_x^R is the market-clearing spread – and the high-capital dealers purchase the rest. The optimal purchase of the high-capital dealers, per (6), and the market clearing condition (7) deliver this spread in a variation of (9):

$$s_x^R = \left(\frac{\left(\hat{\varepsilon}^R\right)^2}{2} - \beta \frac{\omega}{(R_{2,x} - s_x^R)} \right) \frac{c_x}{1 - \beta}, \text{ for } x \in \{g, b\} , \tag{14}$$

At $t = 0$, when determining the threshold $\hat{\varepsilon}^R$, asset managers anticipate the spread would be set as in (14) in a state where the constraint is binding.

For the rest of the analysis of the baseline setup, we will work in a region of the parameter space where the regulatory constraint binds *only* in the good state (as derived in Appendix B.1 and reported in Table 4 (second row)). This emulates the idea that the leverage-ratio constraint is consequential only in states of the world where risk is relatively low, with risk-management considerations or risk-based regulation taking precedence in other states. We thus define the equilibrium from the standpoint of $t = 0$ as follows.

Definition 2. ***The equilibrium with bank regulation*** *is also a threshold strategy. An asset manager invests in the asset if and only if she faces an expected liquidation level that is lower than the* $\hat{\varepsilon}^R$ *solving (8), where* $s^R = \pi s_g^R + (1-\pi)\, s_b^R$*,* s_b^R *is given by (9) and* s_g^R *by (14).*

On the basis of this definition, we prove the following proposition (Appendix B.1):

Proposition 1. ***Equilibrium existence, uniqueness and comparative statics.*** *For the parameter restrictions specified in Table 4 (second row), bank regulation binds only in the good state and the equilibrium in Definition 2 exists and is unique. In this equilibrium: (i) as* ω *declines, the ceiling on low-capital dealers' purchases,* $\frac{\omega}{R_{2,g}-s_g}$*, decreases as a share of the liquidation volume* $\frac{(\hat{\varepsilon}^R)^2}{2}$*, i.e. the regulatory constraint tightens; (ii) investment in the asset is higher for: a looser constraint (*$d\hat{\varepsilon}^R/d\omega > 0$*), lower asset riskiness (*$d\hat{\varepsilon}^R/c_x < 0$*), or a lower fraction of constrained dealers (*$d\hat{\varepsilon}^R/d\beta < 0$*); (iii) the fire-sale spread is higher for: a tighter constraint (*$ds^R/d\omega < 0$*), higher asset riskiness (*$ds^R/dc_x > 0$*), higher expected asset return (*$ds^R/dR_{2,x} > 0$*) or a higher fraction of constrained dealers (*$ds^R/d\beta > 0$*).*

2.4.3 Welfare

From the standpoint of $t = 0$, we first derive expected utilities in the asset-management and dealer sectors separately and then aggregate them to obtain social welfare. Given Definitions 1 and 2, we study whether this welfare can be raised by a social planner selecting the investment threshold, $\hat{\varepsilon}$.

In the **absence of regulation**, expressions (1)-(3) imply that the overall expected utility in the asset management sector is:

$$\begin{aligned} U_m &= 1 + \hat{\varepsilon}(R_2 - 1) - ys \\ &= 1 + \hat{\varepsilon}(R_2 - 1) - c\frac{\hat{\varepsilon}^4}{4} \end{aligned} \tag{15}$$

which increases in the excess expected return from investing in the asset (second term) and decreases in the fire-sale cost (third term). We see that U_m is maximised at $\hat{\varepsilon} = ((R_2 - 1)/c)^{\frac{1}{3}}$, which is lower than the equilibrium level in (10). There is thus overinvestment from the perspective of the asset-management sector, as its atomistic members do not internalise the positive impact of their actions on the spread s, per (9).

Turning to the dealers and assuming no bank regulation, equation (4) implies that the expected utility in the sector is

$$U_l + U_h = \frac{ys}{2}. \tag{16}$$

A comparison with (15) reveals that asset managers' liquidation costs are dealers' benefits.

In fact, the transfer from asset managers to dealers is *exactly* equal to the negative externality within the asset management sector. Social welfare – i.e. $W = U_m + U_l + U_h$ – is equal to:

$$\begin{aligned} W &= 1 + \hat{\varepsilon}(R_2 - 1) - \frac{ys}{2} \\ &= 1 + \hat{\varepsilon}(R_2 - 1) - c\frac{\hat{\varepsilon}^4}{8}, \end{aligned} \tag{17}$$

which the social planer would maximise by setting the same threshold level of the liquidation expectation as the privately chosen one: the value of $\hat{\varepsilon}$ that maximises W is the one in (10). We thus prove the following proposition:

Proposition 2. ***Welfare in the baseline model without regulation.*** *The privately chosen level of the threshold liquidation expectation, $\hat{\varepsilon}$ in equation (10), attains the social optimum.*

Bank regulation affects social welfare through two channels. First, by constraining bank dealers' market-making capacity, the direct effect of binding regulation is to increase fire-sale costs (for a similar argument, see e.g. Cimon and Garriott, 2019; Saar et al., 2020). Second, since asset managers anticipate this direct effect, they cut down on risk-taking, which would serve to reduce fire-sale costs. Since risk-taking in the baseline model is socially optimal, however, the effect of regulation on fire-sale costs lowers welfare (see Appendix B.2 for a proof):

Proposition 3. ***Bank regulation in the baseline model.*** *A binding regulatory constraint reduces social welfare.*

3 Liquidity backstop by the central bank

To study the implications of bank regulation when asset managers take on excessive risk – i.e. when a planner can improve social welfare by reducing the investment threshold, $\hat{\varepsilon}$ – we extend the baseline model. In Section 3.2, we introduce central bank liquidity injections and study if they have an unintended *ex ante* effect – by encouraging risk-taking in the asset management sector – even if they are beneficial *ex post* for given fire sales by asset managers. Then, we study how social welfare changes with the introduction of a regulatory constraint on bank dealers, i.e. the sector that does *not* take on excessive risk (Section 3.3). We will see that the liquidity backstop and regulation interact in shaping the equilibrium at $t = 0$, even though they matter in different states at $t = 1$. Before that, we motivate the specific extension by referring to a recent example of central bank liquidity injections (Section 3.1).

3.1 Historical liquidity injections

When dealers' unwillingness or incapacity to absorb fire sales generates extreme liquidity shortages, central banks tend to step in.

Prominent central bank interventions took place in response to the March 2020 market turmoil. Bond purchase schemes by the Federal Reserve (Primary and Secondary Market Corporate Credit Facilities, launched on 23 March) and the ECB (the Pandemic Emergency Purchase Programme, 26 March) helped open-ended funds regain normalcy by April. Likewise, the money market fund liquidity facility (MMLF) in the United States offered relief to MMFs. Given the focus on such funds in our empirical analysis below, we discuss this facility in detail.

For MMF asset managers and their dealers, March 2020 unfolded as follows. The commercial paper (CP) market came under severe stress, as testified by the spike in the spread between high quality 3-month CPs and US Treasury bills (Figure 2, black solid line). In parallel, investors' redemptions from prime MMFs were massive (dashed line), amounting to 40% or more of the assets under management for one-fifth of the funds, thus forcing them to fire-sell their CP holdings (Avalos and Xia, 2021). Despite the initial absorption of fire sales by banks, conditions at MMFs and the CP market started normalising only when the US Federal Reserve implemented the MMLF on 23 March (second vertical red line) and banks drew on it (dotted line) (Blackrock, 2020). Banks secured MMLF loans with assets purchased from MMFs, which helped the latter meet redemption demands. Without any other policy change, bank dealers could have been reluctant to participate in the facility for the same reason they did not absorb all fire sales before the facility was introduced – their attendant balance-sheet expansion threatened to breach the leverage ratio requirement. Thus, authorities excluded MMLF loans from that requirement (see Federal Reserve Board (2020)). In sum, the Fed backstopped market liquidity by acting as a market maker of last resort (Li et al., 2021a), using banks' balance sheets to this end.

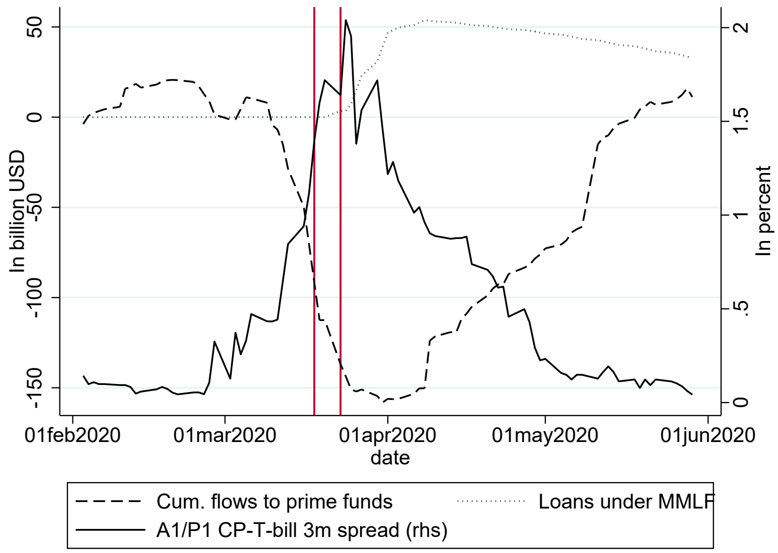
The decisive policy interventions during the Covid-19 market turmoil are part of a recurrent pattern of emergency measures that address systemic events. Indeed, such interventions were already a notable feature during the great financial crisis, when banks' balance sheets were also used as conduits for the Fed's assistance to MMFs (Duygan-Bump et al., 2013; Bank for International Settlements, 2014; Anadu et al., 2021). Emergency liquidity injections by central banks have time and again broken self-fulfilling selling sprees and put a cap on risk premia in order to restore normal market functioning. This has however raised concerns about potential moral hazard, prompting statements by policymakers that central bank backstops should not be taken for granted and that the financial system should be ready for the possibility to absorb fire-sales on its own (Committee on the Global Financial System, 2017a; Bank of England, 2021; Markets Committee, 2022)).

3.2 Liquidity injection without bank regulation

3.2.1 The setup

We introduce the central bank as an additional strategic player. Namely, it has the option to inject liquidity at $t = 1$ by absorbing a state-contingent amount $z_x \in (0, y^I)$ of asset managers' fire sale, y^I, where I stands for injection. The central bank purchases z_x at the spread, s_x^I that dealers charge for the remaining fire-sale amount, $(y^I - z_x)$. In addition to its impact on this spread, the central bank's action generates social costs equal to $\frac{\gamma}{2}z^2$, in the spirit of Acharya et al. (2022), Hauser (2021)

Figure 2: Money market stress and the role of central bank interventions: a Covid-19 example



Notes: The vertical lines refer respectively to the dates when the money market fund liquidity facility (MMLF) was announced (18 March 2020) and when it started operating (23 March 2020). The solid line plots the spread between high-quality 3-month US commercial paper and 3-month US Treasury bills. The dashed line plots cumulative flows to US prime money market funds. The dotted line plots loans granted by the Federal Reserve under the MMLF.
Source: Bloomberg; Crane data; JPMorgan Chase; FRED.

and Yang and Zhu (2021).[11] Ultimately, we assume that the central bank absorbs the amount, $z_x \in (0, y^I)$, that maximises social welfare in state x:

$$
\begin{aligned}
W_x^I &= \underbrace{1 + \hat{\varepsilon}(R_2 - 1) - y^I s_x^I}_{U_m} + \underbrace{\frac{1}{2}\left(y^I - z_x\right) s_x^I}_{U_l + U_h} - \underbrace{\frac{\gamma}{2} z_x^2}_{\text{social cost of injection}} \\
&= 1 + \hat{\varepsilon}(R_2 - 1) - y^I\left(y^I - z_x\right) c_x + \frac{c_x}{2}\left(y^I - z_x\right)^2 - \frac{\gamma}{2} z_x^2
\end{aligned}
\tag{18}
$$

W_x^I generalises (17) and incorporates $s_x^I = c_x(y^I - z_x)$, per unconstrained dealers' optimisation (6). Since $dW_x^I/dz_x = z_x\,(c_x - \gamma)$, the central bank acts as follows:

Proposition 4. ***Central bank's action.*** *Taking the fire-sale volume y^I as given, the central bank abstains, setting $z_x = 0$, if $\gamma > c_x$ and injects liquidity $z_x = y^I$ if $\gamma < c_x$. In the latter case, $s_x^I = 0$.*

[11] To avoid modelling the CB as an additional dealer, which would effectively take us back to the baseline setup, we do not let it account for its expected profit on the fire-sale purchase. Appendix C.1 elaborates on this and outlines an alternative problem for the central bank, which delivers the same equilibrium as in the main text.

