

# Regulatory Arbitrage and Systemic Liquidity Crises\*

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We derive a novel bank run equilibrium within a standard banking framework. Intermediaries optimally rely on wholesale funding to manage liquidity needs, setting the stage for *systemic* runs: When some intermediaries are subject to a run, they raise funds by liquidating their assets. Fire sales in turn induce an overall scarcity of liquid funds, depressing asset prices and hence deteriorating the funding conditions of other intermediaries in the market for secured wholesale funding. We apply the concept of systemic runs in a model in which regulated banks and shadow banks coexist. First, we show that even without contractual linkages between the two sectors and despite the absence of runs on regulated banks, shadow banking panics can cause insolvency of the regulated banking sector. Second, even though some shadow banking is efficient, from a social planner's perspective, the shadow banking sector grows too large in equilibrium due to a pecuniary externality. Third, prudential regulation and central bank interventions change the equilibrium composition of the financial system and affect welfare in non-standard ways.

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# 1. Introduction

Regulatory arbitrage and the growth of shadow banking have been identified as essential ingredients to the 2007-09 financial crisis (Financial Crisis Inquiry Commission 2011). In particular, explicit or implicit contractual linkages between commercial banks and the shadow banking sector,<sup>1</sup> such as liquidity or credit enhancements, have been a source of fragility (Acharya et al. 2009; Brunnermeier 2009; Hellwig 2009; Acharya et al. 2013). Accordingly, post-crisis reforms have targeted the contractual channels through which the turmoil in the shadow banking sector has affected the commercial banking sector (“Volcker Rule”, “Vickers Commission”, “Liikanen Report”).<sup>2</sup> Naturally, the question arises whether the implemented and proposed reforms are effective. Can the prohibition of contractual linkages between commercial banks and non-bank financial institutions be successful in eliminating fragilities arising from regulatory arbitrage?

We formalize a novel argument as to why the prohibition of explicit and implicit contractual linkages may be insufficient. We argue that a financial panic originating in the shadow banking sector can be contagious and can affect the regulated banking sector via pecuniary channels: Suppose that a large-scale withdrawal from the shadow banking sector is imminent. In this case, shadow banks will be forced to raise funds by liquidating assets in a fire sale, potentially triggering an overall scarcity of liquid funds in the money market. Hence, the conditions under which regulated banks obtain wholesale funding also deteriorate, even though the fundamentals remain unchanged. Runs on shadow banks may thus cause illiquidity and insolvency of regulated banks, even without runs inside the banking sector and in the absence of contractual linkages between commercial banks and non-bank financial institutions.

The formalization of this pecuniary contagion channel requires us to develop a new type of run equilibrium. The theoretical foundation is the interplay between two frictions. There is the standard friction in bank run models that contracts cannot be made contingent on agents’ types (see, e.g., Diamond and Dybvig 1983; Goldstein and Pauzner 2005).<sup>3</sup> We add a second friction that prevents intermediaries from contracting with fu-

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<sup>1</sup>We use the term “shadow banking” to describe banking activities (risk, maturity, and liquidity transformation) that take place outside the regulatory perimeter of banking and do not have direct access to public backstops, but may require backstops to operate; compare Pozsar et al. (2013), FSB (2013), Claessens and Ratnovski (2014), and Luck and Schempp (2014a).

<sup>2</sup>See Section 619 of the Dodd-Frank Act (“Volcker Rule”), the Financial Services Act (“Report of the Vickers Commission”), and the proposed EU law on bank structural reform (“Liikanen Report”); see Section 2 for a more detailed description of shadow banking activities prior to and during the financial crisis of 2007-09 as well as on the regulatory response after the crisis.

<sup>3</sup>Following Bryant (1980) and Diamond and Dybvig (1983), there is an extensive literature on bank

ture providers of liquidity (e.g., as in Holmström and Tirole 1998, 2011).<sup>4</sup>

The interaction of these two frictions gives rise to a novel class of bank run equilibria in which runs on some intermediaries affect the funding conditions of other intermediaries. We refer to these types of runs as *systemic runs*. The underlying mechanism is that runs on some intermediaries may lead to a binding cash-in-the-market constraint (see, e.g., Allen and Gale 1994, 2007). Even though the market for wholesale funding is perfectly competitive, once a run induces a scarcity of liquid funds, liquidity providers will be able to earn rents. Hence, those intermediaries that are not subject to a run, but rely on raising liquid funds via the market, are affected via a deterioration of their funding liquidity.

In contrast to previous work, the systemic aspect of runs does not result from interbank linkages (Allen and Gale 2000; Freixas et al. 2000; Farboodi 2015) or correlated risks (Acharya and Yorulmazer 2007, 2008). The contagion operates via the exposure to a common pool of liquidity and deteriorating funding conditions. We argue that the notion of systemic runs is stronger than in previous work in which contagion operates via fire sales (Uhlig 2010; Diamond and Rajan 2005, 2011; Martin et al. 2014b).

The particular feature of our model is that even in the absence of any fundamental risk or contractual linkages between intermediaries, runs on some intermediaries *necessarily* affect other intermediaries, and may even make a run on all intermediaries inevitable. The systemic property stems from the fact that liquidity management relies on short-term wholesale funding, exposing intermediaries to movements in asset prices that result from runs elsewhere. Unlike in other work (Shleifer and Vishny 1997, Brunnermeier 2009, and Greenwood et al. 2015, Adrian and Shin 2014), there is no difference between market and funding liquidity of intermediaries in our model. The conditions under which assets can be sold and under which funds can be borrowed are isomorphic. An intermediary that is subject to a run is facing tight market liquidity, and an intermediary that is not subject to a run is facing tight funding liquidity, where the former causes the latter.

We apply the concept of systemic runs to a model in which regulated banks and shadow

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runs on single institutions. See, e.g., the literature regarding information-based runs (Jacklin and Bhattacharya 1988; Postlewaite and Vives 1987; Chari and Jagannathan 1988), models with macroeconomic risk (Hellwig 1994; Allen and Gale 1998), contagion via interbank linkages (Bhattacharya and Gale 1987; Allen and Gale 2000), models that combine macroeconomic risk and strategic uncertainty (Rochet and Vives 2004; Morris and Shin 2003; Morris and Shin 2010), and dynamic runs (He and Xiong, 2012).

<sup>4</sup>The friction that agents cannot commit to future financing is used in banking contexts by Uhlig (2010), Bolton et al. (2011), Luck and Schempp (2014b), and Hakenes and Schnabel (2015), among others. Moreover, the friction also arises naturally in banking models in OLG environments, as in Qi (1994) and Martin et al. (2014a,b).

banks coexist. Three important implications follow: First, the prohibition of contractual linkages between commercial banks and non-bank banking entities is insufficient to safeguard the regulated banking sector. Even though there are no contractual linkages between the sectors, no fundamental risk of insolvency, and no prospect of panics at regulated and insured banks, insured institutions may yet turn illiquid and insolvent. Funding conditions may deteriorate due to a run on uninsured shadow banks. The possibility of regulatory arbitrage thus challenges the conventional wisdom that the provision of a safety net can eliminate strategic complementarity between depositors at zero cost. If the extent of regulatory arbitrage cannot be controlled, a deposit insurance eliminates runs only partially and the deposit insurance scheme is costly as it needs to live up to its promise in case of systemic liquidity crises.

Second, while the existence of shadow banks may be efficient in our model, the shadow banking sector is too large in equilibrium. Hence, we do not argue that regulatory arbitrage is diabolic per se. A certain degree of regulatory arbitrage is efficient and desirable, as shadow banks make efficient use of the disciplining effect of short-term debt.<sup>5</sup> However, we find that regulatory arbitrage is excessive from a social planner's perspective. The underlying mechanism is a pecuniary externality that operates through fire-sale prices. When consumers decide whether to deposit at a shadow bank or at a regular bank, agents face the following trade-off: A regular bank offers a low interest payment as it is subject to regulatory cost, but the safety net eliminates all risk. In contrast, a shadow bank offers a higher interest, but it comes with the prospect of panic-based runs. When making their choice, depositors do not internalize that depositing in the shadow banking sector reduces the equilibrium fire-sale price.<sup>6</sup> Lower fire-sale prices in turn have three negative effects: First, they increase the probability of runs taking place.<sup>7</sup> Second, they reduce the amount of funds available to shadow banks in case of a

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<sup>5</sup>On the disciplining effect of short-term debt, see Calomiris and Kahn (1991) and Diamond and Rajan (2001). Our argument complements other arguments why shadow banking may be desirable, such as comparative advantages in securitizing assets (compare, e.g., Gennaioli et al. 2013; Hanson et al. 2015), or by relaxing imperfect prudential constraints and utilizing self-regulating reputational concerns (see Ordoñez 2013; Huang 2014).

<sup>6</sup>The fact that a pecuniary externality impacts welfare is reminiscent of findings in the literature on pecuniary externalities in an incomplete markets setup; compare, e.g., Lorenzoni (2008). See also Bengui and Bianchi (2014) for a sectoral model with circumvention of regulatory requirements and Diamond and Rajan (2011) for a banking model with fire sales. In our model, the intuition for why the pecuniary channel affects welfare is similar; however, the exact mechanisms cannot be compared, as we only do a partial equilibrium analysis.

<sup>7</sup>In our model, runs occur with a positive probability as in Cooper and Ross (1998), but we assume that the probability is a function of the model's variables and decreasing in the fire-sale price as in Gertler and Kiyotaki (2015).

run. Third, they increase the shortfall of funds in the regulated banking sector and thus the funding required for the deposit insurance scheme.

Finally, if the extent of regulatory arbitrage cannot be controlled, the welfare effects of prudential regulation and central bank interventions are ambiguous. Restricting wholesale funding for regulated banks, as in the liquidity regulation of Basel III, would allow the regulated banking sector to be shielded from adverse consequences originating outside the sector. However, it would also lead to allocative inefficiencies in the banking sector and would thus induce more regulatory arbitrage, i.e., a larger shadow banking sector, making severe fire sales even more severe. Liquidity regulation may thus backfire: even though it stabilizes the regulated banking sector, overall financial stability may be weakened.

Likewise, central bank interventions such as lender of last resort (LoLR) and market maker of last resort (MMLR) shield commercial banks from adverse events originating in the shadow banking sector. Both types of interventions increase the relative attractiveness of shadow banking by reducing the need of regulated banks to sell assets in a fire sale, making the fire sale less severe for shadow banks. Interestingly, the anticipation of central bank interventions creates systemic risk not via the standard channels of moral hazard with respect to risk choices (Acharya and Yorulmazer 2008) or the degree of maturity mismatch (Farhi and Tirole 2012), but solely via changing the composition of the financial system.

The relevance of the risk of systemic runs in our current financial system becomes clear if we have a look at the pure quantities involved. After the crisis of 2007-09, shadow banking remains a concern for regulators, economists, and market participants. According to the FSB (2014), shadow banking activities globally amount to 25% of total financial assets, 50% of assets held by the banking system, and 120% of GDP on average. Moreover, shadow banking activities as measured by overall assets have grown relative to assets financed by the regular banking sector since 2008. When narrowing down to those shadow banking institutions that have no legal connection to commercial banks, they still hold about 30% of all financial assets in both, the US as well as in the euro area. Also, these types of measures have continued to grow since 2008, and their growth has outpaced that of the banking sector. At the same time, despite having declined since 2007, wholesale funding still makes up around 15-25% of the regulated banks' liabilities<sup>8</sup>

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<sup>8</sup>The numbers vary depending on what types of funding are counted as wholesale funding and whether long-term funding is excluded or not. Typical definitions include short-term unsecured funds, inter-bank loans, commercial paper (CP), and wholesale certificates of deposit (CDs), repurchase agreements (repos), swaps, and asset-backed commercial paper. Long-term funding includes bonds issuance and various forms of securitization, including covered bonds and private-label mortgage-backed

in the United States and in the euro area (International Monetary Fund 2013; European Central Bank 2014). Thus, the two main ingredients of our model are present in our current financial system: A large shadow banking sector and regulated banks' exposure to the risk of changing conditions in the market for wholesale funding.

We proceed as follows: Section 2 gives a brief overview of shadow banking prior to and during the crisis of 2007-09 and the regulatory response after the crisis. Sections 3 and 4 describe the setting and the concept of systemic runs. Section 5 shows how deposit insurance combined with a capital requirement can eliminate the fragility, but also how regulatory arbitrage reintroduces fragility even in the absence of contractual linkages. Section 6 derives the equilibrium size of the shadow banking sector and shows that regulatory arbitrage is excessive in equilibrium. Finally, Section 7 discusses the effects of wholesale funding restrictions, central bank interventions, and liquidity guarantees. Section 8 concludes.