In other words, the central bank intervenes if it has a cost advantage relative to dealers. Since empirical studies (e.g., Li et al., 2021a) and the evidence presented in Section 3.1 indicate that central banks inject liquidity only during severe market stress, we assume $c_g < \gamma < c_b$.[12]

We pause to reflect on the setup with liquidity injection. In practice, central banks provide liquidity backstops by using banks as intermediaries and simultaneously loosening their balance sheet constraints in order to mitigate the fire-sale repercussions. We attain a similar outcome with a modeling shortcut whereby the central bank provides liquidity directly to asset managers. By insulating the fire-sale spread from market conditions, the modelled liquidity injection shields asset managers in the bad state from the impact of regulatory constrains on bank dealers' actions.

3.2.2 Excessive risk-taking

Assuming that γ is known, asset managers anticipate the spread to be zero in the bad state and to be set by dealers, per (9), in the good state. We examine now the wedge that this anticipation drives between the privately chosen investment threshold, $\hat{\varepsilon}^I$, and the socially optimal level, $\hat{\varepsilon}^{I*}$.

Parameter restrictions that ensure interior solutions and liquidity injection only in the bad state (Table 4, third row) underpin the following definition, which reflects the first-order condition (8):

Definition 3. ***The equilibrium with liquidity injection*** *is a threshold strategy. An asset manager invests in the asset if and only if she faces an expected liquidation amount that is lower than the level of $\hat{\varepsilon}^I$ solving (19), where the expected spread $s^I = \pi s_g^I$ because $s_b^I = 0$.*

$$\hat{\varepsilon}^I \underbrace{\frac{\pi\left(\hat{\varepsilon}^I\right)^2}{2} c_g}_{\equiv s^I} = R_2 - 1, \tag{19}$$

which implies $\hat{\varepsilon}^I = (2(R_2 - 1)/(\pi c_g))^{1/3}$.

While asset managers bear no cost in the bad state, the social planner accounts for the social costs that their fire sales generate in that state through the central bank. As a result, the planner

[12]We impose such sandwiching constraints on γ throughout the paper. Thus, our results would not change if we allowed for state-contingent values of γ, provided that both belong to the relevant interval.

would set the threshold level that solves the following equation, which parallels (17), with the social cost of liquidity injection replacing the fire sale-driven welfare loss in the bad state:

$$\hat{\varepsilon}^{I*}\left(\pi\frac{\left(\hat{\varepsilon}^{I*}\right)^2}{2}c_g + (1-\pi)\frac{\left(\hat{\varepsilon}^{I*}\right)^2}{2}\gamma\right) = R_2 - 1. \tag{20}$$

Considered together, (19) and (20) reveal that the negative externality of asset managers' investment surfaces as excessive risk-taking: $\hat{\varepsilon}^{I} > \hat{\varepsilon}^{I*}$ as long as the bad state is a possibility, $\pi < 1$.

3.2.3 Welfare

A key takeaway so far is that, while the central bank maximises welfare from the standpoint of period $t = 1$, the anticipation of this action leads asset managers to take on excessive risk at $t = 0$. This prompts the question of whether the beneficial effect at $t = 1$ (*ex post*) might be outweighed by the detrimental effect at $t = 0$ (*ex ante*). Would the central bank have wished to precommit unconditionally to abstaining but cannot do so because, once the asset managers have acted and the bad state materialises, its dominant strategy is to inject liquidity? In other words, is the central bank subject to a classic time inconsistency of policy (à la Kydland and Prescott (1977))?

The following proposition (proved in Appendix C.2) specifies when time inconsistency arises.

Proposition 5. ***Liquidity injection impact.*** *Suppose that $c_g < \gamma < c_b$. Liquidity injection improves social welfare if and only if $\gamma < \bar{\gamma}\left(\pi, c_g, c_b\right)$, where $\bar{\gamma}$ increases in each of its arguments.*

For the intuition behind this proposition, it is useful to keep in mind that central bank liquidity injection insulates the spread in the bad state from the intensity of fire sales. To fix ideas, for a given γ, we discuss why increases in any of $\bar{\gamma}$'s arguments create an environment in which the (anticipated) liquidity injection improves welfare *relative to* the baseline in Section 2. First, a higher c_b lowers welfare in the baseline model, as it stands for a higher riskiness of an asset sold by the risk-neutral asset managers to the risk-averse dealers. By contrast, when the central bank injects liquidity, such sales do not take place – and thus c_b does not affect the equilibrium and welfare. Therefore, liquidity injection improves welfare if c_b is high enough.

To see the effects of the other two arguments of $\bar{\gamma} - c_g$ and π – we recall that risk-taking generates costs in both states but – in the presence of liquidity injections – asset managers internalise only those costs that materialise in the good state. By equation (19), the magnitude of the latter costs increases in the asset's riskiness in that state, c_g. In turn, the probability of having to incur them is π. All else equal, the higher are c_g and π, the larger is the share of risk-taking costs that asset managers internalise, thus behaving more in line with the social planner's objective. Ultimately, for sufficiently high c_g and π, the excesses of asset managers' risk-taking are sufficiently small so that liquidity injection raises welfare by absorbing fire-sales in the bad state.

Combined with the derivations in Section 3.2.2, Proposition 5 indicates that – for $c_g < \gamma < min\{\bar{\gamma}, c_b\}$ – there is excessive risk-taking in the asset management sector even though liquidity injections do not face a time inconsistency problem. We show in Appendix C.2 that such a parameter configuration exists for a sufficiently high probability of the good state, π, and a sufficiently high perceived riskiness in the bad state, c_b. While, in this case, liquidity injections are socially valuable also *ex ante*, authorities would still wish to mitigate the attendant risk-taking distortion through other means. In the rest of the paper, we argue that one such means is bank regulation.

3.3 Bank regulation: impact in the presence of liquidity injection

As motivated at the beginning of the section, we assume that bank regulation binds (at least) in the good state. The next proposition (proved in Appendix C.3) states conditions under which the central bank's optimal action is to inject liquidity only in the bad state (the superscript *IR* stands for an environment with both injection and regulation).

Proposition 6. ***Central bank liquidity injection and binding bank regulation.*** *If bank regulation binds in the good state, the central bank abstains, setting $z_g = 0$, if and only if $\gamma > c_g + \delta$, for some $\delta \in \left(0, c_g \frac{\beta}{1-\beta}\right)$. In the bad state, irrespective of whether regulation binds or not, the central bank prefers to bring s_b^{IR} to zero by injecting liquidity, $z_b = y^{IR}$, provided that $\gamma < c_b$.*

This proposition delivers the following messages. First, in conjunction with Proposition 4, $\delta > 0$ implies that, in the presence of bank regulation, a higher cost parameter γ is needed to dissuade the central bank from injecting liquidity in the good state. In other words, the adverse welfare impact of bank regulation in the baseline model (recall Propostion 3) strengthens the case for liquidity injection. Second, $\gamma > c_g/(1-\beta)$ is a sufficient condition for no liquidity injection in the good state. Third, while "full" injection, $z_b = y^{IR}$, dominates no injection in the bad state for $\gamma < c_b$, the central bank may in principle prefer "partial" injection, $z_b \in \left(0, y^{IR}\right)$. We verify numerically the existence of parameter configurations – those specified in Table 4 (last two rows) for which the latter is not the case.[13] For such parameters, the condition $c_g/(1-\beta) < \gamma < c_b$ implies that the central bank injects liquidity only in the bad state; and when it does so, it drives dealers out of the asset market and renders bank regulation inconsequential.

Parameter restrictions such that bank regulation binds (at least) in the good state and there is (full) liquidity injection only in the bad state lead to the next proposition (proved in Appendix C.4):

Proposition 7. ***Equilibrium existence, uniqueness and comparative statics.*** *Under the parameter restrictions specified in Table 4 (fourth row), a unique $\hat{\varepsilon}^{IR}$ defines the equilibrium. This equilibrium shares the following properties with that in the absence of liquidity injection (Proposition 1): (i) a lower ω tightens the constraint; (ii) investment in the asset is higher for: a looser constraint ($d\hat{\varepsilon}^{IR}/d\omega > 0$), lower asset riskiness in the good state ($d\hat{\varepsilon}^{IR}/c_g < 0$), or a lower fraction of constrained dealers ($d\hat{\varepsilon}^{IR}/d\beta < 0$); (iii) the fire-sale spread is higher for: a tighter constraint ($ds^{IR}/d\omega < 0$), higher asset riskiness in the good state ($ds^{IR}/dc_g > 0$), higher expected asset return in the good state ($ds^{IR}/dR_{2,g} > 0$) or a higher fraction of constrained dealers ($ds^{IR}/d\beta > 0$).*

In the next proposition, we state our key result about the socially optimal regulation in the presence of liquidity injection – i.e. when asset managers take on excessive risk (see Appendix C.5 for a proof). For it, we abstract from the region in the parameter space where optimal regulation is to set $\omega^* = 0$, i.e., to completely drive low-capital dealers out of the asset market.

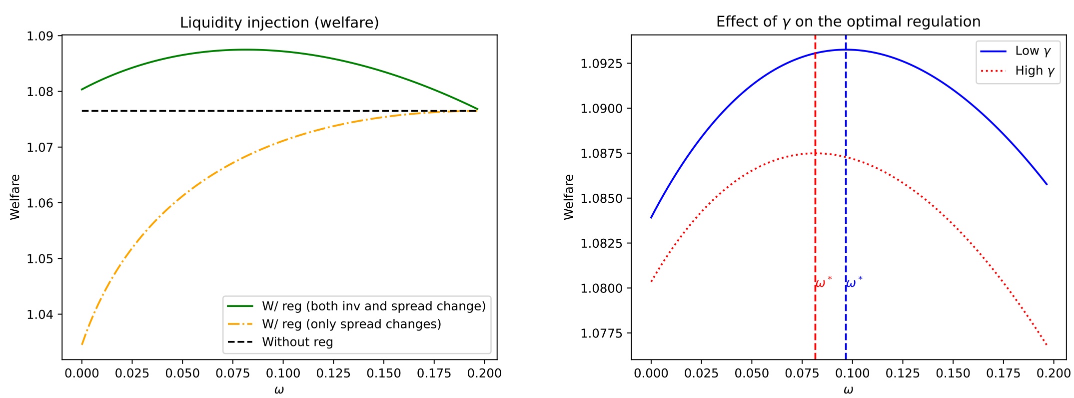
Proposition 8. ***Benefits of bank regulation.*** *In the presence of central bank liquidity injection and under the parameter restrictions in Table 4 (bottom row), there exists a unique binding ω^* that maximises social welfare. The optimal regulatory constraint is tighter, i.e. ω^* is lower, when the liquidity injection cost is larger, i.e. γ is higher.*

[13] This is in line with the intuition that bank regulation strengthens the case for liquidity injection.

In other words, the policy measures – bank regulation and liquidity injection – interact across states. When regulation binds in the *good* state, it reduces asset managers' risk-taking. This is socially beneficial because the liquidity injection in the *bad* state generates excessive risk-taking.

Figure 3 illustrates the welfare implications of bank regulation and the interaction of the two policies. In the left-hand panel, the unique maximum of the solid line showcases the first part of Proposition 8. The upward sloping dash-dotted line – which keeps asset manages' risk-taking constant across different degrees of regulatory tightness – implies that the benefits of bank regulation stem only from its disciplining effect. In turn, as the cost of liquidity injection at $t = 1$ increases, asset managers' risk-taking at $t = 0$ becomes more excessive. Hence, bank regulation needs to be tighter to impose stronger discipline – this is what the right-hand panel illustrates.

Figure 3: Welfare impact of regulation when liquidity injection is an option



Notes: This figure shows the welfare impact of regulation. The left-hand panel corresponds to the setting with central bank liquidity injection. The green solid (respectively, horizontal dashed) line denotes welfare in the presence (absence) of regulation. The dash-dotted orange line denotes welfare in the counterfactual scenario in which regulation does not change asset managers' risk-taking. The right-hand panel shows the effect of liquidity injection cost on the optimal regulation. Parameter values: $R_{2,g} = 1.3, R_{2,b} = 1.1, c_g = 2, c_b = 6, \beta = 0.5, \pi = 0.7$. In the left-hand panel $\gamma = 5$. In the right-hand panel, low $\gamma = 4.5$ and high $\gamma = 5.5$.

Asset managers' losses stem from the market clearing spread in the good state at $t = 1$, which – per expression (6) – is determined by the magnitude of the fire-sales that need to be absorbed by unconstrained (i.e. high-capital) dealers. In light of expressions (5) and (7), this magnitude is equal to $(y - \beta\frac{\omega}{R_{2,g}-s_g})/(1-\beta)$, which is a measure of the tightness of regulation that reins in asset managers' risk-taking. Using this measure, the following proposition (proved in Appendix C.6) showcases how the optimal *tightness* of regulation depends on the social cost of liquidity injection.

Proposition 9. ***Optimal tightness of bank regulation.*** *In the presence of liquidity injection and under the parameter restrictions in Table 4 (fourth row), the higher the injection costs, γ, the tighter the regulatory constraint that maximises welfare:* $d\left(\frac{y^{IR}-\beta\frac{\omega}{R_{2,g}-s_g}}{1-\beta}\right)/d\gamma > 0.$

4 Asset managers' response to bank regulation

Do data corroborate a key implication of our theoretical model: that bank regulation curtails asset managers' risk-taking? In addressing this question, we focus on US MMFs, which share important characteristics with similar funds in other countries and with open-ended bond funds (see Cai et al. (2019); Mäkinen et al. (2020); Avalos and Xia (2021)). In Section 4.1, we provide a short background on the institutional structure of MMFs and their investment habitats. Then, in Sections 4.2 and 4.3, we use two alternative measures of risk-taking and, for each of these, study whether the implementation of bank leverage-ratio regulation has a bigger impact on asset managers with a higher exposure to the risk that investor redemptions necessitate fire sales to dealer banks.

4.1 Background on MMFs and the asset classes they invest in

There are two broad categories of MMFs – non-prime (or government) and prime.[14] Non-prime funds can invest only in government securities or repos backed by those securities. In addition to such securities, prime funds provide short-term funding to low-risk non-sovereign entities. The most relevant examples of the underlying instruments are certificates of deposit (CDs, issued by banks) and, especially, commercial paper (CP, issued by highly-rated non-financial corporations, local governments and banks). Prime MMFs' holdings account for about 25% of the volume in the U.S. CP and CD markets (Blackrock, 2020). Since, in comparison to non-prime funds, prime funds invest in riskier securities, they are more likely to fire sale in the event of massive redemptions.

[14] We abstract from municipal funds, a third category of US MMFs.

CP markets undergo distinct phases. In normal times, investment funds – prime MMFs included – tend to purchase CP at issuance and hold them until maturity. This surfaces as little trading on secondary markets, with a negligible role for dealer banks. However, in times of stress with material redemption pressures that necessitate outsize fire sales (the focus of our model), MMF managers count on the dealers that originally offered the securities to absorb the sales (Blackrock, 2020; Financial Stability Board, 2021).[15]

4.2 Riskiness of prime funds' investments

For the measure of *prime* MMFs' risk-taking, we use their monthly regulatory filings (see Appendix D.1 for details on the data). At the fund level, we calculate the ratio of (i) the sum of investments in CP, asset-backed CP and CDs relative to (ii) the corresponding total investments, which also include Treasury and agency securities and repos (mostly backed by these securities). We refer to this ratio as the "risky asset share" (RAS).[16]

Figure 4 plots the median RAS for all prime funds in our sample and delivers four takeaways. First, the RAS was not affected by the introduction of the leverage ratio *disclosure* requirement (dashed vertical line).[17] Second, it dropped sharply in the run-up to the US MMF reform (dotted vertical line) – as funds adjusted their portfolios towards less risky, government securities – but rebounded equally fast thereafter – as the de-risking funds exited the prime category, and thus our sample. Third, the RAS started a distinct downward trend after the leverage ratio requirement became *effective* on January 1st 2018 (vertical solid red line). Fourth, there was a further reduction in 2020, as funds sought refuge in government securities and shed risky investments to meet redemptions during the Covid-19 market turmoil.

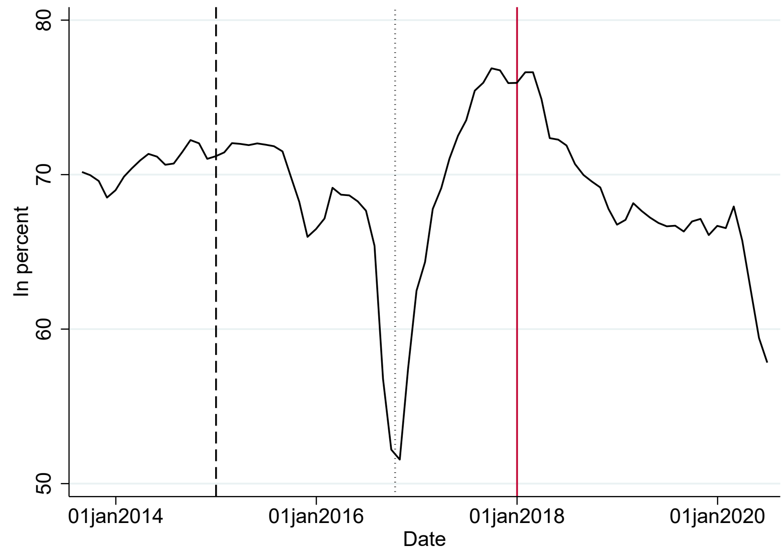
The most important takeaway in the context of this paper is the reduction of RAS after the

[15] Even if central banks do backstop markets in systemic events, such assistance is never guaranteed a priori.

[16] We focus on prime funds for this first analysis as the RAS is negligible for non-prime funds.

[17] A possible reason why MMFs did not move pre-emptively has to do with the short maturity of their portfolios, which allows for a swift repositioning towards less risky securities. Similar logic can explain why portfolio adjustments around the MMF reform took place over a short time window around that reform's implementation date. From banks' perspective, refusing to absorb MMFs' potential fire sales far in advance would have implied foregoing profits from assets that would mature (and thus drop off balance sheets) prior to the leverage-ratio effective date.

Figure 4: Prime MMFs' risky asset share (RAS) and leverage ratio requirements



Notes: RAS is computed as the 3-month moving average of the sum of investments by US prime funds in commercial paper (CP), asset-backed CP and certificates of deposits, divided by the total investments by these funds. The dashed line refers to the start date of the leverage ratio disclosure requirement (1 January 2015), the dotted line is at the end of the implementation period for the MMF reform (14 October 2016), and the solid red line marks the date when the leverage ratio requirement became effective (1 January 2018).
Source: Crane data.

start of the leverage-ratio requirement.[18] It is thus consistent with a disciplining effect of bank regulation on asset managers.[19] Alternatively, however, it could have had a number of unrelated drivers. For instance, broad market developments would drive the prices of CPs, repos and US Treasury bills, which would in turn affect the relative attractiveness of these securities from both issuers' and investors' perspective. In addition, relevant factors at play could be related to funding demand. Concretely, fiscal considerations would drive the volume of US Treasury bill issuance and regulation could constrain the amount of e.g. bank CP issuance that the market needs to absorb (Du et al., 2018; Avdjiev et al., 2019). Any of these factors could alter the relative magnitudes of

[18]This reduction mattered to investors, as it resulted in a drop of the average spread between US prime MMF returns and three-month Treasury rates, from around 15 basis points in the fourth quarter of 2017 to around 7 basis points in the first quarter of 2018.

[19]The disciplining effect could work even while the leverage ratio is not binding, provided that it holds the potential to bind if banks absorb future fire sales. In our theoretical model, asset managers reduce their risk-taking at $t = 0$ not because banks are concurrently constrained but because they may be constrained at $t = 1$.

the RAS measure's numerator and/or denominator.

On the basis of casual observation, such factors do not seem to play a role for the reversal of the RAS measure after end-2017 (see Appendix D.2). For one, CP and Treasury rates' upward march from late 2015 to mid-2019 saw no visible change in end-2017, nor did the spread between CP and repo rates.[20] Furthermore, financial and non-financial CP issuance stayed within historical norms during the time period of interest, whereas the upward trend in Treasury bill issuance that had started in early 2016 did not change around end-2017.[21]

Regression results further corroborate our argument that bank regulation is a driver of asset managers' RAS after end-2017. A motivation for the specific form of this analysis comes from a finding that the drop in the aggregate RAS measure in 2018 was driven by *high RAS* funds, i.e. those whose risky-asset share was higher than the cross-sectional median in at least three months between June and November 2017 (see the parallel-trend plot in the left-hand panel of Figure 8 in Appendix D.2).[22] Since such funds face higher liquidity risk and suffer larger fire sale losses, they could have stronger incentives to decrease their RAS when tighter leverage regulation reduces the market-making capacity of bank-affiliated dealers. Thus, our regression specification seeks to test the hypothesis that the effect of the leverage ratio requirement is non-linear, being stronger at higher initial levels of risk-taking. In particular, we run the following difference-in-difference regression at the fund (f)-month (t) level from July 2017 to June 2018:

$$RAS_{ft} = \alpha + \beta_1 * HighRAS_f + \beta_2 * PostLR + \beta_3 * HighRAS_f * PostLR + Controls_{ft} + FixedEffects + \varepsilon_{ft} \tag{21}$$

The main coefficient of interest is β_3, which captures the product of a high-RAS dummy and a time dummy equal to 1 after 1st January 2018 ($postLR$). We expect a negative value for β_3, which would indicate that, when the leverage-ratio regulation came in force, high-RAS funds reduced

[20] While CDs enter our RAS measure, we abstract from them in the more detailed analysis because their volumes are considerably smaller than those of CPs and data on them are patchier. The results below are robust to also excluding CDs from the RAS measure.

[21] The Federal Reserve started purchasing bills only during the Covid-19 crisis, and until that point had focused its purchases on longer-term instruments.

[22] Results are robust to varying the number of months between 3 and 5, or referring to November only.

their risk-taking by more than low-RAS ones. By contrast, we do not expect a negative value for the same coefficient when we conduct a placebo test around the leverage ratio disclosure date in January 2015 (adjusting *HighRAS* and *PostLR* accordingly).[23]

To account for potential drivers of RAS that are unrelated to the disciplining effect of bank regulation on asset managers (as discussed above), we include as controls: the aggregate (i.e. market-level) spread between financial and non-financial CP rates and repo rates,[24] and the logarithm of the amounts of financial (including bank) and non-financial CP issuance. To further control for funding demand, we include quarter-end effects, which would capture reporting considerations of regulated institutions. We also include fixed effects to control for structural differences in risk-taking at the level of fund types (namely, differentiating between those catering to institutional vs retail investors, as suggested by Kacperczyk and Schnabl (2013)). At the fund level, the controls are: the logarithm of assets under management (AUM), AUM's weighted average maturity and fund fixed effects, which control for time-invariant fund characteristics. In the most stringent specification, we include time (i.e., year-month) fixed effects to capture possible unobserved aggregate shocks, such as changes in policy rates, and variation common to all funds.

We find that high-RAS funds adjusted their risk-taking as expected after the introduction of bank regulation (Table 1 columns (1)-(8)). Column (1) presents the baseline regression, without controls and fixed effects. It reveals that, on average, the risky-asset share of high-RAS funds was about 22 percentage points higher than that of their low-RAS peers during the last six months of 2017. Most importantly, the estimate of β_3 indicates that, after the leverage ratio requirement became effective, the RAS of high-RAS funds dropped by almost 6 percentage points more than that of low-RAS funds, with the result statistically significant at the 5% level.

This result is robust to including additional explanatory variables and breaks down in the placebo test. Namely, it is robust to controlling for the total value of funds' investments as well as the weighted average maturity of those investments (column (2)), quarter-end fixed effects (column

[23]This is the only such placebo test that we can conduct with our dataset, as the 2015 and 2016 yearends are polluted by the MMF reform (see e.g., Baghai et al. (2022)), and gradual adjustments in both the bank and fund sectors under the leverage ratio requirements likely affect the post-2018 data.

[24]Using spreads relative to Treasury rates instead of repo rates delivers very similar results. In each case, we do not believe that there are endogeneity issues, as it is difficult to argue that the repositioning of any individual fund would affect market-level spreads (with all funds accounting for about 25% of investments in US CP).

(3)), fund-type and time fixed effects (column (4)), fund fixed effects (column (5)), the spreads between financial and non-financial CP rates and repo rates (column (6)), financial and non-financial CP issuance (column (7)) and fund and time fixed effects (column (8)). Column (9) presents the results of the placebo test: now the estimate of β_3 is not statistically different from zero and the point estimate itself is quantitatively very small.[25]

Table 1: Prime funds' response to bank regulation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dependent variable:	RAS_{ft}	RAS_{ft}	RAS_{ft}	RAS_{ft}	RAS_{ft}	RAS_{ft}	RAS_{ft}	RAS_{ft}	RAS_{ft}
Period:	2017/18	2017/18	2017/18	2017/18	2017/18	2017/18	2017/18	2017/18	2014/15
$HighRAS_f$	22.35***	22.62***	22.60***	22.59***					
	(3.30)	(3.36)	(3.37)	(3.34)					
$PostLR$	2.65	3.03	3.02		0.16	0.06	-1.08		
	(2.20)	(2.08)	(2.08)		(0.97)	(1.76)	(1.95)		
$HighRAS_f * postLR$	-5.69**	-5.83***	-5.82***	-5.83***	-3.35***	-3.34***	-3.28***	-3.28**	-0.10
	(2.33)	(2.17)	(2.17)	(2.18)	(1.23)	(1.23)	(1.23)	(1.24)	(0.85)
$Assets_{ft-1}$, WAM_{ft}		✓	✓	✓	✓	✓	✓	✓	✓
QE			✓	✓	✓	✓	✓		
$Fin/NFin\ CP\ spr_t$						✓	✓		
$Fin/NFin\ CP\ iss_t$							✓		
Fund type FE				✓					
Fund FE					✓	✓	✓	✓	✓
Time FE				✓				✓	✓
Observations	754	754	754	754	751	751	751	751	1,490
R-squared	0.34	0.35	0.36	0.37	0.84	0.85	0.85	0.85	0.91

Notes: Based on monthly US MMF data. The dependent variable is the risky asset share (RAS_{ft}), calculated for every prime fund f and month t as the sum of investments in commercial paper (CP), asset-backed CP and certificates of deposits divided by total investments. All regressions are done for a 12-month period, from July until June in the years indicated in column headings. In columns (1)-(7), $PostLR = 1$ refers to 2018 observations (immediately after the leverage ratio requirement became effective). In column (8), $PostLR = 1$ refers to 2015 observations (immediately after the leverage ratio disclosure requirements). $HighRAS_f$ is a dummy capturing whether a fund's risky asset share was above the cross-sectional median pre-treatment. $Assets_{ft-1}$ denotes the logarithm of total investment value and WAM_{ft} is the weighted average maturity. QE is a dummy that equals one at quarter ends. $Fin/NFin\ CP\ spr_t$ denote respectively the spreads between financial and non-financial CP rates, and repo rates. $Fin/NFin\ CP\ iss_t$ denotes the logarithm of the value of financial and non-financial CP issuance. Fund type fixed effects control for whether funds are prime retail or prime institutional. Standard errors are clustered at the fund level. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively.