## **2. Shadow Banking, the Crisis of 2007-09, and the Regulatory Response**

Prior to the 2007-09 financial crisis, many commercial banks had set up off-balance-sheet conduits to finance long-term real investment by issuing short-term debt (Pozsar et al., 2013). From an ex-post perspective, it appears that off-balance-sheet banking had to a large extent been conducted to circumvent existing capital regulation (see, e.g., Acharya et al., 2013).<sup>9</sup> A typical intermediation chain would look as follows: special purpose vehicles such as asset-backed commercial paper conduits were set up to finance mortgage-backed securities (MBS) and other asset-backed securities (ABS) by issuing asset-backed commercial papers (ABCP) and medium-term notes (MTN), which in turn were mostly held by money market mutual funds (MMF). Conduits were either granted explicit credit or liquidity guarantees (credit or liquidity enhancements), or implicit guarantees as in the case of structured investment vehicles (SIV). I.e., less than 30% of the conduits had received outright guarantees. However, most other conduits that were set up by commercial banks had relational contracts with their parent companies. Reputational concerns ensured that parent companies would not let their shadow banking subsidiaries default; see particularly Segura (2014).

In the summer of 2007, increased delinquency rates on subprime mortgages ultimately led to the collapse of the conduits' main source of funding:<sup>10</sup> the market for ABCP (see,

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securities.

<sup>9</sup>To some observers, this had already been clear prior to the crisis; see Jones (2000).

<sup>10</sup>The trigger is widely acknowledged to be BNP Paribas suspending convertibility of three of its funds

e.g., Kacperczyk and Schnabl, 2009; Covitz et al., 2013). The collapse forced banks to take the conduits' assets and liabilities on their balance-sheets, and their insufficient equity cushions created severe solvency issues (Acharya et al., 2013).<sup>11</sup>

The post-crisis narrative has been that shadow banking could only become so large because most shadow banks were set up and operated by commercial banks, which in turn had access to the safety net (i.e., the discount lending window, deposit insurance, implicit bailout guarantees, see Financial Crisis Inquiry Commission, 2011). Consequently, regulatory reforms have tried to close loopholes in regulation by outright prohibition of contractual links between depository institutions and other parts of the financial system. The reform proposals include a ring-fencing of depository institutions and systemic activities (Report of the Vickers Commission, enacted as Financial Services Act in 2013), separation between different risky activities (“Report of the European Commission’s High-level Expert Group on Bank Structural Reform”, known as the Liikanen Report), and prohibition of proprietary trading by commercial banks (Section 619 of the Dodd-Frank Act, referred to as the “Volcker Rule”).

Section 619 of the Dodd-Frank Act – besides prohibiting banking corporations from conducting proprietary trading – also prevents banking corporations from entering into transactions with funds for which they serve as investment advisers. Therefore, conduit operations by commercial banks, in particular rescuing conduits, are heavily restricted. Likewise, following the Report of the Vickers Commission, the Financial Services Act in 2013 limits the exposure of depository institutions to other financial entities within the same bank holding company (BHC). This also implies that any type of outright guarantees or any support in distress from depository institutions to shadow banking subsidiaries becomes impossible. In a similar spirit, the Liikanen Report promotes a mandatory separation of proprietary trading and other high-risk trading (“trading entity”) from commercial banking (“deposit bank”), trying to restrict contractual connections between standard banking and market-based activities. Hence, the regulatory paradigm throughout all three jurisdictions has been that ex-ante or ex-post support to off-balance-sheet activities shall be prohibited or restricted. In the following, we analyze whether this is sufficient to enhance financial stability in the presence of regulatory

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that were exposed to risk of subprime mortgages bundled in ABS.

<sup>11</sup>Subsequent to the runs on ABCP, there had been counterparty runs at Bear Stearns' and Lehman's tri-party repo programs (Copeland et al., 2014). Moreover, there had been severe contractions in overall repo funding throughout 2007 and 2008 (Gorton and Metrick, 2012), which was, however, less important than the contraction in the market for ABCP (Krishnamurthy et al., 2014). Finally, the Lehman failure triggered a large-scale withdrawal from the prime money market industry (Schmidt et al., 2014).

arbitrage.

### 3. Setup

Consider an economy that goes through a sequence of three dates,  $t \in \{0, 1, 2\}$ . There is a single good that can be used for consumption as well as for investment. The economy is populated by three types of agents: consumers, intermediaries, and investors.

#### Technologies

Altogether, there are three technologies available for investment (see a summary of the payoff structure in Table 1). Storage is available in  $t = 0, 1$ , transforming one unit invested in  $t$  into one unit in  $t + 1$ . In addition, two illiquid technologies are available for investment in  $t = 0$ : a “productive technology” and an unproductive “shirking technology”. Both technologies are technologically illiquid, i.e., the physical liquidation rate in  $t = 1$  is assumed to be zero. However, claims on the technologies’ future returns may nonetheless be traded in a secondary market in  $t = 1$ .

The return properties of the illiquid technologies in  $t = 2$  are as follows: One unit invested in the productive technology yields a safe return of  $R > 1$  units in  $t = 2$ . One unit invested in the shirking technology yields a safe return of  $R_{shirk}$  in  $t = 2$ . Moreover, this technology yields a private benefit  $B > 0$  in  $t = 2$  which is non-pledgeable. We assume that  $R_{shirk} + B \leq 1$ . I.e., the shirking technology is inefficient, but may give rise to moral hazard.

	$t = 0$	$t = 1$	$t = 2$
Storage in $t = 0$	-1	1	0
Storage in $t = 1$	0	-1	1
Productive technology	-1	0	$R$
Shirking technology	-1	0	$R_{shirk} + B$

**Table 1:** Payoff structure of technologies

#### Consumers

There is a continuum of consumers with mass one. Each consumer is endowed with 1 unit of the good in  $t = 0$ . There are two types of consumers, *patient* and *impatient* consumers: a fraction  $\pi$  is impatient and derives utility only from consumption in  $t = 1$ ,  $u(c_1)$ , and a fraction  $1 - \pi$  is patient and derives utility only from consumption in  $t = 2$ ,  $u(c_2)$ . We restrict attention to CRRA utility, i.e., the baseline utility function has the form  $u(c_t) = \frac{1}{1-\eta} c_t^{1-\eta}$ , with  $\eta > 1$ .

The demand for liquid assets arises as consumers face idiosyncratic uncertainty with respect to their preferred date of consumption. Initially, the probability of being impatient is identical and independent. At date 1, each consumer privately learns his type, which can be considered as a liquidity shock. The fact that types are private information implies that contracts cannot be made contingent on types. This is the standard friction that gives rise to the possibility of bank runs when illiquid assets are financed by short-term debt.<sup>12</sup>

A consumption profile  $(c_1, c_2)$  denotes an allocation where an impatient consumer receives  $c_1$  and a patient consumer receives  $c_2$ . As of date 0, such a consumption profile induces an expected utility of

$$U(c_1, c_2) = \pi u(c_1) + (1 - \pi)u(c_2) = \frac{1}{1 - \eta} \left[ \pi c_1^{1-\eta} + (1 - \pi)c_2^{1-\eta} \right]. \quad (1)$$

We restrict the action space of consumers to investing in storage and to interacting with intermediaries. In particular, we assume that consumers cannot invest directly in the productive technology.<sup>13</sup>

### Intermediaries

There is a mass  $m$  of intermediaries.<sup>14</sup> While consumers cannot invest in the productive technologies directly, intermediaries face no investment restrictions. Intermediaries have no market power and compete for the consumers' funds in order to invest on their behalf. Moreover, intermediaries have an endowment which they can invest in the intermediation business or in some outside option. We assume that the endowment is sufficiently large such that no result will be driven by the aggregate intermediaries' endowment becoming a binding resource constraint.

Intermediaries care about their wealth at date 2 and have an outside option. The outside option is assumed to induce a required return of  $\rho > R$  in  $t = 2$  for each unit invested in  $t = 0$ . As the required return is larger than the productive technologies' returns, it is costly for the consumers if the intermediaries use their endowment for investment. This assumption makes it costly to use a skin-in-the-game mechanism in order to provide intermediaries with incentives to prevent shirking. Later on,  $\rho$  will

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<sup>12</sup>Compare to the classic bank run literature, e.g., Diamond and Dybvig (1983), Bhattacharya and Gale (1987), and Allen and Gale (1998, 2000, 2007).

<sup>13</sup>This allows us to abstract from issues that arise via the coexistence of financial markets and intermediaries. In Section B of the appendix, we argue briefly why we can focus on a banking solution directly, i.e., why a banking solution dominates a financial markets solution.

<sup>14</sup>It is assumed that  $m$  is small compared to the mass of depositors such that each bank has a very large number of depositors, and thus does not face aggregate liquidity risk by a law of large numbers argument.

therefore also be referred to as regulatory costs.

The assumption is a shortcut for assuming that some market imperfections make issuing equity more costly than debt. The standard argument why equity is costly is based on adverse selection concerns (Myers and Majluf, 1984). Other, more recent reasonings are for instance a detrimentally high cost of renegotiating with existing creditors and an associated leverage-ratchet effect (Admati et al., 2013), non-pecuniary benefits to bank owners (Adrian and Shin, 2011).

### **Investors**

There is a continuum of investors of mass  $n$ . Investors are modeled as liquidity providers to intermediaries, i.e., as agents or institutions that supply liquid funds on the money market.<sup>15</sup> Investors are born at date 1 and care about their wealth at date 2. They are assumed to have a technology with a return of  $\mu$  as an outside option, where  $\mu \in [1, R]$ . That is, investors have a required return of  $\mu$  in  $t = 2$  for each unit they transfer to intermediaries in  $t = 1$ .

Investors are endowed with  $A/n$  units of the good, and the investors' aggregate endowment is given by  $A$ . The endowment  $A$  will be one of the crucial parameters of the model: while it may be sufficiently high to allow investors to supply liquidity in normal times, it may lead to a binding cash-in-the-market constraint in case of systemic runs. Moreover, the fact that investors are born not before  $t = 1$  is the second important friction in our model. It implies that from the  $t = 0$  perspective, intermediaries cannot write contracts with investors and thus their funding conditions may deteriorate.<sup>16</sup>

## **4. Intermediation, Bank Runs, and Systemic Runs**

In the following, we derive the first-best allocation and show how it can be implemented by intermediaries. We then show that not only single intermediaries can be subject to runs, but also that runs can be systemic, i.e., runs on some intermediaries necessarily impact those intermediaries that are not subject to runs.

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<sup>15</sup>Investors should be seen as the standard providers of liquidity on the money market, i.e., agents and institutions with information on and access to the money market: banks with current high liquidity inflow, hedge funds, pension funds, or larger corporations with abundant liquid funds. Later we will also consider the central bank as an actor that competes with investors.

<sup>16</sup>See, e.g., Holmström and Tirole (1998, 2011) on assuming limited commitment of future financing. In the context of banking models, the assumption is made, e.g., by Bolton et al. (2011), Martin et al. (2014a,b), Luck and Schempp (2014a), and Hakenes and Schnabel (2015).

## 4.1. First best

We derive the allocation that maximizes the expected utility of consumers, subject to the participation constraints of intermediaries and investors, and subject to the resource constraints. We refer to the resulting allocation as the first-best allocation and denote it by  $(c_1^*, c_2^*)$ .

Let  $I$  denote the amount that intermediaries invest in the productive technology, and  $I_{shirk}$  the investment in the shirking technology. In the first best, the shirking technology is not used as the productive technology strictly dominates the shirking technology, i.e.,  $I_{shirk} = 0$ . Moreover, let  $e_0$  denote the amount that intermediaries invest in the intermediation business at date 0, and  $e_2$  what they receive at date 2. Given the required return of intermediaries  $\rho > R$ , optimality implies that  $e_0 = e_2 = 0$ . Denote by  $L_1$  the amount of goods that get transferred from investors to consumers in  $t = 1$  (“liquidity”), and  $L_2$  the amount of goods transferred back to investors in  $t = 2$ .