[25] Using different subsets from the set of controls does not affect this takeaway from column (9).

4.3 Evidence from risk-taking through maturity

In this section, we parallel the preceding analysis with two main modifications to the setup. First, we consider maturity as a dimension of risk-taking (Di Maggio and Kacperczyk, 2017). All else the same, we treat a higher weighted average maturity (WAM) of a fund's portfolio as indicating a higher likelihood that redemptions would lead to fire sales. Second, for given WAM, we treat prime MMFs as being more exposed to the risk of fire sales because they hold otherwise riskier portfolios than non-prime MMFs. Thus, we juxtapose the WAM of prime and non-prime funds on the basis of fund flows data from Crane – which MMFs provide on a daily basis – and we expect the WAM of prime funds to decrease by more after the introduction of banks' leverage ratio requirement. We obtain a preliminary evidence in favour of this conjecture from the evolution of WAM for the two groups of funds around end-December 2017 (see parallel trend in right-hand panel of Figure 8, Appendix D.2).

The specific regression is as follows:

$$WAM_{ft} = \alpha + \beta_1 * Prime_f + \beta_2 * PostLR + \beta_3 * Prime_f * PostLR + Controls_{ft} + FixedEffects + \varepsilon_{ft} \quad (22)$$

where WAM_{ft} refers to the weighted average maturity of fund f's portfolio on day t; $Prime_f$ is a dummy that equals 1 when f is a prime fund; $FixedEffects$ refer to fund-type (institutional vs retail) and time fixed effects (capturing market-wide factors, e.g. aggregate funding demand, monetary policy shocks or monetary policy expectations); and $Controls_{ft}$ include lagged assets and lagged returns at the fund level. Since the data are daily, our focus now is on a *two*-month window around end-2017.

The main coefficient of interest is β_3, which captures how prime funds adjusted their risk-taking relative to non-prime funds when the leverage ratio regulation became effective. We expect $\beta_3 < 0$, which would indicate a greater decline in risk-taking by prime funds, as they hold a riskier portfolio and are thus more reliant on bank dealers in the face of investor redemptions. By contrast, we do not expect such a finding in placebo tests that focus on other year-ends.

The evidence again supports the notion that funds with riskier investments curtail their risk-

Table 2: Prime vs non-prime funds' response to bank regulation

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	WAM_{ft}	WAM_{ft}	WAM_{ft}	WAM_{ft}	WAM_{ft}	WAM_{ft}
Period:	2017/2018	2017/2018	2017/2018	2017/2018	2017/2018	2014/2015
$Prime_f$	-3.96***	-5.85***	-5.56***	-5.37***		
	(0.81)	(0.97)	(1.47)	(1.55)		
$PostLR$	0.55***	0.90***	1.07*			
	(0.20)	(0.22)	(0.64)			
$Prime_f * PostLR$	-2.47***	-2.76***	-2.74***	-2.72***	-2.68***	1.99***
	(0.28)	(0.31)	(0.33)	(0.33)	(0.33)	(0.35)
$Assets_{ft-1}$		✓	✓	✓	✓	✓
$30dReturn_{ft-1}$			✓	✓	✓	✓
Time FE				✓	✓	✓
Fund type FE					✓	✓
Observations	27,724	20,301	20,301	20,301	20,301	24,835
R-squared	0.06	0.10	0.10	0.10	0.14	0.05

Notes: Based on daily US MMF data, covering both prime and non-prime funds. The dependent variable is the weighted average maturity of the portfolio of fund f in day t (WAM_{ft}). All regressions are done for a two-month period, from December to January in the years indicated in column headings. In columns (1)-(4), $PostLR = 1$ refers to 2018 observations (immediately after the leverage ratio requirement became effective). In column (5), $PostLR = 1$ refers to 2015 observations, (immediately after the leverage ratio disclosure requirements). $Prime_f$ is a dummy that is equal to 1 for a prime fund. $Assets_{ft}$ denotes the logarithm of total assets of the fund, and $30dReturn_{ft}$ denotes the 30-day return of the fund. Fund type fixed effects control for institutional and retail funds within each type of broad fund category (prime, and within non-prime, government and treasury). Standard errors are clustered at the fund level. *** denotes statistical significance at the 1% significance level.

taking by more in the wake of the implementation of bank leverage ratio regulation (Table 2). Relative to non-prime funds' WAM, the reduction in prime funds' WAM is larger by almost three days, which compares to an average WAM of about 27 days in December 2017. This result is robust across the different specifications in columns (2)-(5), where we vary controls and fixed effects. Importantly, a similar result is not observed for other year-ends since 2013. For the sake of parsimony and comparability with the previous subsection, we report placebo results only for end-2014, i.e. the start of a mandatory disclosure of the leverage ratio (column (6)).

5 Conclusion

While commentary acknowledges the contribution of bank regulation to the post-crisis resilience of the banking sector, it also stresses that constraints on banks' balance-sheet space adversely affect market liquidity and, thus, the functioning of other sectors in the financial system. Some see the latter effects as a necessary price to pay for supporting financial stability (Borio et al., 2020). We argue instead that, by reducing market liquidity, bank regulation can actually improve the functioning of other parts of the financial system. We find empirical evidence that the introduction of a leverage ratio constraint on banks reduced risk-taking by US MMFs. In a theoretical model, we derive that such a disciplining effect would improve social welfare when the asset-management sector takes on excessive risk while counting on bank-based market-making in some states of the world. In this model, asset managers' risk-taking is excessive when central bank liquidity injections insulate market liquidity from the intensity of redemptions in other states – as arguably was the case in March 2020.

The theoretical findings in the paper point to avenues for expanding the empirical investigation in future research. While our data confines the analysis to US MMFs, the environment of non-US peers or other parts of the asset management sector – e.g. bond funds – may also be conducive to excessive risk taking, not least because central bank liquidity assistance affects the incentives of many market players. To the extent that this is indeed the case, the disciplining benefits of bank regulation would be broader than the paper finds.

Since excessive risk-taking is an inherent feature of the pro-cyclicality of the financial system, it would be useful to extend the analysis to a dynamic environment, featuring boom-bust transitions. We would expect such an extension to underscore that the tightness of a leverage-ratio constraint evolves with the financial cycle, coming to the fore during booms, exactly when risk-taking is highest. This would imply that bank regulation has counter-cyclical effects in the asset management sector: dampening excesses in booms and disruptions in busts. We leave the analysis of this conjecture also to future research.

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Appendices

A Notation and parameter space

A.1 Notation in the model

Table 3: Notation at a glance

Symbol	Definition
t	One of three dates: $t = \{0, 1, 2\}$
x	One of two states, good or bad: $x = \{g, b\}$
π	Probability of the good state
$R_{t,x}$	Price of the risky asset at $t = \{1, 2\}$, in state x
R_1	Expectation of $R_{1,x}$ from the standpoint of $t = 0$
R_2	Expectation of $R_{2,x}$ from the standpoint of $t = \{0, 1\}$
σ_x	Volatility of $R_{2,x}$ from the standpoint of $t = \{0, 1\}$
s_x	Spread in the pricing of the risky asset at $t = 1$, $s_x = R_{2,x} - R_{1,x}$
s	Expected spread, $s = \pi s_g + (1 - \pi)s_b$
i	Index of asset managers
ε_i	Expected liquidation intensity for asset manager i, $\varepsilon_i \sim U[0, 1]$
$\hat{\varepsilon}$	Threshold liquidation expectation, defining the indifferent asset manager
a_i	Amount of risky asset bought by asset manager i at $t = 0$, $a_i \in [0, 1]$
y	Total liquidation volume by asset managers at $t = 1$
j	Dealer type: low- or high-capital, $j \in \{l, h\}$
ρ	Risk aversion of dealers
c_x	”Riskiness” of the risky asset, $c_x = \rho\sigma_x$
c	Expected riskiness, $c = \pi c_g + (1 - \pi)c_b$
k^j	Capital of dealers of type j
β	Share of low-capital bank dealers
λ	Regulatory parameter governing the constraint on bank dealers
ω^j	Effective regulatory parameter $\omega^j = k^j/\lambda$
κ_x^j	Maximum amount that a constrained dealer can buy at $t = 1$, $\kappa_x^j \equiv \frac{\omega^j}{R_{1,x}} \equiv \frac{k^j}{\lambda R_{1,x}}$
y^j	Purchase volume by dealers of type j at $t = 1$
γ	Cost of liquidity injection by the central bank
U	Utility of a particular type of agents, e.g. asset managers, low- or high-capital dealers
W	Social welfare
Superscripts	R and I indicate respectively the presence of binding regulation and liquidity injection, and $*$ indicates the social optimum

A.2 Parameter space of interest

Table 4: Parameter restrictions

Baseline, without regulation and injection	$\frac{R_2-1}{c} \in (0, \frac{1}{2}), R_{2,x} > \frac{c_x}{2}\left(\frac{2(R_2-1)}{c}\right)^{\frac{2}{3}}$
Baseline, regulation binds only in the good state	$\frac{R_2-1}{c} \in (0, \frac{1}{2}), R_{2,x} > \frac{c_x}{2}\left(\frac{2(R_2-1)}{c}\right)^{\frac{2}{3}}, \omega \in (\underline{\omega}, \bar{\omega})$
Central bank liquidity injection, only in the bad state	$\frac{R_2-1}{\pi c_g} \in (0, \frac{1}{2}), R_{2,g} > \left(\frac{c_g}{2}\right)^{\frac{1}{3}}\left(\frac{R_2-1}{\pi}\right)^{\frac{2}{3}}, \gamma \in (c_g, c_b)$
Central bank liquidity injection only in the bad state and bank regulation binds only in the good state	$\frac{R_2-1}{\pi c_g} \in (0, \frac{1}{2}), R_{2,g} > \left(\frac{c_g}{2}\right)^{\frac{1}{3}}\left(\frac{R_2-1}{\pi}\right)^{\frac{2}{3}}, \gamma \in \left(\frac{c_g}{1-\beta}, c_b\right), \omega \in (0, \bar{\omega}^I)$
Central bank liquidity injection only in the bad state, bank regulation binds only in the good state and $\omega^* > 0$	$\frac{R_2-1}{\pi c_g} \in (0, \frac{1}{2}), R_{2,g} > \left(\frac{c_g}{2}\right)^{\frac{1}{3}}\left(\frac{R_2-1}{\pi}\right)^{\frac{2}{3}}, \gamma \in \left(\frac{c_g}{1-\beta}, \min(c_b, \frac{\pi c_g(3-\beta)}{2(1-\pi)})\right).$

Note: $\bar{\omega}$ (resp, $\bar{\omega}^I$) is the marginally binding constraint for the low capital banks in the good state in the baseline setup (respectively, the setup with liquidity injection only in the bad state), and $\underline{\omega}$ is the marginally binding constraint for the low capital banks in the bad state in the baseline setup. Further detail in Appendices B.1 and C.4.

B Bank regulation: tightness, implied equilibrium and welfare

In this appendix, we suppress the R superscript, as everything is in the context of bank regulation.

B.1 Proof of Proposition 1

We start from an equilibrium without bank regulation and with an initial level of ω given by: $\overline{\omega} \equiv (R_{2,g} - s_g)\hat{\varepsilon}^2/2 = \left(R_{2,g} - \frac{c_g}{2}\left(\frac{2(R_2-1)}{c}\right)^{\frac{2}{3}}\right)\frac{1}{2}\left(\frac{2(R_2-1)}{c}\right)^{\frac{2}{3}} > 0$, with the equality implied by (10) and the inequality by (13). Since $\hat{\varepsilon}$ is set on $t = 0$ and is the same across states, we know that $\overline{\omega} > (R_{2,b} - c_b\hat{\varepsilon}^2/2)\hat{\varepsilon}^2/2$ because $R_{2,g} > R_{2,b}$ and $c_g < c_b$. Thus, bank regulation is marginally binding in the good state and not binding in the bad state, implying that the equilibrium is the same as in the absence of bank regulation.