The optimization problem for the first best is the following:

$$\max_{(c_1, c_2, I, L_1, L_2) \in \mathbb{R}_+^5} \quad \pi u(c_1) + (1 - \pi)u(c_2), \quad (2)$$

$$\text{subject to} \quad \pi c_1 \leq (1 - I) + L_1, \quad (3)$$

$$(1 - \pi)c_2 \leq IR - L_2, \quad (4)$$

$$L_2 \geq \mu L_1, \quad (5)$$

$$L_1 \leq A, \quad \text{and} \quad (6)$$

$$I \leq 1. \quad (7)$$

The budget constraints for date one and two are given by (3) and (4). Investors may transfer  $L_1$  to consumers in  $t = 1$  in exchange for  $L_2$  units in  $t = 2$ . (5) represents the participation constraint of investors. The resource constraint on the investors’ provision of “liquidity” is given by (6), and (7) denotes the constraint on the initial investment.

Depending on the model parameters  $A, R, \mu$ , and  $\pi$ , as well as on the shape of the utility function, the first-best program has three solution candidates. As discussed in detail in Section A of the appendix, investment in storage is only optimal if  $A$  is small, and becomes unnecessary when  $A$  is sufficiently large. For the remaining part of the paper we restrict attention to the parameter space in which intermediation optimally relies exclusively on investors providing liquid funds at date 1. That is, it is optimal to invest exclusively in the productive technology, i.e.,  $I^* = 1$  and the storage technology is redundant. This restriction is formalized by the following:

**Assumption 1.**  $A \geq \xi \equiv \pi \mu^{-\frac{1}{\eta}} \frac{R}{(1-\pi) + \pi \mu^{1-\frac{1}{\eta}}}$ .

This allows us to characterize the first-best allocation:

**Lemma 1** (First-best Allocation). *The first-best allocation is characterized by*

$$I^* = 1, \quad L_1^* = \pi c_1^*, \quad L_2^* = \mu \pi c_1^*, \quad \text{and } I_{shirk} = e_0 = e_2 = 0,$$

and the optimal consumption profile is given by

$$c_1^* = \mu^{-\frac{1}{\eta}} \frac{R}{(1-\pi) + \pi \mu^{1-\frac{1}{\eta}}} \quad \text{and} \quad c_2^* = \frac{R}{(1-\pi) + \pi \mu^{1-\frac{1}{\eta}}}. \quad (8)$$

Under Assumption 1, it is optimal to invest exclusively in the illiquid productive technology and entirely rely on investors to provide funds for those that are subject to a liquidity shock at date 1. When using investor funds to satisfy the demand for liquid assets in  $t = 1$ , the technological rate of substitution between date 1 and 2 is given by the investors' required return  $\mu$ . Therefore, the risk-sharing between early and late consumers is described by the FOC  $u'(c_1) = \mu u'(c_2)$ , and it holds that  $R > c_2^* > c_1^* > R/\mu$ , where  $R/\mu$  is the rate of return on the productive asset between date 0 and 1, when it is traded against liquid funds from investors.<sup>17</sup>

## 4.2. Implementation

In the following, we show that the first-best allocation can be implemented by intermediaries issuing demand-deposit contracts to finance the illiquid investment.

**Lemma 2** (Intermediation). *There exists a subgame-perfect Nash equilibrium in which the first-best consumption profile  $(c_1^*, c_2^*)$  is implemented by the intermediaries offering demand-deposit contracts. Intermediaries rely on secured wholesale funding by investors in order to manage liquidity needs.*

The implementation of the first-best allocation via demand-deposit contracts offered by intermediaries has three dimensions. The first dimension is that demand-deposit contracts allow consumers to share their risk optimally, and at the same time incentives

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<sup>17</sup>In the banking model of Diamond and Dybvig (1983) – which is nested in our model for the class of constant relative risk aversion – risk-sharing between patient to impatient consumers is optimal, implying that  $R > c_2^{DD} > c_1^{DD} > 1$ , where 1 is the technological rate of return between date 0 and 1 (storage).

are such that agents reveal their type in  $t = 1$  truthfully (e.g., as in Diamond and Dybvig, 1983). The latter is incentive-compatible as  $c_2^* > c_1^*$ .

The second dimension is the disciplining effect of short-term debt. We discuss why demand deposits are disciplining in our setup in detail in the Section C of the appendix.<sup>18</sup> The underlying logic is as in Calomiris and Kahn (1991) and Diamond and Rajan (2001): Demand deposits allow the prevention of shirking. Intermediaries, when investing on behalf of the financiers, are subject to moral hazard as they may have incentives to invest in the shirking technology to capture the private benefit  $B$ . Whenever an intermediary has invested in the shirking technology, consumers learn about it at  $t = 1$  and have an incentive to withdraw collectively. As the debt is demandable, this is in fact possible. Moreover, as the private benefit accrues not before  $t = 2$ , the intermediary will thus not be rewarded for shirking, and have no incentive to do so in the first place.

The third dimension is raising funds from investors to pay out consumers at the interim date. Intermediaries invest exclusively in the illiquid assets and need to raise funds from investors in order to serve withdrawing consumers at date 1. We consider two types of isomorphic institutional arrangements on how intermediaries can obtain funds from investors in order to manage the consumers' liquidity demand: asset sales and secured wholesale funding.

In order to raise funds via asset sales, an intermediary must sell an overall amount of  $\pi c_1^*/(R/\mu)$  units of claims on his investments at price  $p = R/\mu$  per unit (which we define as the “fundamental value” of the asset) to the investors. An investor receives an asset that promises a cash-flow of  $R$  in  $t = 2$  for  $R/\mu$ , and thus earns a return  $\mu$ , satisfying her participation constraint.

An alternative arrangement is “secured wholesale funding”. As the fundamental value of the asset is  $R/\mu$ , the first best could be implemented by the following collateralized<sup>19</sup> debt contract: At date 1, the intermediary receives an amount of liquidity  $L_1 = \pi c_1^*$ , which can be used to pay out those consumers who withdraw out of a consumption motive. In exchange, the intermediary promises to pay back  $L_2 = \mu \pi c_1^*$ , implying a gross interest rate of  $r = \mu$ . Moreover, the intermediary pledges an amount of assets  $\pi c_1^*/(R/\mu)$  as collateral. This collateral has a “fundamental value” of  $\pi c_1^*$  at date 1, and a value of  $\mu \pi c_1^*$  at date 2. Thus, collateralizing claims gives investors full seniority. They are thus able to earn their required return with certainty, ensuring participation.

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<sup>18</sup>As discussed in the appendix, there are also equilibria with partial shirking, which can, however, be ruled out by restricting investment decisions to be binary.

<sup>19</sup>Importantly, claims have to be secured and collateralized, thus giving the investors de facto seniority. Otherwise, strategic complementarity among investors may arise; compare Luck and Schempp (2014b).

Importantly, the two institutional arrangements – asset sales and collateralized borrowing – are isomorphic in our setup and it holds that the interest rate can be expressed as  $r = R/p$ . For expositional purposes, we assume that intermediaries conduct secured wholesale funding in normal times and asset sales (fire sales) when they are subject to a run.

### 4.3. Bank runs and systemic runs

While short-term debt can have a disciplining effect in our model, it is also a source of fragility: the model exhibits multiple equilibria in the  $t = 1$  subgame. Runs on single intermediaries always constitute an equilibrium for the same logic as in standard bank run models with maturity transformation. If all consumers of a particular intermediary withdraw, this intermediary becomes insolvent, as she can raise at most  $R/\mu$  units of liquidity at date 1 by selling all her assets. However, the consumers are altogether entitled to  $c_1^* > R/\mu$  at date 1. If a patient consumer has a belief that all other consumers withdraw, she can either withdraw and to get  $R/\mu$  in  $t = 1$ ,<sup>20</sup> or she can wait until  $t = 2$  and receive nothing. Thus, withdrawal is the best response to withdrawal of all other agents. The bank-run risk results from the demandable nature of deposit contracts which is necessary because the information friction concerning the consumer types makes contingent contracts unfeasible. Intermediaries cannot distinguish whether an individual is withdrawing out of a consumption or out of a panic motive.

Our analysis, however, goes beyond the classical bank-run problem and asks: When do runs on some intermediaries impact other intermediaries? Runs can become systemic via the interaction of the standard friction of non-observable types with the second friction that prevents intermediaries from contracting with investors at the initial date. If intermediaries could settle with investors on funding conditions initially, they would be unaffected when other intermediaries are subject to a run. However, because such contracts are not feasible, intermediaries may face tightening funding conditions once other intermediaries have to sell assets. Here, the amount of investors' funds  $A$  plays a crucial role because, depending on  $A$ , our model features qualitatively different run equilibria. If the amount of funds  $A$  is sufficiently large, runs on some intermediaries cannot affect market conditions, and thus they cannot affect other intermediaries. However, if  $A$  is limited, the situation is different: If sufficiently many intermediaries are subject to a run, then liquidity becomes scarce relative to the demand for liquid funds.<sup>21</sup> In this case, the

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<sup>20</sup>We abstract from a sequential-service constraint throughout the paper. We assume that in case of illiquidity, all funds available are distributed evenly across all consumers who wish to withdraw.

<sup>21</sup>We follow the standard bank run literature in assuming that deposits when withdrawn are consumed

market for liquidity clears at terms that are unfavorable for all intermediaries that have to raise funds from investors.

Since we are interested in the latter case, we assume that the secondary market has limited depth, i.e., that  $A$  is not arbitrarily high. This implies that liquidity is not globally abundant, and cash-in-the-market pricing prevails if sufficiently many assets are sold. Technically, this requires the following:

**Assumption 2.**  $A < R/\mu$ .

Suppose a mass  $\alpha$  of intermediaries are subject to a run, whereas the remaining  $1 - \alpha$  are not. The following result holds:

**Proposition 1** (Systemic Runs). *Consider an equilibrium of the  $t = 1$  subgame in which  $\alpha$  intermediaries are subject to a run. This run is a “systemic run”, i.e., it deteriorates the funding conditions of all intermediaries, if  $\alpha > \bar{\alpha}$ , where*

$$\bar{\alpha} = \frac{A - \pi c_1^*}{R/\mu - \pi c_1^*} < 1.$$

If  $\alpha > \bar{\alpha}$ , the run on  $\alpha$  intermediaries affects *all* intermediaries. In particular, also those  $1 - \alpha$  intermediaries that are not subject to a run face deteriorated funding conditions.<sup>22</sup>

The underlying mechanism is as follows: The  $\alpha$  intermediaries that are subject to a run must sell *all* their assets in order to raise as many liquid funds as possible. In addition, the  $1 - \alpha$  intermediaries need to raise a total amount of liquidity of  $(1 - \alpha)\pi c_1^*$  in order to serve impatient consumers. At price  $p = R/\mu$ , all intermediaries taken together would sell  $\alpha + (1 - \alpha)\pi c_1^*/(R/\mu)$  units of the asset, thus raising an amount of liquidity of  $\alpha R/\mu + (1 - \alpha)\pi c_1^*$ . If this liquidity demand is smaller than the amount of liquid funds

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and not redeposited. Without this restriction, further frictions would be needed to explain systemic runs, such as frictions in interbank trade, as pointed out, e.g., by Skeie (2008).

<sup>22</sup>Notice that not every  $\alpha \in [0, 1]$  can necessarily prevail in equilibrium as for  $\alpha$  sufficiently large, a deterioration of funding conditions may necessarily lead to a run on all intermediaries. Let us define

$$\tilde{\alpha} = \frac{A - \pi c_1^*}{\frac{\pi c_1^* R}{R - (1 - \pi)c_1^*} - \pi c_1^*}.$$

If it holds that  $\tilde{\alpha} < 1$ , then there exists no equilibrium with  $\alpha \in (\tilde{\alpha}, 1)$ , for the following reason: If there is a run on  $\tilde{\alpha}$  intermediaries, the funding conditions for the remaining intermediaries are such that they can only pay out exactly  $c_2 = c_1^*$  to their patient consumers at date 2. Thus, whenever  $\alpha > \tilde{\alpha}$ , it is the dominant strategy of all consumers at all intermediaries to withdraw early, so  $\alpha = 1$  is the only remaining equilibrium.

$A$ , the market does actually clear at  $p = R/\mu$ . This is the case if  $\alpha \leq \bar{\alpha}$ . Otherwise, i.e., if  $\alpha > \bar{\alpha}$ , the market clears at a cash-in-the-market price à la Allen and Gale (1994). The cash-in-the-market price is equal to the ratio of the funds available,  $A$ , to the amount of assets that need to be sold at price  $p$ , which is given by  $\alpha + (1 - \alpha)\pi c_1^*/p$ .