Next, we examine the equilibrium when ω is in a small neighborhood below $\overline{\omega}$. By continuity, we know that regulation is still nonbinding in the bad state. We conjecture for now that it is binding in the good state and confirm this conjecture below. Under the conjecture, $y_g^l = \kappa_g \equiv \omega/(R_{2,g} - s_g)$, $y_g^h = \left(\frac{\hat{\varepsilon}^2}{2} - \beta y_g^l\right)\frac{1}{1-\beta}$ and $s_g = c_g y_g^h$ (in the good state); $y_b^l = y_b^h = y_b = \frac{\hat{\varepsilon}^2}{2}$ and $s_b = c_b y_b$ (in the bad state). By (8) and $s = \pi s_g + (1-\pi)s_b$, the threshold $\hat{\varepsilon}$ is determined by the following equation:

$$\frac{R_2-1}{\hat{\varepsilon}}=\pi\left(\left(\frac{\hat{\varepsilon}^2}{2}-\beta\frac{\omega}{R_{2,g}-s_g}\right)\frac{c_g}{1-\beta}\right)+(1-\pi)c_b\frac{\hat{\varepsilon}^2}{2},$$

where each side is equal to s. Substituting in for $s_g=\frac{1}{\pi}\left(\frac{R_2-1}{\hat{\varepsilon}}-(1-\pi)s_b\right)$, we rewrite this equation so that $\hat{\varepsilon}$ is the only endogenous variable:

$$\frac{R_2-1}{\hat{\varepsilon}}=\pi\left(\left(\frac{\hat{\varepsilon}^2}{2}-\beta\frac{\omega}{R_{2,g}-\frac{R_2-1}{\pi\hat{\varepsilon}}+\frac{1-\pi}{\pi}c_b\frac{\hat{\varepsilon}^2}{2}}\right)\frac{c_g}{1-\beta}\right)+(1-\pi)\,c_b\frac{\hat{\varepsilon}^2}{2}. \tag{A1}$$

The **existence** and **uniqueness** of the equilibrium $\hat{\varepsilon}$ is ensured by the constraint $(R_2-1)/c\in(0,1/2)$, which we imposed already in the absence of regulation. First, the left-hand (right-hand) side of (A1) – henceforth, $LHS(\hat{\varepsilon})$ ($RHS(\hat{\varepsilon})$) – decreases (increases) in $\hat{\varepsilon}$. Second, in the limit $\hat{\varepsilon}\to 0$, $LHS(\hat{\varepsilon})$ converges to $+\infty$, and is thus higher than $RHS(\hat{\varepsilon})$, which converges to 0. Third, in the limit $\hat{\varepsilon}\to 1$, the $LHS(\hat{\varepsilon})$ converges to R_2-1, which, by the above restriction, is lower than the lowest possible value of the $RHS(\hat{\varepsilon})$, i.e., c. To see why $RHS(\hat{\varepsilon})$ is guaranteed to be above c, note that $RHS(\hat{\varepsilon})$ decreases in $\omega/\left(\left(R_{2,g}-\frac{1}{\pi}\left(\frac{R_2-1}{\hat{\varepsilon}}-(1-\pi)c_b\frac{\hat{\varepsilon}^2}{2}\right)\right)\right)$, that – for the constraint to be binding – this expression cannot be above $1/2$, and that the $RHS(\hat{\varepsilon})$ converges to c if this expression is equal to $1/2$ when $\hat{\varepsilon}\to 1$. In sum, the two sides of (A1) cross at $\hat{\varepsilon}\in(0,1)$. This implies that we are guaranteed to have a positive fire-sale price in the good state at $t=1$, i.e. $R_{1,g}=R_{2,g}-s_g>0$.

The following comparative statics **with respect to** ω help us prove, *inter alia*, our earlier conjecture that the constraint binds in the good state for $\omega\le\overline{\omega}$:

$$\frac{d\hat{\varepsilon}}{d\omega}>0,\ \frac{ds}{d\omega}<0,\ \frac{ds_b}{d\omega}>0 \text{ and } \frac{ds_g}{d\omega}<0.$$

The first two inequalities follow from the fact that $LHS(\hat{\varepsilon})$ (respectively, $RHS(\hat{\varepsilon})$) of (A1) does not depend on ω (respectively, shifts down when ω rises) and are downward (upward) sloping. In turn, the third equality follows from the first and $s_b=c_b\hat{\varepsilon}^2/2$. The fourth follows from combining the second and the third with $s=\pi s_g+(1-\pi)s_b$. Given that $s_g=\left(\frac{\hat{\varepsilon}^2}{2}-\beta\frac{\omega}{(R_{2,g}-s_g)}\right)\frac{c_g}{1-\beta}$ and $\beta\in(0,1)$, the results $d\hat{\varepsilon}/d\omega>0$ and $ds_g/d\omega<0$ imply that $\hat{\varepsilon}^2/2$ decreases more slowly in equilibrium than $\frac{\omega}{(R_{2,g}-s_g)}$ as ω declines. Thus, not only does the constraint bind in the good state as ω declines below $\overline{\omega}$ but such a decline leaves a greater portion of the liquidation volume to be absorbed by unconstrained dealers. It is in this sense that the constraint tightens as ω declines.

Even though s_g increases when ω declines, it does not reach $R_{2,g}$ for any given $\omega > 0$. If it did, the RHS of (B.1) would explode to $-\infty$. This leads us to a contradiction: the RHS of (B.1) is positive and finite since we proved above that an equilibrium exists at $\hat{\varepsilon} \in (0, 1)$.

Next, we consider what happens when ω declines outside the neighborhood of $\overline{\omega}$. By equation (A1), we know that $\hat{\varepsilon}^2$ – and thus both s_g and s_b – converge to some positive numbers bounded away from zero. This implies that there exists $\underline{\omega} \in (0, \overline{\omega})$ such that the constraint binds in both states and equation (A1) does not describe the equilibrium for $\omega < \underline{\omega}$. For the analysis of regulation in the baseline setup, we assume $\omega \in \left[\underline{\omega}, \overline{\omega}\right]$.

Additional comparative statics. **With respect to c_x:**

$$\frac{d\hat{\varepsilon}}{dc_x} < 0, \frac{ds}{dc_x} > 0 \text{ and } \frac{ds_b}{dc_g} < 0, \text{ for } x \in \{g, b\}\,.$$

The first two inequalities follow from the slopes of $LHS\ (\hat{\varepsilon})$ and $RHS\ (\hat{\varepsilon})$ of (A1) and the fact that only the $RHS\ (\hat{\varepsilon})$ depends on c_x, moving up as c_g or c_b rise. The third inequality follows from the first and $s_b = c_b\hat{\varepsilon}^2/2$.

With respect to $R_{2,x}$:

$$\frac{ds}{dR_{2,x}} > 0$$

because both $LHS\ (\hat{\varepsilon})$ and $RHS\ (\hat{\varepsilon})$ shift up when $R_{2,g}$ or $R_{2,b}$ rises.

With respect to β:

$$\frac{d\hat{\varepsilon}}{d\beta} < 0, \frac{ds}{d\beta} > 0, \frac{ds_b}{d\beta} < 0 \text{ and } \frac{ds_g}{d\beta} > 0.$$

These inequalities follow from an argument similar to the one in the context of ω above but using the fact that the $RHS\ (\hat{\varepsilon})$ of (A1) shifts up when β rises.

B.2 Proof of Proposition 3

Substituting s_x in (1) and (4) and paralleling (17), the state-contingent social welfare on $t = 1$ is:

$$
\begin{aligned}
W_g &= 1+\hat{\varepsilon}(R_2-1) - y s_g + (1-\beta)(y^h s_g - \frac{c_g}{2} y^h) + \beta(\kappa_g s_g - \frac{c_g}{2}\kappa_g^2), \\
&= 1+\hat{\varepsilon}(R_2-1) - y s_g + (1-\beta)\frac{y^h s_g}{2} + \beta(\kappa_g s_g - \frac{c_g}{2}\kappa_g^2), \\
&= 1+\hat{\varepsilon}(R_2-1) - y s_g + \frac{(y-\beta\kappa_g)s_g}{2} + \beta(\kappa_g s_g - \frac{c_g}{2}\kappa_g^2), \\
&= 1+\hat{\varepsilon}(R_2-1) - \frac{y s_g}{2} + \frac{\beta\kappa_g}{2}(s_g - c_g\kappa_g), \qquad \text{(A2)} \\
W_b &= 1+\hat{\varepsilon}(R_2-1) - \frac{y s_b}{2}. \qquad \text{(A3)}
\end{aligned}
$$

In (A2), the second equality incorporates $y^h = s_g/c_g$ and the third $y = (1-\beta)y^h + \beta\kappa_g$. In turn, the expected social welfare from the standpoint of $t=0$ is:

$$
\begin{aligned}
W &= \pi W_g + (1-\pi)\, W_b \\
&= 1+\hat{\varepsilon}(R_2-1) - \pi\left(\frac{y s_g}{2} - \frac{\beta\kappa_g}{2}(s_g - c_g\kappa_g)\right) - (1-\pi)\frac{y s_b}{2} \qquad \text{(A4)} \\
&= 1+\hat{\varepsilon}\,(R_2-1) - \pi\left(\frac{1}{2}\frac{c_g}{1-\beta}\left(\left(\frac{\hat{\varepsilon}}{2}\right)^2 - \beta\kappa_g\right)^2 + \frac{c_g\beta}{2}\kappa_g^2\right) - (1-\pi)\frac{c_b}{2}\left(\frac{\hat{\varepsilon}}{2}\right)^2
\end{aligned}
$$

where we have used $y = \frac{\hat{\varepsilon}}{2}$ and $s_g = \frac{c_g}{1-\beta}\left(\left(\frac{\hat{\varepsilon}}{2}\right)^2 - \beta\kappa_g\right)$

Taking the derivative with respect to ω delivers:

$$\frac{dW}{d\omega} = (R_2 - 1)\frac{d\hat{\varepsilon}}{d\omega} - \pi\left(\frac{c_g}{1-\beta}\left(\left(\frac{\hat{\varepsilon}}{2}\right)^2 - \beta\kappa_g\right)\left(\varepsilon\frac{d\hat{\varepsilon}}{d\omega} - \beta\frac{d\kappa_g}{d\omega}\right) + c_g\beta\kappa_g\frac{d\kappa_g}{d\omega}\right) - (1-\pi)c_b\frac{\hat{\varepsilon}^3}{2}\frac{d\hat{\varepsilon}}{d\omega} \tag{A5}$$

$$= \left(\underbrace{R_2 - 1 - \hat{\varepsilon}\left(\frac{\pi c_g}{1-\beta}\left(\left(\frac{\hat{\varepsilon}}{2}\right)^2 - \beta\kappa_g\right) - (1-\pi)c_b\frac{\hat{\varepsilon}^2}{2}\right)}_{=R-1-\hat{\varepsilon}\left(\pi s_g+(1-\pi)s_b\right)=0}\right)\frac{d\varepsilon}{d\omega} + \pi\underbrace{\frac{c_g\beta}{1-\beta}\left(\left(\frac{\hat{\varepsilon}}{2}\right)^2 - \beta\kappa_g\right)}_{=\beta s_g}\frac{d\kappa_g}{d\omega} - \pi c_g\beta\kappa_g\frac{d\kappa_g}{d\omega} \tag{A6}$$

$$= \pi\beta(s_g - c_g\kappa_g)\frac{1}{\left(R_{2,g} - s_g\right)}\left(1 - \frac{\omega}{R_{2,g} - s_g}\frac{ds_g}{d\omega}\right) \geq 0 \tag{A7}$$

For the second equality, we use asset managers' equilibrium condition (A1). For the third equality, we use the definition $\kappa_g \equiv \omega/\left(\left(R_{2,g} - s_g\right)\right)$. The inequality follows from: (i) $R_{2,g} > s_g$ by (13), (ii) $ds_g/d\omega < 0$ by Appendix B.1, and (iii) the meaning of a binding constraint: $\kappa_g < y_g = s_g/c_g$. Thus, the constraint reduces unambiguously social welfare in the baseline model.

C Appendix to Section 3

In this appendix, we use an I and/or R superscript to denote endogenous variables in the presence of liquidity injection and/or regulation only if there is risk of ambiguity.

C.1 Alternative optimization problem for the central bank

In the main text, we assume that the central bank does not account for the profits it makes from the asset purchase, $z_x s_x^I$. Here, we study implications of incorporating such profits in the central bank's objective function.