The fire-sale price as a function of  $\alpha$  is given by

$$p(\alpha) = \begin{cases} R/\mu & \text{if } \alpha \leq \bar{\alpha} \\ \frac{A - (1 - \alpha)\pi c_1^*}{\alpha} & \text{if } \alpha > \bar{\alpha}. \end{cases} \quad (9)$$

An economy-wide run is necessarily systemic because it induces cash-in-the-market pricing,  $p(1) = A < R/\mu$ . Thus, in a (potentially off-equilibrium) scenario where all intermediaries but one experience a run, the particular intermediary who is not subject to a run would still face deteriorated funding conditions.

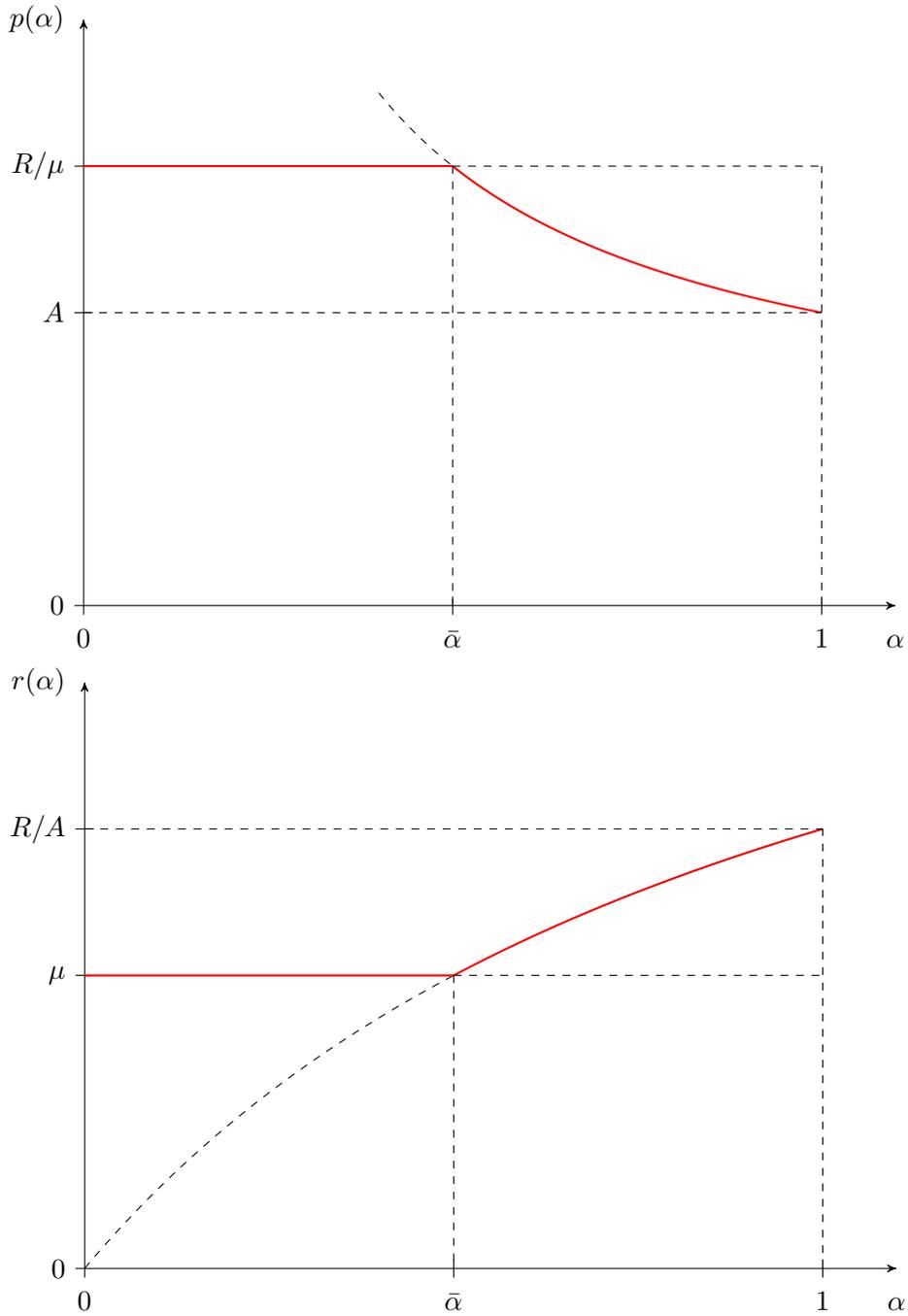
Recall that we have argued that  $r(\alpha) = R/p(\alpha)$ . This implies that a fire sale with cash-in-the-market pricing is isomorphic to a spike in interest rates (or a deterioration of funding conditions) in the market for secured wholesale funding, as depicted in Figure 1. If those intermediaries that are subject to a run sell their assets, and the others raise funds via secured wholesale funding, it must hold that cash-in-the-market pricing induced by the behavior of the former leads to deteriorated funding conditions for the latter.

Our notion of systemic runs is different from the notion of systemic effects via interbank linkages (e.g., as in Allen and Gale, 2000; Farboodi, 2015) or via the potential liquidation rate in case of a run (e.g., as in Diamond and Rajan, 2005; Uhlig, 2010; Martin et al., 2014b). In our setup, runs on some intermediaries *necessarily* affect other intermediaries via a pecuniary channel.<sup>23</sup> Moreover, the systemic component results from the fact that intermediaries have to rely on a spot market for the liquidity of investors. There is no exogenously imposed mark-to-market or leverage constraint in  $t = 1$ , but wholesale funding acts like an endogenous mark-to-market constraint.<sup>24</sup>

The underlying friction is the inability to settle on funding conditions initially. If intermediaries were able to contract with investors initially, runs on single intermediaries would still be possible. However, they would not be systemic as they would not have any external effects on other intermediaries. In the presence of this friction, runs on some intermediaries may induce a scarcity of liquidity at the interim date and depress asset

<sup>23</sup>The key difference is that, in our model, runs on some intermediaries necessarily affect other intermediaries, while in (Martin et al., 2014b), runs on some intermediaries only affect the potential fire-sale price.

<sup>24</sup>Typically, mark-to-market constraint are assumed to be exogenous and the emphasis is put on amplification mechanisms (Shleifer and Vishny, 1997; Brunnermeier, 2009; Greenwood et al., 2015), or they are operating via skin-in-the-game mechanism (Adrian and Shin, 2014).



**Figure 1:** This graph depicts the the asset price as well as the interest rate in the market of secured wholesale funding as a function of  $\alpha$ , the mass of intermediaries that are subject to a run. For  $\alpha > \bar{\alpha}$ , a run leads fire-sale pricing via the binding cash-in-the-market constraint. As both types of funding are isomorphic, this is equivalent to a spike in interest rates in the market for secured wholesale funding.

prices. In this case, even though investors are competitive, they earn a rent, as liquidity is scarce relative to demand. Thus, they can purchase assets at discounts or, equivalently, charge higher interest rates and demand more collateral. Given that intermediaries that are not subject to a run nonetheless need to raise liquid funds in order to serve those consumers that withdraw out of a consumption motive, they are necessarily affected by deteriorating market conditions. The need for short-term financing thus acts like an endogenous mark-to-market constraint, creating an externality of runs via a deterioration of funding conditions. This finding is key to understanding the sectoral effects in the extended model featuring regulated banks and shadow banks in the next section.

## 5. Banks and Shadow Banks

In this section, we first show that a deposit insurance scheme<sup>25</sup> accompanied by a capital requirement may enable the elimination of the adverse run equilibria. However, we also show that if regulatory arbitrage is possible a shadow banking sector may emerge to circumvent regulatory requirements. Moreover, runs in the shadow banking sector can be contagious, triggering insolvency of the regulated banking sector via the pecuniary channel.

### 5.1. Deposit insurance

Assume that a deposit insurance scheme is in place that insures all intermediaries' demand deposits.

**Assumption 3.** *Given that a consumer owns a demand-deposit contract  $(c_1, c_2)$ , a deposit-insurance scheme guarantees that she receives her promised consumption level in any contingency. The deposit insurance is financed by a uniform lump-sum tax  $T$  on all consumers.*

In a setup without aggregate uncertainty and with multiple equilibria, introducing a deposit insurance as above may eliminate the adverse run equilibrium at no cost.<sup>26</sup>

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<sup>25</sup>Or, more generally, a safety net that guarantees claims of short-term debtors. To this end, a bail-out has the same effect.

<sup>26</sup>By guaranteeing patient consumers that they will receive their promised payment in the final date, the strategic complementarity is eliminated. Thus, the deposit insurance is never tested in equilibrium and is costless, and  $T = 0$  in any state. An alternative measure often discussed in the literature is to allow intermediaries to suspend convertibility. One can easily see that the discussion below would be equivalent under suspension of convertibility: Suspending of convertibility may successfully prevent panic-based runs, but also undermines the disciplining effect of demand-deposit contracts. If banks

In our setup, however, a deposit insurance can give rise to opportunistic behavior on the part of intermediaries. Once deposits are insured, consumers do not care about the investment behavior of the intermediary, thus eliminating the disciplining effect of short-term debt.

Given the moral hazard problem arising from the deposit insurance, diligence can nonetheless be ensured by imposing a capital requirement on intermediaries. To induce diligence, the incentive compatibility constraint of the intermediary has to be satisfied: an intermediary needs to be promised some amount  $e_2$  which is larger than the private benefit she would get from shirking, i.e.,  $e_2 \geq (1 + e_0)B$ . Moreover, the intermediary's participation constraint,  $e_2 \geq \rho e_0$ , needs to be fulfilled. Because  $\rho > R$ , it holds that in an optimal regulatory regime, as little intermediary capital as possible is used. Thus, both constraints are binding, yielding the equity requirement  $e_0^{**} = \frac{B}{\rho - B}$  and  $e_2^{**} = \rho e_0^{**}$ .

**Lemma 3.** *Under a deposit insurance and a capital requirement, intermediaries implement the following consumption allocation via offering demand-deposit contracts with*

$$c_1^{**} = \gamma^{-\frac{1}{\eta}} \frac{R - \frac{B}{\rho - B}(\rho - R)}{(1 - \pi) + \pi\gamma^{1 - \frac{1}{\eta}}} < c_1^* \quad \text{and} \quad c_2^{**} = \frac{R - \frac{B}{\rho - B}(\rho - R)}{(1 - \pi) + \pi\gamma^{1 - \frac{1}{\eta}}} < c_2^*.$$

*There exists no run equilibrium in the  $t = 1$  subgame, and the deposit insurance scheme is costless in equilibrium.*

See Section D of the appendix for a derivation of the allocation. The risk-sharing is similar to that in Lemma 1, but the costly capital requirement implies that the consumption levels are decreasing in the private benefit  $B$ , as well as in the required return of intermediaries  $\rho$ .<sup>27</sup> However, given the deposit insurance, there are no run equilibria in the interim date. The benefit of financial stability thus comes with the drawback of allocative inefficiency.

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are able to suspend convertibility, they can protect their shirking investment against depositors that try to induce discipline, and regulation is necessary to ensure diligent behavior of intermediaries.

Moreover, note that Wallace (1988) points out that under a sequential service-constraint the run equilibrium cannot be easily eliminated by a deposit insurance that is financed via taxation on withdrawn funds when funds can be consumed before taxation can take place. As we abstract from a sequential service constraint, we can ignore this type of problem.

<sup>27</sup> Observe that the first best (Lemma 1) and the allocation with a capital requirement would coincide if either  $B = 0$  or  $\rho = R$ . E.g., if  $B > 0$ , but  $\rho = R$ , using intermediary funds is not costly, and the first best can always be implemented by using sufficiently many intermediary funds and investing them in the production technology until incentives are provided. Whenever  $B > 0$  and  $\rho > R$ , the promised consumption levels under a capital requirement are strictly lower than in the first-best allocation.

## 5.2. Regulatory Arbitrage

We now consider the possibility of regulatory arbitrage. We maintain the assumption that the regulator provides a deposit insurance and imposes a capital requirement on those intermediaries that are covered by the deposit insurance, hereafter referred to as “regulated banks”. However, we assume that it is also possible for intermediaries to place themselves outside of the regulatory perimeter of banking. Intermediaries that engage in this kind of regulatory arbitrage are referred to as “shadow banks” in the following. They are neither regulated nor covered by the deposit insurance. However, shadow banks are disciplined in their investment behavior by short-term debt contracts.<sup>28</sup>

Throughout this section, we take the size of the respective sectors as given and analyze how systemic risk that emerges in the shadow banking sector can spread to the regulated banking sector. The equilibrium composition of the financial system is derived in the next section.