The state contingent welfare is now a version of (18), where $s_x = c_x(y - z_x)$:

$$
\begin{aligned}
\tilde{W}_x &= 1+\hat{\varepsilon}(R_2-1)-ys_x+\frac{1}{2}(y-z_x)s_x+z_xs_x-\frac{\gamma}{2}z_x^2 \\
&= 1+\hat{\varepsilon}(R_2-1)-\frac{c_x}{2}(y-z_x)^2-\frac{\gamma}{2}z_x^2. \qquad \text{(A8)}
\end{aligned}
$$

First and second-order conditions indicate that $\tilde{W}_x$ is maximised at

$$
z_x=\frac{c_x}{c_x+\gamma}y. \qquad \text{(A9)}
$$

We see two issues with this implication. First, for a finite γ and $c_x > 0$, the central banks injects liquidity whenever there are redemption-driven fire sales by asset managers. In practice, such interventions occur only in exceptional cases. Second, since now the spread in each state reflects the cost of liquidity injections, $s_x=\frac{c_x\gamma}{c_x+\gamma}y$, asset managers internalise these costs and the private equilibrium attains the social optimum (see next). In other words, the central bank acts as an additional dealer and we are effectively back to the baseline setup of Section 2.

To compare the private and socially optimal equilibria under (A9), we proceed as follows. First, we rewrite (17) when $s_x=\frac{c_x\gamma}{c_x+\gamma}y$ and $y=\frac{\hat{\varepsilon}^2}{2}$:

$$
1+\hat{\varepsilon}(R_2-1)-\frac{\hat{\varepsilon}^4}{8}\left(\frac{c_g\gamma}{c_g+\gamma}\pi+\frac{c_b\gamma}{c_b+\gamma}(1-\pi)\right),
$$

which implies that the privately optimal $\hat{\varepsilon}$ solves $\frac{\hat{\varepsilon}^3}{2}\left(\frac{c_g\gamma}{c_g+\gamma}\pi+\frac{c_b\gamma}{c_b+\gamma}(1-\pi)\right)=R_2-1$. In turn, a social planer would maximise $\pi\tilde{W}_g+(1-\pi)\tilde{W}_b$ per (A8)

$$
\begin{aligned}
&1+\hat{\varepsilon}(R_2-1)-\pi\left(\frac{c_g}{2}\left(\frac{\gamma}{c_g+\gamma}\right)^2\frac{\hat{\varepsilon}^4}{4}+\frac{\gamma}{2}\left(\frac{c_g}{c_g+\gamma}\right)^2\frac{\hat{\varepsilon}^4}{4}\right) \\
&+(1-\pi)\left(\frac{c_b}{2}\left(\frac{\gamma}{c_b+\gamma}\right)^2\frac{\hat{\varepsilon}^4}{4}+\frac{\gamma}{2}\left(\frac{c_b}{c_b+\gamma}\right)^2\frac{\hat{\varepsilon}^4}{4}\right),
\end{aligned}
$$

which is maximised at the privately optimal $\hat{\varepsilon}$.

A way to avoid reverting to the baseline setup under $\tilde{W}_x$ is to only allow the central bank a binary choice: either abstain, $z_x=0$, or purchase the entire liquidation amount, $z_x=y$. In this case, the central bank would consider $\tilde{W}_x(z_x = 0) - \tilde{W}_x(z_x = y) = \frac{\gamma - c_x}{2} y^2$ and would conclude that abstaining is the optimal choice if and only if $\gamma > c_x$. This is equivalent to the setup in Section 3.2.

C.2 Proof of Proposition 5

Since $c_g < \gamma < c_b$, Proposition 4 implies that the central bank injects liquidity only in the bad state. Paralleling (17), we then obtain that social welfare is equal to:

$$W^I = 1 + \hat{\varepsilon}(R_2 - 1) - \pi \frac{y s_g}{2} - (1-\pi)\frac{\gamma}{2} y^2$$

Using $s_g = (R_2 - 1) / (\hat{\varepsilon}\pi)$, $s_g = y c_g = \hat{\varepsilon}^2 c_g / 2$ and (19) for $\hat{\varepsilon}$, we rewrite W^I:

$$\begin{aligned} W^I &= 1 + \frac{3}{8}\hat{\varepsilon}^4 \pi c_g - \frac{1}{8}\hat{\varepsilon}^4 (1-\pi)\gamma, \\ &= 1 + \left(\frac{3(R_2 - 1)}{4} - \frac{(R_2 - 1)(1-\pi)\gamma}{4\pi c_g}\right)\left(\frac{2(R_2 - 1)}{\pi c_g}\right)^{\frac{1}{3}}. \end{aligned} \tag{A10}$$

Comparing with (17), where we use $\hat{\varepsilon}$ from (10), the difference vis-a-vis the baseline is:

$$\begin{aligned} W^I - W &= \left(\frac{3(R_2 - 1)}{4} - \frac{(R_2 - 1)(1-\pi)\gamma}{4\pi c_g}\right)\left(\frac{2(R_2 - 1)}{\pi c_g}\right)^{\frac{1}{3}} - \left(\frac{3(R_2 - 1)}{4}\right)\left(\frac{2(R_2 - 1)}{\pi c_g + (1-\pi) c_b}\right)^{\frac{1}{3}} \\ &= \frac{\hat{\varepsilon}^I}{4}(R_2 - 1)\left(3\left(1 - \left(\frac{\pi c_g}{\pi c_g + (1-\pi) c_b}\right)^{\frac{1}{3}}\right) - \frac{1-\pi}{\pi}\frac{\gamma}{c_g}\right), \end{aligned} \tag{A11}$$

Thus, liquidity injection improves welfare relative to the baseline for $\gamma < \bar{\gamma}\left(\pi, c_g, c_b\right) \equiv \frac{3\pi c_g}{1-\pi}\left(1 - \left(\frac{\pi c_g}{\pi c_g + (1-\pi) c_b}\right)^{\frac{1}{3}}\right)$, where $\bar{\gamma}$ increases in each of its arguments. Given γ and c_g, we obtain $c_g < \gamma < min\{\bar{\gamma}, c_b\}$ for a sufficiently high π and c_b.

C.3 Dominant strategy for the central bank with regulation

Revert to the baseline setup and suppose that bank regulation is binding at least in the good state (see Appendix C.4 for the underlying conditions). We now study the impact of liquidity injection on welfare, first in the good and then in the bad state, taking the liquidation volume y as given.

Good state. In contrast to Section 3.2.1, there are now constrained dealers in the good state and there is no closed-form expression for the *value* of their purchase, κ_g^{IR} (see Appendix B.1), as a function of the central bank's purchase, z_g. Thus, we use (A2) to study the change in welfare stemming from a given $z_g > 0$:

$$\begin{aligned}
\Delta_g^{IR} &= \underbrace{\left(-ys_g^{IR} + \frac{1}{2}\left(y - z_g\right)s_g^{IR} - \frac{\gamma}{2}z_g^2 + \frac{\beta\kappa_g^{IR}}{2}\left(s_g^{IR} - c_g\kappa_g^{IR}\right)\right)}_{\text{w/ injection}} - \underbrace{\left(-\frac{ys_g}{2} + \frac{\beta\kappa_g}{2}(s_g - c_g\kappa_g)\right)}_{\text{w/o injection}} \\
&= \frac{c_g}{2(1-\beta)}\left(\begin{array}{c} y(y-\beta\kappa_g) - y(y - z_g - \beta\kappa_g^{IR}) + z_g(\tilde{y}_g - \beta\kappa_g^{IR}) \\ +\beta\kappa_g^{IR}(y - z_g - \kappa_g^{IR}) - \beta\kappa_g(y-\kappa_g) \end{array}\right) - \frac{\gamma}{2}z_g^2 \\
&= \frac{\frac{c_g}{1-\beta} - \gamma}{2}z_g^2 + \frac{\beta c_g}{2(1-\beta)}\underbrace{(\kappa_g^{IR} - \kappa_g)}_{<0}\underbrace{(2y - \kappa_g^{IR} - \kappa_g)}_{>0},
\end{aligned} \tag{A12}$$

where the second equality stems from $s_g = \frac{c_g}{1-\beta}(y - \beta\kappa_g)$ and $s_g^{IR} = \frac{c_g}{1-\beta}(y - z_g - \beta\kappa_g^{IR})$. The second inequality in the third line, follows from: the central bank injecting a positive amount, $z_g > 0$; and the meaning of binding regulation, $y > \kappa$ and $y - z_g > \kappa_g^{IR}$. We establish the first inequality in the third line through contradiction. Suppose that $\kappa_g^{IR} \geq \kappa_g$. From one perspective, given that $s_g = \frac{c_g}{1-\beta}(y - \beta\kappa_g)$, $s_g^I = \frac{c_g}{1-\beta}(y_g^I - \beta\kappa_g^I)$ and $z_g > 0$, it follows that $s_g > s_g^{IR}$. From another, the definitions $\kappa_g \equiv \frac{\omega}{R_{2,g} - s_g}$ and $\kappa_g^{IR} \equiv \frac{\omega}{R_{2,g} - s_g^{IR}}$ and the maintained assumption $\kappa_g^{IR} \geq \kappa_g$ imply that $s_g \leq s_g^{IR}$. This is a contradiction, implying that $\kappa_g^{IR} < \kappa_g$.

We note that, at $\gamma = c_g$ and $\left(y - z_g\right) = \kappa_g^{IR} = 0$, $\Delta_g^{IR} = \frac{\beta c_g}{2(1-\beta)}\left(y - \kappa_g\right)^2 > 0$, whereas $\Delta_g^{IR} = 0$ at $z_g = 0$ for any γ. Since Δ_b^{IR} decreases in γ, (A12) then implies that there exists $\delta \in \left(0, c_g\frac{\beta}{1-\beta}\right)$ such that the central bank injects liquidity if and only if $\gamma > c_g + \delta$.

Bad state. Suppose first that bank regulation does not bind. Then:

$$W_b^I = \frac{c_b - \gamma}{2}\left(z_b\right)^2.$$

Thus, $z_b = y$ and the attendant $s_b = 0$ maximise welfare in the bad state if and only if $\gamma < c_b$.

Suppose next that regulation binds in the bad state. Then, the welfare improvement from liquidity injection is:

$$\Delta_b^{IR} = \frac{\frac{c_b}{1-\beta} - \gamma}{2} z_b^2 + \frac{\beta c_b}{2(1-\beta)} \underbrace{(\kappa_b^{IR} - \kappa_b)}_{<0} \underbrace{(2y - \kappa_b^{IR} - \kappa_b)}_{>0}, \tag{A13}$$

When $\gamma = c_b$ and $(y - z_b) = \kappa_b^{IR} = 0$, (A13) simplifies to $\frac{\beta c_b}{2(1-\beta)} (y - \kappa_b)^2 > 0$. Since Δ_b^{IR} decreases in γ, there is a strictly poistive welfare gain of moving from $z_b = 0$ to $z_b = y$ for any $\gamma < c_b$.

C.4 Proposition 7: equilibrium existence, uniqueness and comparative statics

Throughout this appendix, we impose $\frac{c_g}{1-\beta} < \gamma < c_b$, which implies that the central bank injects liquidity only in the bad state. In that case, $s = \pi s_g$. The following market-clearing condition in the good state (based on (14)) – where each side is equal to s_g – delivers $\hat{\varepsilon}$ that defines the equilibrium:

$$\frac{R_2 - 1}{\pi \hat{\varepsilon}} = \left(\frac{\hat{\varepsilon}^2}{2} - \beta \frac{\omega}{R_{2,g} - \frac{R_2 - 1}{\pi \hat{\varepsilon}}} \right) \frac{c_g}{1 - \beta}. \tag{A14}$$

As in Appendix B.1, we need to specify the boundaries of the regulatory parameter ω. We start with $\overline{\omega}^I$ at which regulation is marginally binding in the good state, by (19): $\overline{\omega}^I \equiv \left(R_{2,g} - \frac{R_2 - 1}{\pi \left(2 \frac{R_2 - 1}{c_g \pi} \right)^{\frac{1}{3}}} \right) \frac{\left(2 \frac{R_2 - 1}{c_g \pi} \right)^{\frac{2}{3}}}{2}$.

To ensure $\bar{\omega}^I > 0$, we need to impose the following restriction:

$$c_g < 2\pi^2 \frac{R_{2,g}^3}{(R_2 - 1)^2}. \tag{A15}$$

Since, in the present context, we do not need to ensure that regulation does not bind in the bad state, we set $\underline{\omega}^I = 0$.

Thus, $\omega \in (0, \bar{\omega}^I)$ implies that regulation binds (at least) in the good state. We work with such ω in the rest of this appendix.

For an equilibrium $\hat{\varepsilon} \in (0, 1)$ to be consistent with a positive price of the asset in the good state, $R_{2,g} > (R_2 - 1) / (\pi \hat{\varepsilon})$ – it is necessary that $\pi \in \left(\frac{R_2 - 1}{R_{2,g}}, 1 \right)$. This is a well-defined interval, because $(R_2 - 1) / R_{2,g} > 0$ and, since $R_2 < R_{2,g}$, $(R_2 - 1) / R_{2,g} < 1$.