### Coexistence

Assume that in  $t = 0$ , intermediaries can decide whether they want to become a regulated bank or a shadow bank.<sup>29</sup> A regulated bank can offer a demand-deposit contract with  $(c_1^b, c_2^b) = (c_1^{**}, c_2^{**})$ , where the superscript  $b$  stands for *bank*. The expected utility of a bank customer is thus decreasing in the “regulatory cost”  $B$  and  $\rho$ . A shadow bank can offer a demand-deposit contract with  $(c_1^{sb}, c_2^{sb}) = (c_1^*, c_2^*)$ , where the superscript  $sb$  stands for *shadow bank*. While a shadow bank can promise higher consumption levels, the drawback of a being a customer at a shadow bank is that the shadow banking sector is not covered by the safety net and thus panic-based runs may take place.

Both types of intermediation rely on receiving funds from investors at the interim date to pay out those consumers that withdraw out of a consumption motive. We continue using the narrative that both types of intermediation rely on secured wholesale funding in normal times. Only in crisis times do runs on the shadow banking sector induce fire sales.

Denote by  $\sigma$  the fraction of consumers that deposit at shadow banks, and by  $1 - \sigma$

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<sup>28</sup>While by legal standards shadow banks have historically not offered demand deposits in reality, they do issue claims that are essentially equivalent to demand deposits, such as equity shares with a stable net assets value (stable NAV), or other instruments such as asset-backed commercial papers, repurchase agreements, or shares in other types of funds managed by asset management firms (see Cetorelli, 2014; International Monetary Fund, 2015). For tractability, we assume that shadow banks are literally taking demand deposits.

<sup>29</sup>This decision is assumed to be binary. We relax this assumption later in Section E such that an intermediary can operate a regulated bank and a shadow bank at the same time.

the fraction that deposit at regulated banks. Thus,  $\sigma$  and  $1 - \sigma$  denote the size of the respective sectors.

### Fire Sales and the Deterioration of Funding Conditions

Taking the size of the shadow banking  $\sigma \in [0, 1]$  sector as given, it holds that systemic runs in the spirit of Proposition 1 are possible whenever the shadow banking sector becomes too large.

**Proposition 2.** *A run on all shadow banks is systemic and affects the regulated banks' funding conditions if  $\sigma > \bar{\sigma}$ , i.e., if the shadow banking sector is larger than  $\bar{\sigma}$ , given by*

$$\bar{\sigma} = \frac{A - \pi c_1^b}{R/\mu - \pi c_1^b}.$$

As  $A < R/\mu$  by assumption, it holds that  $\bar{\sigma} < 1$ . The threshold  $\bar{\sigma}$  is increasing in the aggregate available liquidity  $A$ , i.e., the deeper the secondary market, the larger the shadow banking sector can become before a run becomes systemic. Moreover, the threshold is decreasing in the demand for liquid assets by regulated banks  $\pi c_1^b$ . That is, whenever regulated banks require a large amount of funding on the market for secured wholesale funding to serve their impatient consumers, a relatively smaller shadow banking sector induces systemic runs.

The proposition holds via a similar reasoning to the one used to derive Proposition 1. In case of a run on the shadow banking sector, all shadow banks must try to serve all withdrawing depositors. In order to fulfill their obligations, they sell all their assets, i.e., each shadow bank sells  $L^{sb} = 1$  assets, and the shadow banking sector as a whole liquidates a total amount of  $\sigma$  units. As long as there is no cash-in-the-market pricing, shadow banks thus absorb  $\sigma R/\mu$  units of the available liquidity.

In addition, regulated banks also need an amount  $(1 - \sigma)\pi c_1^b$  of liquidity to serve their withdrawing impatient consumers. A run on shadow banks is thus not compatible with a price  $p = R/\mu$  (i.e., it leads to cash-in-the-market pricing) if

$$R/\mu[\sigma + (1 - \sigma)\pi c_1^b/(R/\mu)] > A \Leftrightarrow \sigma > \frac{A - \pi c_1^b}{R/\mu - \pi c_1^b} \equiv \bar{\sigma}.$$

Thus, there exists some threshold  $\bar{\sigma}$  above which a run on shadow banks induces cash-in-the-market pricing. As we have assumed that  $A < R/\mu$ , it holds that  $\bar{\sigma} < 1$ , i.e., for a sufficiently large shadow banking sector, there is cash-in-the-market pricing.

We denote the fire-sale price as a function of the size of the shadow banking sector  $\sigma$  (as opposed to being a function of  $\alpha$  in Section 4.2) which is given by

$$p(\sigma) = \begin{cases} R/\mu & \text{if } \sigma \leq \bar{\sigma} \\ \frac{A-(1-\sigma)\pi c_1^b}{\sigma} & \text{if } \sigma > \bar{\sigma}. \end{cases} \quad (10)$$

Contingent on a run on all shadow banks in  $t = 1$ , the price falls short of its fundamental value whenever the shadow banking sector is larger than  $\bar{\sigma}$ .

### Cost of deposit insurance and taxation

Under the premise that the deposit insurance scheme is credible,<sup>30</sup> no bank customer withdraws out of a panic motive. Yet, the deposit insurance scheme may be required to pay out funds. That is, although regulated banks cannot be subject to classic bank runs themselves, as they are covered by the deposit insurance, they are affected via a deterioration of the funding conditions whenever the cash-in-the-market constraint becomes binding.

At the interim date, regulated banks need to serve their impatient customers. Because the terms of wholesale funding deteriorate, regulated banks have to promise higher interest rates and they must post more assets in order to collateralize their obligations. Depending on how low the fire-sale price turns out to be, regulated banks may become insolvent in  $t = 2$  or even illiquid in  $t = 1$ . This in turn requires raising taxes in order to finance the deposit insurance.

In case of a systemic run in the shadow banking sector, each regulated bank has to promise an interest  $r = R/p(\sigma) > \mu$  for  $p < R/\mu$  and pledge an amount of collateral  $L^b$  per unit borrowed, where

$$L^b(p) = \min \left[ \frac{\pi c_1^b}{p(\sigma)}, 1 + e_0^b \right].$$

Note that a regulated bank cannot pledge more assets than the  $1 + e_0$  assets that it owns. The amount that needs to be pledged is decreasing in  $p$  and thus increasing in  $\sigma$ .

Promising a higher interest and the necessity to pledge more collateral in turn decreases the funds that are available for equity holders as well as late consumers of regulated banks. Thus, the regulated banks may need to default on their obligations and may become insolvent in  $t = 2$ , or even illiquid already in  $t = 1$ .

Ultimately, contagious runs may make it necessary for the deposit insurance scheme to live up to its promise and taxation may become necessary. The cost for the deposit

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<sup>30</sup>We verify later that this holds true.

insurance scheme, or alternatively the shortfall of funds in the regulated banking sector in case of a run on the shadow banking sector can be calculated as a function of  $\sigma$ . We denote these costs by  $DI(\sigma)$ . It is given by

$$DI(\sigma) = (1 - \sigma) \cdot \begin{cases} 0 & \sigma \leq \tilde{\sigma} \quad (\text{no default}), \\ (1 - \pi)c_2^b - \left(1 + e_0^b - \frac{\pi c_1^b}{p(\sigma)}\right) R & \sigma \in [\tilde{\sigma}, \hat{\sigma}] \quad (\text{insolvency in } t = 2), \\ (1 - \pi)c_2^b + \pi c_1^b - (1 + e_0^b)p(\sigma) & \sigma \geq \hat{\sigma} \quad (\text{illiquidity in } t = 1), \end{cases}$$

where  $\tilde{\sigma}$  denotes the threshold size of shadow banking above which banks become insolvent in  $t = 2$ , and  $\hat{\sigma}$  denotes the threshold at which they become illiquid in  $t = 1$ .

Observe that  $DI(\sigma)$  is continuous and hump-shaped. As  $\sigma$  becomes larger, the fire-sale price decreases and the shortfall of a regulated bank increases. Therefore, the deposit insurance becomes more costly per agent depositing in the banking sector, i.e., along the intensive margin. However, as the banking sector shrinks with  $\sigma$ , the cost of deposit insurance decreases again, i.e., along the extensive margin. Ultimately, at  $\sigma = 1$ , the fire-sale price is lowest, but there is no banking sector and thus the deposit insurance cost is zero, i.e.,  $DI(1) = 0$ .

## Discussion

The contagion from shadow banks to regulated banks arises from the fact that both types of banking share a common pool of liquidity. If a run on shadow banks induces scarcity of liquid funds, the change in the price of liquidity also affects regulated banks because they need to raise funds at the interim date to serve their withdrawing consumers. As described above, this exposes regulated banks to market conditions that may deteriorate in case of a run on shadow banks.

In our model, regulated banks and shadow banks hold the same type of illiquid assets. However, our contagion result does not depend on this assumption; it would also hold if the two sectors were holding different types of assets. E.g., Hanson et al. (2015) argue that regulated banks naturally have a comparative advantage in holding more illiquid assets. Our setup could easily incorporate such a feature by assuming that investors have higher discount rates for assets from regulated banks than shadow bank assets, i.e.,  $\mu^b > \mu^{sb}$ . As long as both types of banking rely on the same investors to provide liquidity, the contagion effect carries through.

As we have argued earlier, many post-crisis policies have been implemented under the presumption that a prohibition of explicit or implicit contractual linkages between regulated banking and other types of banking can shield the former from turmoil originating in the latter. In particular, regulation has focused on prohibiting sponsor support in the

form of ex-ante guarantees and ex-post support. In Proposition 8 of the appendix, we show that such linkages can arise endogenously because they are privately optimal for intermediaries. We also show that this aggravates the problem of contagion, and that the prohibition of such links is indeed helpful in reducing contagion. However, our model indicates that prohibiting contractual linkages is not sufficient to shield the regulated banking sector from financial fragility. Whenever regulated banks rely on market funding to manage their liquidity needs, runs on the shadow banking sector are contagious via market prices.

Hence, the result challenges the classic finding in the banking literature that in the absence of aggregate risk, a deposit-insurance scheme may eliminate panic-based runs without any cost. Importantly, even though the deposit insurance is credible and thus there is no risk of a classic bank run, regulated banks may nonetheless turn illiquid and insolvent.

## 6. Equilibrium and Welfare

Until this point, we have not specified the probability at which a run occurs in equilibrium. The focus has been on the date-1 subgame of the economy and the characterization of equilibria in this subgame. We now explicitly introduce sunspots as a coordination device at date 1.<sup>31</sup> This allows us to address the problem that consumers face as of date 0 and to derive the equilibrium of the whole game. We can specify the equilibrium composition of the financial system and analyze the welfare effects of regulatory arbitrage.

### 6.1. Sunspot-induced runs

We assume that the event of a systemic run on all shadow banks is triggered by the realization of a sunspot, and the probability  $q$  of sunspots is known at date 0. We further assume that the probability of sunspots positively depends on the fire-sale price of assets.

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<sup>31</sup>Notice that in the absence of such a coordination device, runs would never be observed in a subgame-perfect equilibrium: Either all agents have the belief that a run takes place in the shadow banking sector and thus deposit with regulated banks, or all agents anticipate that no run takes place and exclusively deposit in the shadow banking sector. Thus, by tying our hand to the concept of subgame-perfect equilibrium without exogenous coordination devices, we lose interesting trade-offs. However, if we assume that there is a coordination device, and if the probability of sunspots is known to the consumers when they make their deposit decision, a run can take place with a positive probability in a subgame-perfect equilibrium.

**Assumption 4.** *With probability  $q(p)$ , all shadow bank customers coordinate on withdrawing from all shadow banks in  $t = 1$ , and with probability  $1 - q(p)$  only impatient customers withdraw, where  $q'(p) \leq 0$ .*

A similar assumption is also made by Cooper and Ross (1998) and Gertler and Kiyotaki (2015) in the context of banking models. Generally, it would be desirable to pin down the probability of a run by relaxing the assumption of common knowledge and using global games techniques as pioneered by Morris and Shin (1998, 2003) and applied to bank runs in particular by Rochet and Vives (2004) and Goldstein and Pauzner (2005). Under this approach, the probability of runs is tied to fundamentals. However, introducing fundamental uncertainty would complicate the analysis and would shift the focus away from liquidity crises. As a shortcut, we instead assume that  $q$  is determined as an exogenously given function of the fire-sale price  $p$ . This is a plausible and natural property that would also result out of a standard unique-equilibrium bank-run model: The higher the liquidation value (fire-sale price) of the illiquid asset is, the lower is the critical threshold at which a run succeeds. Thus, a higher fire-sale price would imply that runs are less likely.

We further assume that the contracts offered by banks and shadow banks are not altered by the fact that agents anticipate runs. It is important to notice that the contracts derived so far may not actually be the optimal contracts once we assign a positive probability to the event of a run in the shadow banking sector. By making this assumption, the analysis is conducted as if consumers anticipated runs, but intermediaries did not. The assumption keeps the analysis tractable and does not change the basic results.<sup>32</sup>

## 6.2. Equilibrium level of regulatory arbitrage

The equilibrium composition  $\sigma^*$  of the financial system is determined by the consumers' binary decision either to deposit funds at a shadow bank or at a regulated bank. Therefore, we need to formalize the trade-off that each consumer faces: If a consumer chooses to deposit at a regulated bank, the promised interest is relatively low due to the regulatory cost, but no runs are possible. Alternatively, if a consumer chooses to deposit at a shadow bank, the promised interest is higher; however, there is a prospect of panic-based

<sup>32</sup>In fact, we show in Section F of the appendix that, in equilibrium, contracts do depend on the probability  $q$ . The terms of the demand-deposit contract in both sectors are a function of the probability of sunspots, i.e., promised consumption levels of both regulated banks and shadow banks are weakly decreasing in  $q$ . In the case of regulated banks, the consumption levels decrease as the required return of the equity holder increases. In the case of shadow banks, the consumption levels weakly decrease because if the run probability  $q$  is sufficiently high, partial investment in storage becomes optimal.

runs. Given  $\sigma$ , the expected utility of becoming a customer of a regulated bank is given by

$$EU^b(\sigma) = (1 - q(p(\sigma)))U(c_1^b, c_2^b) + q(p(\sigma))U(c_1^b - DI(\sigma), c_2^b - DI(\sigma)).$$

At a regulated bank, a consumer gets the expected utility associated with the demand deposit  $(c_1^b, c_2^b)$  with probability  $1 - q(p(\sigma))$ . With probability  $q(p(\sigma))$  there is a run on all shadow banks. In this case, the consumer still receives the payoff promised by his demand-deposit contract; however, she has to pay the lump-sum tax  $DI(\sigma)$ .

The expected utility of becoming a customer of a shadow bank is given by

$$EU^{sb}(\sigma) = (1 - q(p(\sigma)))U(c_1^{sb}, c_2^{sb}) + q(p(\sigma))u(p(\sigma) - DI(\sigma)).$$

At a shadow bank, a consumer gets the expected utility associated with the more attractive contract  $(c_1^{sb}, c_2^{sb})$  with probability  $1 - q$ . However, with probability  $q$  a run takes place. In this case, all shadow bank customers need to share the proceeds of the fire sale,  $p(\sigma)$ . Moreover, the lump-sum tax to finance the deposit insurance scheme accrues.

We assume that at date 0, consumers can choose between depositing in either of the two sectors. In equilibrium it must hold that either both sectors have a positive size and consumers are indifferent between the two sectors, or one of the sectors has zero mass. Both sectors coexist in equilibrium if and only if there exists  $\sigma^* \in (0, 1)$  such that

$$EU^b(\sigma^*) = EU^{sb}(\sigma^*),$$

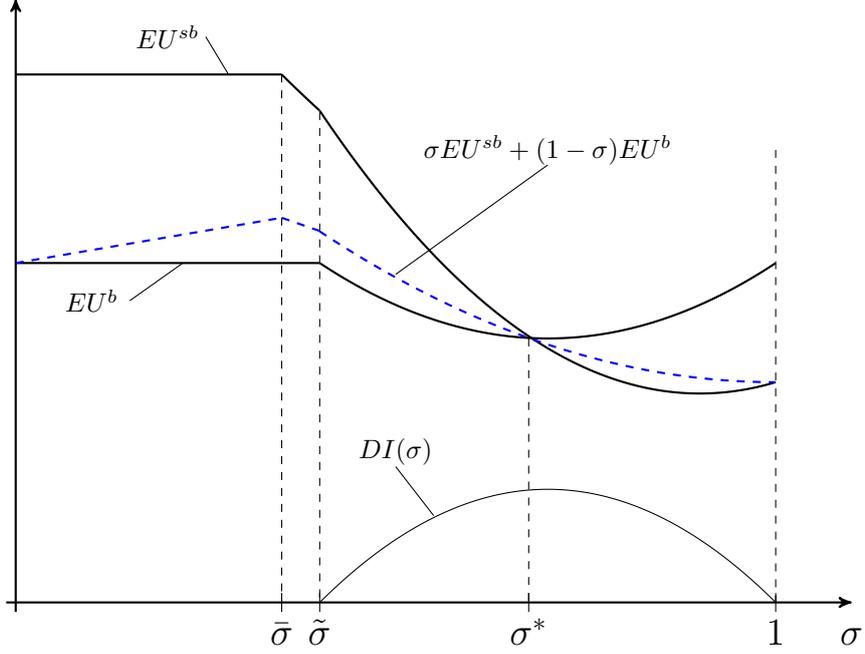
and the size of the shadow banking sector is determined by this indifference condition. Using this condition, we can characterize the equilibrium level of shadow banking:

**Proposition 3.** *There exists  $\hat{q}$  and  $\bar{q}$  such that for  $q(p(0)) < \bar{q}$  and  $q(p(1)) > \hat{q}$ , it holds that*

$$\sigma^* \in (\bar{\sigma}, 1).$$

*If  $q(p(1)) \leq \hat{q}$ , it holds that  $\sigma^* = 1$ , i.e., only shadow banks prevails; and if  $q(p(0)) \geq \bar{q}$ , it holds that  $\sigma^* = 0$ , i.e., only regulated banking prevails.*

The proof as well as the definitions of  $\bar{q}$  and  $\hat{q}$  can be found in the appendix. It holds that  $1 > \hat{q} > \bar{q} > 0$ . The first part of the proposition states that if the two sectors coexist in equilibrium, it must be true that the equilibrium size  $\sigma^*$  is larger than the threshold  $\bar{\sigma}$  at which runs become systemic, i.e., induce cash-in-the-market pricing. Consumers can only be indifferent between the sectors if there is cash-in-the-market pricing in case of a run, implying that an equilibrium necessarily also features contagion to the banking



**Figure 2:** Expected utilities, welfare, and deposit-insurance cost

sector.<sup>33</sup> This contagion can have two qualitatively different effects: If  $\sigma^* \in (\bar{\sigma}, \tilde{\sigma}]$ , the run only reduces the value of the claims of the equity holders (the intermediaries), but if  $\sigma^* \in (\tilde{\sigma}, 1]$ , it triggers the insolvency of regulated banks and the deposit insurance scheme becomes costly, as illustrated in Figure 2.

The second part of the proposition states that whenever runs are very likely, no consumer wants to deposit at a shadow bank even if the shadow banking sector is arbitrarily small, implying  $\sigma^* = 0$ . Likewise, if runs are very unlikely, a consumer prefers the shadow banking contract even if all other consumers have invested in the shadow banking sector, so there exist only shadow banks in equilibrium.

### 6.3. Socially optimal level of regulatory arbitrage

In order to analyze the welfare of the equilibrium allocation, we consider the constrained efficient allocation that a social planner would choose. For this analysis, we assume that the social planner can control the extent of regulatory arbitrage by choosing the

<sup>33</sup>Moreover, if  $\sigma^* \in (\bar{\sigma}, 1)$ , i.e., if both sectors coexist in equilibrium, comparative static with respect to the regulatory cost is such that  $\sigma_\rho^* > 0$  and  $\sigma_B^* > 0$ . Hence, the equilibrium size of the shadow banking sector is increasing in the “cost of regulation” which is determined by the required return of intermediaries and their shirking incentive.

composition of the financial system. His only decision variable is the sector size  $\sigma$ , and we analyze whether the social planner would choose a composition that deviates from the equilibrium composition  $\sigma^*$ .

The economic trade-off the social planner faces can be illustrated by the following two extremes: On the one hand, the social planner could choose a banking system in which all deposits are insured, but regulatory costs imply low interest rates for consumers,  $\sigma = 0$ . On the other hand, he could choose a banking system in which there is no deposit insurance and no regulatory cost,  $\sigma = 1$ .<sup>34</sup> The social planner chooses an allocation  $\sigma^{sp}$  that trades off the benefit of a deposit insurance and the associated costs of regulation against the costs of panic-based runs which are a necessity in the presence of disciplining short-term debt.

We assume that the social planner chooses the composition of the financial system and thus the degree of regulatory arbitrage in order to maximize the weighted sum of expected utilities. Formally, his preferred sector size  $\sigma^{sp}$  is the solution to the following problem:

$$\max_{\sigma} (1 - \sigma)EU^b(\sigma) + \sigma EU^{sb}(\sigma).$$

By comparing the socially optimal and the equilibrium level of shadow banking, we get an unambiguous ranking:

**Proposition 4.** *If  $\sigma^* \in (\bar{\sigma}, 1)$ , it holds that  $\sigma^{sp} < \sigma^*$ .*

The proof can be found in the appendix. The proposition states that if the equilibrium is given by an interior solution, the social planner prefers a shadow banking sector that is strictly smaller than in a laissez-faire equilibrium. This results from the fact that the social planner – unlike the agents that are atomistic – internalizes the adverse effects of increasing  $\sigma$  on the level of expected utility in each sector. As discussed in more detail in the appendix, the adverse effect of  $\sigma$  via the fire-sale price  $p$  can be decomposed into three components. All three components are internalized by the social planner, but not by atomistic agents. First, there is the effect of the fire-sale price on the probability of a run. Second, there is the direct effect of the fire-sale price, i.e., the proceeds of liquidation in case of a run in the shadow banking sector. Finally, there is the effect on the cost of the deposit insurance and thus the level of taxation. In addition, there is the direct effect of  $\sigma$  in determining how many consumers get to enjoy the utility in the respective sector. While this direct effect is the only locally positive effect of  $\sigma$ , it does

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<sup>34</sup>E.g., this allocation can be compared to the banking system in the US in the 19th century under the the National Banking Act.

not offset the negative effects because, in the constrained efficient allocation, consumers in both sectors are better off compared to the equilibrium.<sup>35</sup>

The pecuniary externality has a welfare impact, reminiscent of findings in the literature on pecuniary externalities in a setup with incomplete markets (compare, e.g., Lorenzoni (2008)).<sup>36</sup> Because regulated banks cannot initially contract the funding conditions for date 1, a low fire-sale price impacts the overall allocation via deteriorated funding conditions ex-post. A social planner would internalize this effect, and by limiting the fire-sale effect, he would also reduce contagion.

Remarkably, however, the social planner would not completely eliminate shadow banking. He would choose a positive size of the shadow banking sector,  $\sigma^{sp} > 0$ , and thus accept that panic-based runs will occur with a positive probability. E.g., in the example of Figure 2, he would like to choose the shadow banking sector to be of size  $\bar{\sigma}$ . The social planner finds it optimal to utilize the disciplining role of short-term debt. Thus, it is socially desirable that the shadow banks has a positive size, and the social planner is willing to accept a positive probability of runs in the shadow banking sector.<sup>37</sup> However, regulatory arbitrage and shadow banking is excessive in equilibrium, and the social planner would like to contain the adverse consequences of shadow banking that are not internalized by agents.

## 7. Policy Implications

In this section, we analyze the effect of government interventions on the equilibrium composition of the economy. First, we analyze the effect of wholesale funding restrictions, similar to liquidity regulation in Basel III. Second, we analyze the effect of interventions by a central bank. Throughout the section, we assume that the extent of regulatory arbitrage  $\sigma$  is an equilibrium object and cannot be controlled by a social planner.

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<sup>35</sup>The direct effect of  $\sigma$  is locally locally positive if  $EU^{sb}(\sigma) > EU^b(\sigma)$ .

<sup>36</sup>Notice, however, that our setup is partial equilibrium and thus general findings in this literature cannot be applied one-to-one. Nonetheless, the underlying mechanism is similar: agents take the equilibrium fire-sale price as given.

<sup>37</sup>This is complementary to other arguments why shadow banking may be desirable, such as comparative advantages in securitizing assets (compare, e.g., Gennaioli et al., 2013; Hanson et al., 2015), or by relaxing imperfect prudential constraints and utilize self-regulating reputational concerns (see Ordoñez, 2013).