There exists a unique equilibrium $\hat{\varepsilon} \in \left(\frac{R_2-1}{\pi R_{2,g}}, 1\right)$ for $\pi \in \left(\frac{R_2-1}{R_{2,g}}, 1\right)$, c_g as in (A15), $\omega \in (0, \bar{\omega}^I)$ and $\beta \in (0,1)$. To prove this, we first note that, similar to (A1) above, the left-hand side (LHS) of (A14) decreases in $\hat{\varepsilon}$ and the right-hand side (RHS) increases in $\hat{\varepsilon}$. Second, we report that:

$$LHS\left(\hat{\varepsilon} = \frac{R_2-1}{\pi R_{2,g}}\right) = R_{2,g} > -\infty = RHS\left(\hat{\varepsilon} = \frac{R_2-1}{\pi R_{2,g}}\right),$$

$$LHS\left(\hat{\varepsilon} = 1\right) = \frac{R_2-1}{\pi} < \left(\frac{1}{2} - \beta\frac{\omega}{R_{2,g} - \frac{R_2-1}{\pi}}\right)\frac{c_g}{1-\beta} = RHS\left(\hat{\varepsilon} = 1\right). \tag{A16}$$

For the latter inequality, note first that, for the leverage ratio constraint to be binding, $\kappa_g \equiv \omega/\left(R_{2,g} - \frac{R_2-1}{\pi}\right) < y \leq \frac{1}{2}$, which implies that $RHS\left(\hat{\varepsilon} = 1\right) > c_g/2$. Then, the inequality in (A16) follows from the first parameter restriction in Table 4 (third to bottom rows). In sum, the LHS and RHS of (A14) cross exactly once on the interval $\hat{\varepsilon} \in \left(\frac{R_2-1}{\pi R_{2,g}}, 1\right)$. This also ensures that the price in the good state is positive, i.e. $R_{1,g} = R_{2,g} - s_g = R_{2,g} - \frac{R_2-1}{\pi\hat{\varepsilon}} > 0$.

Comparative statics. Following Appendix B.1 – since (A14) is a version of (A1) in which $c_b = 0$ – we obtain that: $\hat{\varepsilon}$ decreases in c_g and β; s_g and s both increase in c_g, $R_{2,g}$ and β.

In addition, we use (A14), to write out the following:

$$\frac{d\hat{\varepsilon}}{d\omega} = -\frac{\frac{d\frac{R_2-1}{\pi\hat{\varepsilon}} - \left(\frac{\hat{\varepsilon}^2}{2} - \beta\frac{\omega}{R_{2,g} - \frac{R_2-1}{\pi\hat{\varepsilon}}}\right)\frac{c_g}{1-\beta}}{d\omega}}{\frac{d\frac{R_2-1}{\pi\hat{\varepsilon}} - \left(\frac{\hat{\varepsilon}^2}{2} - \beta\frac{\omega}{R_{2,g} - \frac{R_2-1}{\pi\hat{\varepsilon}}}\right)\frac{c_g}{1-\beta}}{d\hat{\varepsilon}}} = \frac{\beta c_g \hat{\varepsilon}(R_{2,g} - s_g)}{s_g(R_{2,g} - s_g)^2(1-\beta) + c_g\hat{\varepsilon}^2(R_{2,g} - s_g)^2 + c_g s_g \beta\omega} > 0. \tag{A17}$$

$$\frac{ds_g}{d\omega} = -\frac{d\hat{\varepsilon}}{d\omega}\frac{R_2-1}{\pi\hat{\varepsilon}^2} < 0. \tag{A18}$$

$$\begin{aligned}\frac{d\kappa_g}{d\omega} &= \frac{1}{R_{2,g} - s_g}\left(1 - \frac{\omega(R_2-1)}{\pi\hat{\varepsilon}^2(R_{2,g} - s_g)}\frac{d\hat{\varepsilon}}{d\omega}\right) \\ &= \frac{s_g(R_{2,g} - s_g)(1-\beta) + c_g\hat{\varepsilon}^2(R_{2,g} - s_g)}{s_g(R_{2,g} - s_g)^2(1-\beta) + c_g\hat{\varepsilon}^2(R_{2,g} - s_g)^2 + c_g s_g \beta\omega} > 0.\end{aligned} \tag{A19}$$

Again as in Appendix B.1, while (A17) and (A19) imply that both the liquidiation volume ($\hat{\varepsilon}^2/2$) and the amount purchased by the constrained dealers (κ_g) decrease as ω decreases, the former decline is slower because the spread s_g is higher for a lower ω. Thus, a lower ω is equivalent to a tighter constraint.

C.5 Proof of Proposition 8

Let injection take place only in the bad state and bank regulation bind only in the good state. The exact parameter restrictions for the proposition are stated at the end of this appendix.

First, binding regulation raises welfare. Paralleling (A4), the expected social welfare is:

$$W^{IR} = 1 + \hat{\varepsilon}(R_2 - 1) - \pi\left(\frac{ys_g}{2} - \frac{\beta\kappa_g}{2}(s_g - c_g\kappa_g)\right) - (1-\pi)\frac{\gamma}{2}y^2. \tag{A20}$$

In turn, (A4) to (A7) imply the following effect of regulatory strictness (ω):

$$\frac{dW^{IR}}{d\omega} = \beta\pi(s_g - c_g\kappa_g)\frac{d\kappa_g}{d\omega} - \underbrace{(1-\pi)\gamma\frac{\hat{\varepsilon}^3}{2}\frac{d\hat{\varepsilon}}{d\omega}}_{>0}. \tag{A21}$$

Combining (A17), (A19) and (A21), it follows that:

$$\begin{aligned}\frac{dW^{IR}}{d\omega} &= \beta\pi(s_g - c_g\kappa_g)\frac{1}{(R_{2,g} - s_g)}\left(1 - \frac{\omega}{(R_{2,g} - s_g)}\frac{R_2 - 1}{\pi\hat{\varepsilon}^2}\frac{d\hat{\varepsilon}}{d\omega}\right) - (1-\pi)\gamma\frac{\hat{\varepsilon}^3}{2}\frac{d\hat{\varepsilon}}{d\omega},\\ &= \frac{\beta(R_{2,g} - s_g)}{s_g(R_{2,g} - s_g)^2(1-\beta) + c_g\hat{\varepsilon}^2(R_{2,g} - s_g)^2 + c_g s_g\beta\omega}\left(\pi(s_g - c_g\kappa_g)((1-\beta)s_g + c_g\hat{\varepsilon}^2) - \frac{(1-\pi)c_g\gamma\hat{\varepsilon}^4}{2}\right)\end{aligned} \tag{A22}$$

As $\omega \in (0, \bar{\omega}^I)$, we first examine the two extremes. First, let the constraint be marginally binding – i.e. $\omega = \bar{\omega}^I$, implying $\kappa_g = y = s_g/c_g$. Tightening the constraint (i.e. reducing ω) from this starting point raises welfare: $\frac{dW^{IR}}{d\omega}|_{\omega=\bar{\omega}^I} < 0$, as shown in (A21). This result stems from the effect of bank regulation on asset managers' risk-taking. We prove this by fixing the investment volume – that is, $\hat{\varepsilon}$ – in (A20), which shuts off the disciplining channel. In this counterfactual, (A19) and

(A21) imply that social welfare declines unambiguously with stricter binding regulation:

$$\frac{dW^{IR}}{d\omega}|_{\hat{\varepsilon}=cons} = \beta\pi\frac{s_g - c_g\kappa_g}{R_{2,g} - s_g} > 0,$$

where the inequality follows from $s_g = c_g y > c_g\kappa_g$ under binding regulation and the positive fire-sale price $R_{2,g} - s_g > 0$ by Appendix C.4.

Next, we derive parameter values under which welfare increases as ω rises from zero. When $\omega = 0$ and thus $\kappa_g = 0$, (A22) implies:

$$\frac{dW^{IR}}{d\omega} = \frac{\beta(R_{2,g} - s_g)}{s_g(R_{2,g} - s_g)^2(1-\beta) + c_g\hat{\varepsilon}^2(R_{2,g} - s_g)^2 + c_g s_g\beta\omega}\left(\pi s_g((1-\beta)s_g + c_g\hat{\varepsilon}^2) - \frac{(1-\pi)c_g\gamma\hat{\varepsilon}^4}{2}\right).$$

Since $s_g > c_g\frac{\hat{\varepsilon}^2}{2}$ under a binding constraint, we know that:

$$\begin{aligned}\pi s_g((1-\beta)s_g + c_g\hat{\varepsilon}^2) - \frac{(1-\pi)c_g\gamma\hat{\varepsilon}^4}{2} &> \pi c_g\frac{\hat{\varepsilon}^2}{2}((1-\beta)c_g\frac{\hat{\varepsilon}^2}{2} + c_g\hat{\varepsilon}^2) - \frac{(1-\pi)c_g\gamma\hat{\varepsilon}^4}{2}\\ &= \frac{1}{4}\hat{\varepsilon}^4 c_g\left(\pi c_g(3-\beta) - 2\gamma(1-\pi)\right)\end{aligned}$$

Thus, $\frac{dW^{IR}}{d\omega}|_{\omega=0} > 0$ is ensured by $\gamma \in \left(\frac{c_g}{1-\beta}, \frac{\pi c_g(3-\beta)}{2(1-\pi)}\right)$, where the lower bound rules out injection in the good state. This interval is well-defined as long as $\pi > \frac{1}{5-4\beta+\beta^2}$, which belongs to $\left(\frac{1}{5}, \frac{1}{2}\right)$.

When $dW^{IR}/d\omega < 0$ at $\omega = \bar{\omega}^I$ and $dW^{IR}/d\omega > 0$ at $\omega = 0$, there **exists** a welfare maximising $\omega^* > 0$. We next derive that this level is **unique**. (A22) implies $\hat{\varepsilon}^*$ solving:

$$(s_g - c_g\kappa_g)\left((1-\beta)s_g + c_g(\hat{\varepsilon}^*)^2\right) = \frac{(1-\pi)c_g\gamma(\hat{\varepsilon}^*)^4}{2\pi}.$$

Using $s_g - c_g\kappa_g = c_g\left(y - \beta\kappa_g\right)/(1-\beta) - c_g\kappa_g = \left(s_g - c_g\frac{\hat{\varepsilon}^2}{2}\right)/\beta$ and $s_g = (R_2 - 1)/(\pi\hat{\varepsilon})$ in the latter equation and rearranging, we obtain the following equation for $(\hat{\varepsilon}^*)^3$:

$$\left(\frac{R_2 - 1}{\pi(\hat{\varepsilon}^*)^3} - \frac{c_g}{2}\right)\left((1-\beta)\frac{R_2 - 1}{\pi(\hat{\varepsilon}^*)^3} + c_g\right) = \frac{\beta c_g\gamma(1-\pi)}{2\pi} \tag{A23}$$

The unique positive solution of (A23) in terms of $\hat{\varepsilon}^{*3}$ is:

$$\frac{1}{(\hat{\varepsilon}^{*})^{3}}=\frac{\pi c_g}{2(1-\beta)(R_2-1)}\left(\sqrt{\left(\frac{1+\beta}{2}\right)^{2}+\frac{2(1-\beta)}{\pi c_g}(\pi c_g+\beta\gamma(1-\pi))}-(\frac{1+\beta}{2})\right) \tag{A24}$$

It implies that the unique ω^* is given by the following expression and (A24):

$$\begin{aligned}\omega^{*} &= \frac{R_{2,g}-\frac{R_2-1}{\pi\hat{\varepsilon}^{*}}}{\beta}\left(\frac{(\hat{\varepsilon}^{*})^{2}}{2}-\frac{1-\beta}{c_g}\frac{R_2-1}{\pi\hat{\varepsilon}^{*}}\right)\\ &= \frac{(\hat{\varepsilon}^{*})^{2}}{2\beta}\left(R_{2,g}-\frac{R_2-1}{\pi\hat{\varepsilon}^{*}}\right)\left(1-\left(\sqrt{\left(\frac{1+\beta}{2}\right)^{2}+\frac{2(1-\beta)}{\pi c_g}(\pi c_g+\beta\gamma(1-\pi))}-\left(\frac{1+\beta}{2}\right)\right)\right)\end{aligned} \tag{A25}$$

On the basis of (A24) and (A25), we obtain that:

$$\frac{d\omega^{*}}{d\gamma}=\underbrace{\frac{\partial\omega^{*}}{\partial\hat{\varepsilon}}}_{>0}\underbrace{\frac{d\hat{\varepsilon}}{d\gamma}}_{<0}+\underbrace{\frac{\partial\omega^{*}}{\partial\gamma}}_{<0}<0,$$

as stated in the proposition.