## 7.1. Restrictions on wholesale funding

Given that the contagion of turmoil in the shadow banking sector is due to a deterioration of funding conditions, limiting the exposure of regulated banks to market conditions may appear desirable. Can wholesale funding restrictions for regulated banks actually improve financial stability? For instance, the liquidity regulation in the Third Basel Accord (Basel III) proposes such restrictions.<sup>38</sup> In the following, we analyze a very simple and extreme case: the complete prohibition of wholesale funding for regulated banks.

**Assumption 5.** *Regulated banks are required to manage their entire liquidity needs via storage, i.e., regulated banks face a constraint of  $L = 0$ .*

Under this constraint, regulated banks can now only offer a contract that is less attractive than before.

**Lemma 4.** *Assume that regulated banks face capital requirement and wholesale funding restrictions, and are covered by a deposit insurance scheme. By offering demand-deposit contracts, they can implement a consumption allocation of*

$$c_1^r = R^{-\frac{1}{\eta}} \frac{R - \frac{B}{\rho - B}(\rho - R)}{\pi R^{1 - \frac{1}{\eta}} + (1 - \pi)} < c_1^b, \quad \text{and} \quad c_2^r = \frac{R - \frac{B}{\rho - B}(\rho - R)}{\pi R^{1 - \frac{1}{\eta}} + (1 - \pi)} < c_2^b.$$

*The regulated banking sector cannot experience runs, and it is shielded from adverse consequences of runs in the shadow banking sector, so the deposit insurance scheme is costless in equilibrium, i.e.  $DI(\sigma) = 0$ .*

Wholesale funding restrictions induce a further allocative inefficiency, as relying on the liquidity provision by investors allows the generating of higher returns for consumers.<sup>39</sup>

<sup>38</sup>Basel III introduces a new assessment and regulation of liquidity risk by defining two minimum standards of funding liquidity, first described in Basel Committee (2010). The two central measures are the Liquidity Coverage Ratio (LCR) and the Net Stable Funding Ratio (NSFR). The LCR requirement aims to ensure that a bank can withstand a “significantly severe liquidity stress scenario” with a horizon of 30 days and is described in detail in Basel Committee (2013). It aims to ensure that a bank has a sufficient stock of liquid assets in order to cover its liquidity needs during the next month. The objective of the NSFR requirement, elaborated in Basel Committee (2014), is to ensure stable funding over a one-year horizon. It requires a bank to have an amount of equity, long-term debt, and other “stable” funding that is sufficient to finance its stock of illiquid assets during the next year. Taken together, the proposed restrictions act like a restriction on short-term wholesale funding.

<sup>39</sup>The allocation follows from the observation that the consumption allocation under wholesale funding restrictions coincides with the allocation of Lemma 3 for the case of  $\mu = R$ , i.e., for the case that the required return of investors is so high that relying on liquidity provision by investors is equal to investing in storage. Note that the  $(c_1^r, c_2^r)$  coincides with the first-best allocation of the Diamond and Dybvig model if we assume that  $B = 0$  or  $\rho = R$ , i.e., if there is no cost of equity.

Thus, it holds that

$$U(c_1^b, c_2^b) > U(c_1^r, c_2^r).$$

However, combined with a deposit insurance scheme, wholesale funding restrictions actually eliminate the fragility in the banking sector altogether.

We maintain the assumption that shadow banks offer the demand-deposit contract  $(c_1^{sb}, c_2^{sb})$ ; thus, the equilibrium composition  $\sigma^r$  in case of wholesale funding restrictions is determined by the indifference condition

$$U(c_1^r, c_2^r) = EU^{sb}(\sigma^r).$$

As depicted in Figure 3, the equilibrium composition of the financial system changes unambiguously.

**Proposition 5.** *Introducing wholesale funding restrictions for regulated banks increases the size of the shadow banking sector,  $\sigma^r > \sigma^*$ .*

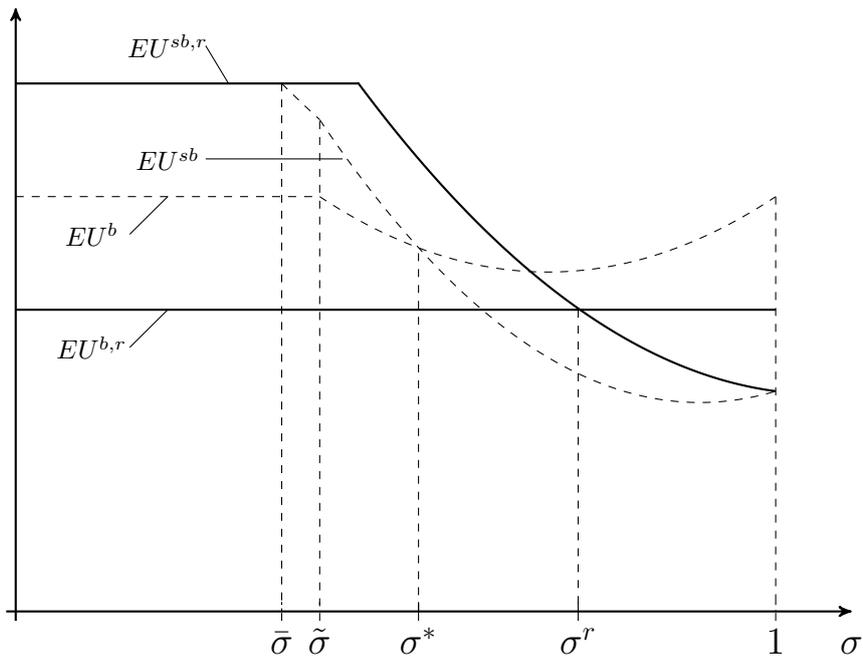
The banking sector becomes less attractive for two reasons: On the one hand, regulated banks need to hold storage which has a lower return than investing in the productive asset and managing liquidity needs by relying on wholesale funding. On the other hand, as banks are not relying on wholesale funding, they will not contribute to the fire sale. Therefore, shadow banks benefit from the fact that fire sales are less severe and the fire-sale price is higher, so more consumers will deposit in the shadow banking sector in equilibrium.

From a social planner's perspective, this is only desirable if

$$\sigma^r EU^{sb,r}(\sigma^r) + (1 - \sigma^r)EU^{b,r}(\sigma^r) \geq EU^*,$$

where  $EU^* = EU^{sb}(\sigma^*) = EU^b(\sigma^*)$  is the level of expected utility that consumers obtain in equilibrium at both a shadow bank and at a regulated bank in the absence of such restrictions. Wholesale funding restrictions are desirable if the induced inefficiency in maturity transformation is less severe than the expected negative effects of the equilibrium fire-sale price for the regulated banking sector. In the example of Figure 3, overall welfare decreases. However, the welfare effect is ambiguous in our model and depends on how inefficient the use of storage is relative to wholesale funding and how severe the fire-sale pricing is in equilibrium.

Using our model to take a stand in how the trade-off solves in practice is difficult. However, the important message of our result is that it is not enough to judge a policy by its effect on the regulated banking sector alone. It is true that the restrictions shield the regulated banking sector, and they make their maturity transformation less



**Figure 3:** The solid lines represent the expected utility of holding deposits in the respective sector in the presence of wholesale funding restrictions; the dotted lines represent the expected utility of holding deposits in the respective sector in the absence of such restrictions. Introducing the restriction increases the equilibrium size of the shadow banking sector from  $\sigma^*$  to  $\sigma^r$ .

attractive. But if we are interested in the overall stability of banking, the effects on the shadow banking system must be considered as well. If one argues in favor of wholesale funding restrictions, it has to be carefully laid out why shielding the banking sector is desirable over having more risks outside the regulated banking sector.

## 7.2. Central bank interventions

So far, we have not considered that regulated banks might have access to the discount window of a central bank (lender of last resort, LoLR). Furthermore, a central bank may decide to intervene in the secondary market in order to prevent cash-in-the-market pricing (market maker of last resort, MMLR). In the following, we analyze how the anticipation of such interventions changes the equilibrium composition of the financial system. Moreover, given the cost of intervening, we argue under which conditions such interventions may be desirable.

We assume that there is an institution called central bank that has unlimited funds

at its disposal at date 1, and that can commit to being either a LoLR or a MMLR. In a richer setup that distinguishes between nominal and real values, one could also directly model the cost of central bank interventions (e.g., political costs, distortions resulting from inflationary interventions, moral hazard, etc.). As a shortcut, we assume that the central bank faces a non-pecuniary cost of intervening  $C(m)$ , where  $m$  are the funds that the central bank needs to use.<sup>40</sup>

### Lender of last resort (LoLR)

We first consider the case that regulated banks have access to the discount window to borrow funds at the rate that reflects the fundamental value of the regulated banks' assets.

**Assumption 6.** *The LoLR commits to providing liquidity at date 1 at interest rate  $r = \mu$ , and demanding collateral based on the fundamental value  $R/\mu$ .*

The LoLR policy implies that regulated banks do not have to borrow at deteriorated funding conditions once there is a run in the shadow banking sector. Because regulated banks face the same terms at the discount window as they do in the market for secured wholesale funding in normal times, a LoLR policy effectively shields regulated banks from turmoil in the shadow banking sector. Runs in the shadow banking sector can still occur, but there is no contagion and the deposit insurance scheme is not tested in equilibrium.

Surprisingly, shadow banks also benefit from such interventions, although they do not have access to the discount window. First, shadow bank customers do not face any taxation to fund the deposit insurance scheme. But second, and more importantly, because the liquidity need of regulated banks is now satisfied by the central bank, shadow banks have fewer competitors on the market for liquid funds. In the presence of a LoLR, the fire-sale price as a function of sector size is given by

$$p^{LOLR}(\sigma) = \begin{cases} R/\mu & \text{if } \sigma \leq A\mu/R \\ A/\sigma & \text{if } \sigma > A\mu/R. \end{cases} \quad (11)$$

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<sup>40</sup>Generally,  $C(m)$  might have different shapes. E.g., if there is a high political cost to central bank interventions, we could have a fixed cost for any positive intervention. If interventions create inflation, then  $C(m)$  should be increasing in  $m$ . Moreover, other types of costs may be associated with ex-post intervention, e.g., if the central bank cannot distinguish between insolvent and illiquid banks or if interventions give rise to moral hazard. Notice that for both types of intervention policies (LoLR and MMLR), the central bank is repaid  $\mu m$  units at date 2 if it provides an amount of liquidity  $m$  at date 1. The cost  $C(m)$  takes this into account and only measures the net cost of the intervention.

The fire-sale price is higher for any composition of the financial system, i.e.,  $p^{LOLR}(\sigma) > p(\sigma)$  for any  $\sigma$ . This implies, even though both sectors become more attractive for consumers, that the shadow banking sector becomes relatively more attractive for the same  $\sigma$ .

**Proposition 6.** *A LoLR policy increases the equilibrium size of the shadow banking sector,  $\sigma^{lolr} > \sigma^*$ .*

The result may appear surprising given that the LoLR policy is exclusively targeted at regulated banks. Nonetheless, customers of shadow banks benefit equally due to the weakened fire-sale effects.