Overall, $\omega^* > 0$ if:

$$\begin{aligned}&\beta\in(0,1),\ \pi\in\left(\frac{1}{5-4\beta+\beta^{2}},1\right),\ R_2\in\left(1,\frac{1}{1-\pi}\right),\\ &c_g\in\left(\frac{2(R_2-1)}{\pi},2R_{2,g}\left(\frac{R_2\pi}{R_2-1}\right)^{2}\right),\ \gamma\in\left(\frac{c_g}{1-\beta},\frac{\pi c_g\,(3-\beta)}{2\,(1-\pi)}\right),\ c_b>\gamma,\end{aligned}$$

where the upper bound on R_2 ensures that there is a positive fire-sale price at $t = 1$, by (A14), the lower bound on c_g ensures that $\varepsilon^* > 0$ by (A23), the upper bound of c_g stems from (A15), and the condition on c_b implies injection in the bad state. The order of the conditions is such that, if one of them holds, the interval defining the next one is non-empty. These conditions are equivalent to those in Table 4, bottom row.

C.6 Proof of Proposition 9

By (A14), we express the tightness of the optimal constraint as follows:

$$\frac{y^* - \beta \kappa_g}{1 - \beta} = \frac{R_2 - 1}{\pi c_g \hat{\varepsilon}^*}.$$

Since $\frac{d\hat{\varepsilon}^*}{d\gamma} < 0$ by (A24),

$$\frac{d\frac{y-\beta\kappa}{1-\beta}}{d\gamma} = -\frac{R_2 - 1}{\pi c_g \left(\hat{\varepsilon}^*\right)^2} \underbrace{\frac{d\hat{\varepsilon}^*}{d\gamma}}_{<0} > 0,$$

as stated in the proposition.

D Appendix to Section 4

D.1 Data

Our key data source are the regulatory filings that US-based MMFs submit on a monthly basis to the Securities and Exchange Commission (SEC N-MFP forms) and Crane Data collects. From these filings we obtain detailed information on the month-end portfolio holdings of MMFs, which include *inter alia*: the type of instruments MMFs invest in (e.g. repos, commercial paper, certificates of deposits), the identity of the issuer of those instruments, the transacted volumes, the prices that MMFs obtain for providing funding, the outstanding maturity of reported positions.

From Crane we also source the "MFI daily data". These data include fund-level information on returns, daily assets under management and weighted average maturity of assets.

Finally, we obtain information on financial and non-financial commercial paper spreads to repo rates and issuance volumes (from FRED), as well as data on issuer-level data on issuance of short-term US-dollar denominated paper.

Table 5 reports variable definitions and data sources.

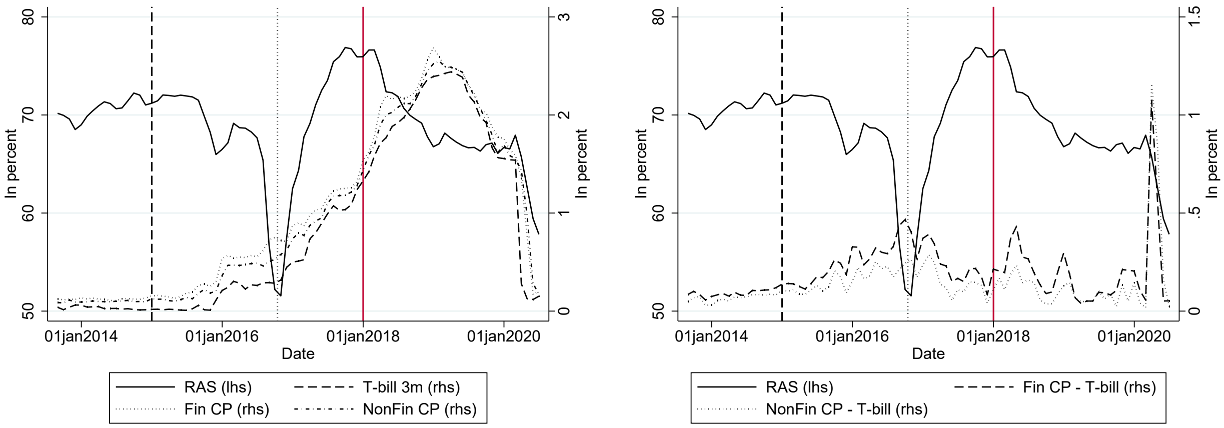
Table 5: Variable definitions and sources

Variable	Definition	Source
RAS_{ft}	Risky asset share of fund f in month t: sum of commercial paper (CP), certificates of deposits and asset-backed CP relative to total fund investments	Crane Data
$Assets_{ft}$	Logarithm of total investment value by fund f in month/day t	Crane Data
WAM_{ft}	Weighted average maturity of fund's f investments in month/day t	Crane Data
$30dReturn_{ft}$	30-day return of fund f in day t	Crane Data
$Fin/NFin\ CP\ spr_t$	Spreads between financial and non-financial CP rates and repo rates, respectively	FRED
$Fin/NFin\ CP\ iss_t$	Financial and non-financial CP issuance volumes, respectively	FRED
$Issuance_{it}$	Issuance of short-term (up to one year maturity) US dollar-denominated paper (in million USD, winsorised at 5/95% level)	Bloomberg & Capital IQ

D.2 Do asset managers respond to bank regulation? – Additional figures

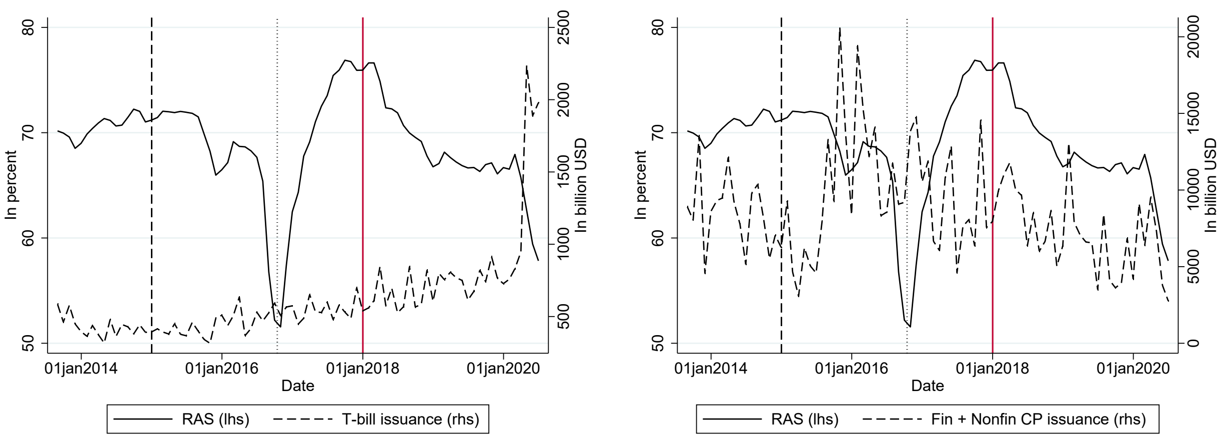
We present here two sets of graphs that relate to Section 4. The first set plots US prime MMFs' risky asset share (RAS) alongside various interest rates, issuance volumes and Fed balance-sheet items. The second set (Figure 8) consists of "parallel trend" plots of RAS (comparing high- and low-RAS prime funds) and WAM (comparing prime and non-prime funds). Each panel in Figure 8 is at the same data frequency and covers the same time period as that underpinning the regressions reported in Tables 1 and 2, respectively.

Figure 5: Risky asset share and money market yields/spreads



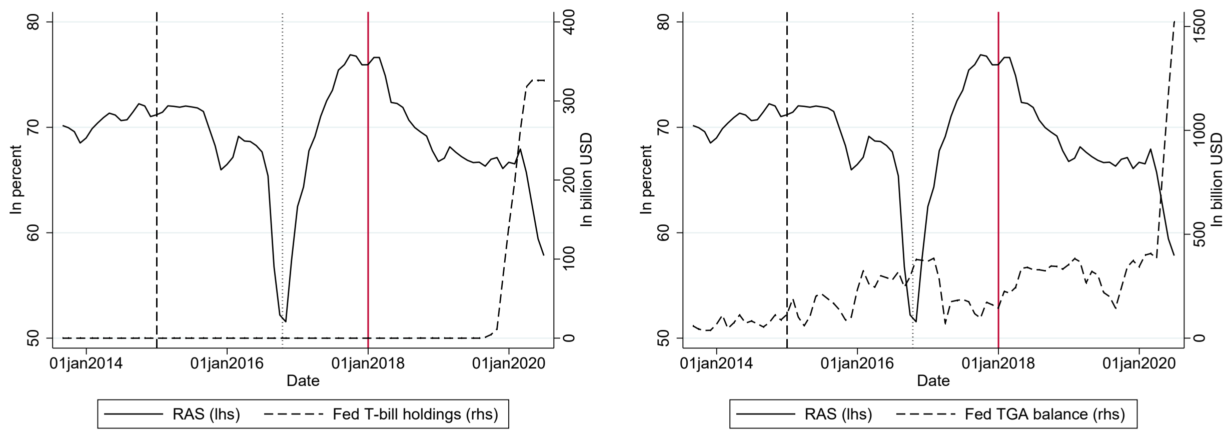
Notes: The risky asset share (RAS) is computed as the 3-month moving average of the sum of investments in commercial paper (CP), asset-backed CP and certificates of deposits, divided by total prime money market fund (MMF) investments. All money market rates are three-month rates. Financial and non-financial CP is AA rated. The dashed vertical line is at the start date of the leverage ratio disclosure requirement (1 January 2015), the dotted vertical line is at the end of the implementation period for the MMF reform (14 October 2016), and the solid red line is at the date when the leverage ratio requirement became effective (1 January 2018).
Source: Crane data; JPMorgan Chase; Bloomberg.

Figure 6: Risky asset share and commercial paper and T-bill issuance



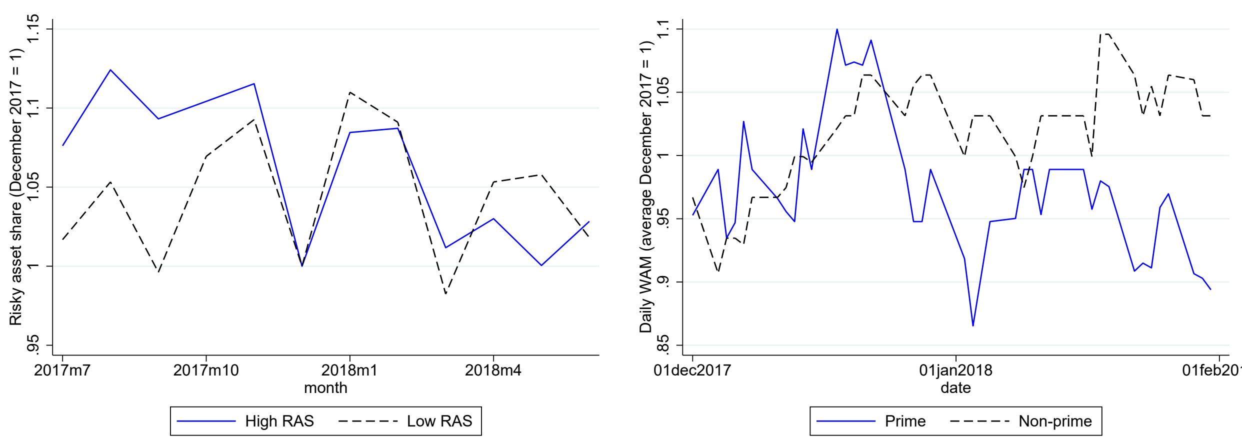
Notes: The risky asset share (RAS) is computed as the 3-month moving average of the sum of investments in commercial paper (CP), asset-backed CP and certificates of deposits, divided by total prime money market fund (MMF) investments. The dashed vertical line is at the start of the leverage ratio disclosure requirement (1 January 2015), the dotted vertical line is at the end of the implementation period for the MMF reform (14 October 2016), and the solid red line is at the date when the leverage ratio requirement became effective (1 January 2018).
Source: Crane data; FRED.

Figure 7: Risky asset share, Fed bills holdings and TGA account



Notes: The risky asset share (RAS) is computed as the 3-month moving average of the sum of investments in commercial paper (CP), asset-backed CP and certificates of deposits, divided by total prime money market fund (MMF) investments. The dashed vertical line is at the start of the leverage ratio disclosure requirement (1 January 2015), the dotted vertical line is at the end of the implementation period for the MMF reform (14 October 2016), and the solid red line is at the date when the leverage ratio requirement became effective (1 January 2018).
Source: Crane data; FRED.

Figure 8: Risky asset share and weighted average maturity around LR implementation



Notes: Both panels report medians for the respective groups. The first panel is based on monthly data; the risky asset share (RAS) is computed as the 3-month moving average of the sum of investments in commercial paper (CP), asset-backed CP and certificates of deposits, divided by total prime money market fund (MMF) investments. The second panel is based on daily data. The series are re-scaled to equal 1 in December 2017 (right-hand panel) and December 15 2017 (right-hand panel).
Source: Crane data.

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