Whether the LoLR policy is desirable depends on the shape of  $C(m)$ . Again, notice that  $EU^r = EU^{sb}(\sigma^{lolr}) = EU^b(\sigma^{lolr})$  is the level of expected utility that prevails in both sectors in an equilibrium with wholesale funding restrictions. If there is a systemic run on shadow banks, the central bank has to lend an amount of  $(1 - \sigma^{lolr})\pi c_1^b$  to the regulated banking sector. The equilibrium probability of a run is given by  $q^{LOLR} = q(p^{LOLR}(\sigma^{lolr}))$ . I.e., the expected cost of the central bank intervention is  $q^{LOLR}(1 - \sigma^{lolr})\pi c_1^b$ , and the intervention is desirable if

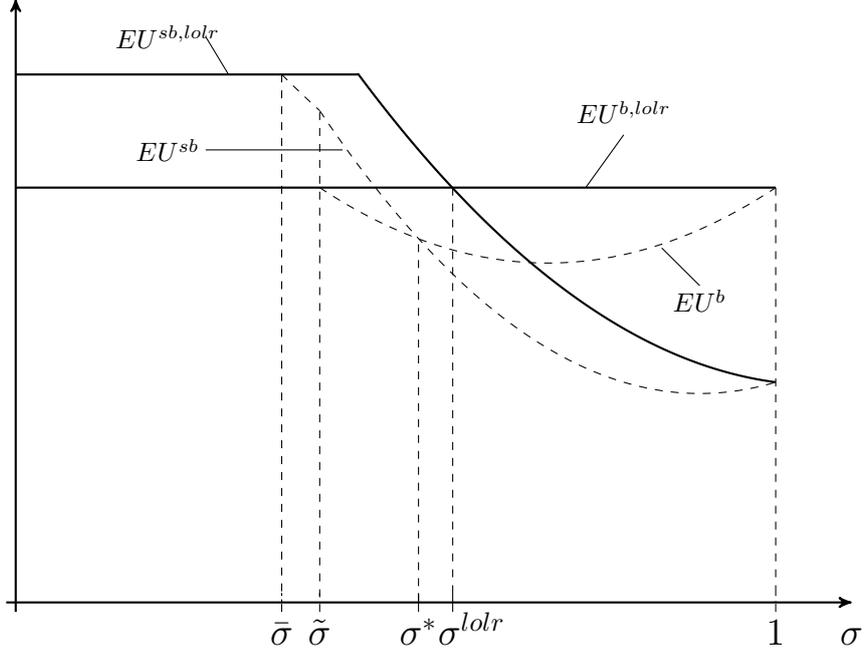
$$EU^r - q^{LOLR}C((1 - \sigma^{lolr})\pi c_1^b) \geq EU^*.$$

That is, a LoLR intervention improves welfare over the equilibrium allocation if the direct gains of higher utility in both sectors outweigh the cost of interventions.

It is important to notice that the anticipation of a LoLR policy can increase the equilibrium probability of a run. Although the fire-sale price under LOLR is higher for any given composition of the financial system, this effect may be offset by a larger equilibrium size of the shadow banking sector. Under our assumption that the probability of runs decreases in the fire-sale price  $p$ , the anticipation of the LoLR policy itself could aggravate systemic risk. This is reminiscent of moral hazard consideration, where the anticipation of government interventions leads to excessive risk-taking (Acharya and Yorulmazer, 2008) or excessive maturity mismatch (Farhi and Tirole, 2012). However, the increased systemic risk is not driven by a moral hazard concern in our model; it is driven by the changed composition of the financial system.

### **Market maker of last resort (MMLR)**

In contrast to the LoLR's discount window lending, the MMLR conducts an open market operation. A MMLR cannot selectively buy assets from regulated banks; it has to buy assets from all market participants and cannot discriminate.



**Figure 4:** The solid lines represent the expected utility of holding deposits in the respective sector in the presence of a LoLR; the dotted lines represent the expected utility of holding deposits in the respective sector in the absence of a LoLR. The LoLR increases the equilibrium size of the shadow banking sector from  $\sigma^*$  to  $\sigma^{lolr}$ .

**Assumption 7.** *The Market Maker of Last Resort commits to purchasing the illiquid assets on the secondary market at price  $R/\mu$ .*

As in the case of the LoLR, regulated banks are unaffected by runs in the shadow banking sector and the cost of the deposit insurance is reduced to zero. But again, the shadow banking sector also benefits from the intervention. In fact, the MMLR policy ensures that the price in the secondary market always remains at  $p = R/\mu$ , i.e., the MMLR eliminates cash-in-the-market pricing altogether. Moreover, the central bank will end up purchasing actual assets whenever there is a run.

**Proposition 7.** *Assume  $q(p(0)) < \bar{q}$ . A MMLR policy completely crowds out regulated banking, and all intermediation takes place in the shadow banking sector,  $\sigma^{mmlr} = 1 > \sigma^*$ .*

If it is optimal for agents to deposit in the shadow banking sector when no other agent does so (i.e., if  $q(p(0)) < \bar{q}$ ), then it holds that under MMLR policy there will be no incentive to deposit in the regulated banking sector at all.

Whether the MMLR policy is desirable depends again on  $C(m)$ . Whenever there is a run, the central bank will have to purchase all assets that are on the market at date 1 at price  $R/\mu$ . Since only shadow banking prevails in equilibrium, and because they sell all their assets in a run, the central bank has to use an overall sum of  $m = R/\mu$ . The run occurs with probability  $q(R/\mu) = q(p(0))$ . The expected cost of the central bank intervention is thus given by  $q(p(0))C(R/\mu)$ . Thus, the MMLR policy is desirable if

$$q(p(0))C(R/\mu) \leq EU^{sb} - \sigma^* EU^{sb} + (1 - \sigma^*)EU^b.$$

Again, an intervention is desirable compared to the equilibrium allocation whenever the expected costs of the intervention are lower than the gains in improving the direct utility of consumers.

Comparing the LoLR and MMLR policies, it is interesting to notice that under a MMLR policy, interventions are more likely and larger in extent, i.e.,

$$q(p(0))C(R/\mu) > q^{LOLR}C((1 - \sigma^{lolr})\pi c_1^b).$$

However, the aggregate level of expected utility of consumers is also higher under a MMLR policy. The desirability of either then depends on the shape of  $C$ .

## 8. Discussion

We develop a model of systemic runs. In contrast to standard bank runs, systemic runs are contagious and negatively affect other intermediaries by deteriorating their funding conditions. The underlying mechanism is as follows: Intermediaries manage their liquidity needs by relying on a market through which investors provide secured funding. If some intermediaries are subject to a run, they need to liquidate their assets. Because of a cash-in-the-market constraint, the resulting fire sale can induce a scarcity of liquid funds in this market and make a run systemic. Here, the reliance on wholesale funding acts like an endogenous mark-to-market constraint, exposing intermediaries to changes in asset prices.

We apply the concept of systemic runs in a model in which regulated banks and shadow banks coexist. Regulated banks are covered by a safety net and are thus immune to runs. Shadow banks, in contrast, circumvent costly regulatory requirements and thereby expose themselves to panic-based runs. We derive a number of important implications: First, cutting contractual linkages between regulated banks and shadow banking entities may be desirable, but it is insufficient to deal with the financial fragilities emerging from shadow banking. Turmoil in the shadow banking sector can also be contagious

via pecuniary channels, i.e., via markets. Thus, regulatory requirements that prohibit contractual linkages between the two sectors may be desirable, but of limited efficacy.

Second, the shadow banking sector grows too large in equilibrium as agents do not internalize their impact on fire-sale prices. While a limited amount of regulatory arbitrage may be desirable, it is excessive in equilibrium.

Finally, prudential policies as well as central bank interventions change the composition of the financial system and may ultimately backfire. Strict liquidity regulation, particularly the prohibition of wholesale funding, is effective in shielding regulated banks from adverse consequences that originate outside the banking sector. However, this necessarily leads to a larger shadow banking sector, potentially eroding overall financial stability. Similarly, central bank interventions targeted at reducing fire-sale effects are more beneficial for the shadow banking sector than they are for regulated banks. Anticipated central bank interventions increase both the likelihood as well as the intensity of such interventions. This results from a changing composition of the financial sector and not from standard moral hazard arguments.

## Appendix A First-Best

We start out with the following first-best maximization program: The first-best maximization program is given by

$$\max_{(c_1, c_2, e_0, e_2, I, L_1, L_2) \in \mathbb{R}_+^7} \pi u(c_1) + (1 - \pi)u(c_2), \quad (12)$$

$$\text{subject to} \quad \pi c_1 \leq (1 + e_0 - I) + L_1, \quad (13)$$

$$(1 - \pi)c_2 \leq IR - L_2 - e_2, \quad (14)$$

$$e_2 \geq \rho e_0, \quad (15)$$

$$L_2 \geq \mu L_1, \quad (16)$$

$$L_1 \leq A, \quad \text{and} \quad (17)$$

$$I \leq 1 + e_0. \quad (18)$$

The budget constraints for date one and two are given by (13) and (14). Investors may transfer  $L_1$  to consumers in  $t = 1$  in exchange for  $L_2$  units in  $t = 2$ . (15) represents the participation constraint of the intermediary, and (16) represents the participation constraint of investors. The resource constraint on the investors' provision of "interim liquidity" is given by (17), and (18) denotes the constraint on the initial investment.

The two budget constraints are always binding. Furthermore, the participation constraint of intermediaries must also be binding. Moreover,  $e_0 > 0$  cannot be optimal. Because  $\rho > R$ , we can reduce  $e_0$  and thus relax the date-2 constraint. It therefore follows that  $e_0^* = e_2^* = 0$ . Because the intermediaries' required return is higher than the asset return, the intermediaries' funds are not used for intermediation in the first-best. As we will see below, moral hazard may make it necessary to force the intermediary to invest some of his endowment.

Let us now turn towards the use of interim liquidity, i.e., wholesale funding at date 1. In the first-best, it also has to hold that the participation constraint of investors is binding. Whenever  $L_2 < \mu L_1$  and  $L_1 \leq A$ , we can decrease  $L_2$ , thereby relaxing the date-2 constraint. Therefore, it holds that  $L_2 = \mu L_1$ .

We are now left with a maximization problem with two weak inequalities.

$$\max_{(c_1, c_2, I, L_1) \in \mathbb{R}_+^4} \pi u(c_1) + (1 - \pi)u(c_2), \quad (19)$$

$$\text{subject to } \pi c_1 = (1 - I) + L_1, \quad (20)$$

$$(1 - \pi)c_2 = IR - \mu L_1, \quad (21)$$

$$L_1 \leq A, \quad (22)$$

$$I \leq 1. \quad (23)$$

Let us define the following thresholds:

$$\xi \equiv \mu^{-\frac{1}{\eta}} \frac{\pi R}{(1 - \pi) + \pi \mu^{1 - \frac{1}{\eta}}} < R/\mu, \quad (24)$$

and

$$\xi_0 \equiv \frac{\pi R^{-\frac{1}{\eta}}}{(1 - \pi) + \pi R^{-\frac{1}{\eta}} \mu} < \xi, \quad (25)$$

Depending on the model parameters  $A, R, \mu$ , and  $\pi$ , as well as on the shape of the utility function, the first-best program now has three solution candidates.

**Lemma 5** (First-best). *If  $A \geq \xi$ , then the first-best allocation is characterized by*

$$I^* = 1 \text{ and } L^* = \xi \mu / R,$$

and optimal consumption is given by

$$c_1^* = \mu^{-\frac{1}{\eta}} \frac{R}{(1 - \pi) + \pi \mu^{1 - \frac{1}{\eta}}} \text{ and } c_2^* = \frac{R}{(1 - \pi) + \pi \mu^{1 - \frac{1}{\eta}}}. \quad (26)$$

For  $A \in (\xi_0, \xi)$ , we have that

$$I^* = 1, \quad L_1^* = A, \text{ and } L_2^* = \mu A, \quad (27)$$

and optimal consumption is given by

$$c_1^* = \frac{A}{\pi} \text{ and } c_2^* = \frac{R - A\mu}{(1 - \pi)}. \quad (28)$$

Finally, if  $A \leq \xi_0$ , then the first-best allocation is characterized by

$$I^* = \frac{(1 - \pi)(1 + A) + \pi R^{-\frac{1}{\eta}} A \mu}{(1 - \pi) + \pi R^{-\frac{1}{\eta}}} \text{ and } L^* = A \mu / R, \quad (29)$$

and optimal consumption is given by

$$c_1^* = R^{-\frac{1}{\eta}} \frac{R + (R - \mu)A}{(1 - \pi) + \pi R^{-\frac{1}{\eta}}} \text{ and } c_2^* = \frac{R + (R - \mu)A}{(1 - \pi) + \pi R^{-\frac{1}{\eta}}}. \quad (30)$$

In the first case ( $A \geq \xi$ ), it holds that  $I^* = 1$  and  $L_1^* < A$ , and the optimal allocation is characterized by

$$u'(c_1) = \mu u'(c_2) \quad (31)$$

$$\pi c_1 \mu + (1 - \pi)c_2 = R. \quad (32)$$

In the third case ( $A < \xi_0$ ), we have  $L_1^* = A$ , and  $I^* < 1$ , and the optimal allocation is characterized by

$$u'(c_1) = R u'(c_2) \quad (33)$$

$$\pi c_1 R + (1 - \pi)c_2 = R + (R - \mu)A. \quad (34)$$

## Appendix B Financial Markets Implementation

We have by assumption ignored the possibility of implementing an allocation via a financial market instead of via intermediaries. The allocation that can be attained via a financial market, i.e., if consumers invest in the technologies directly and trade with investors in  $t = 1$ , is  $(c_1^{fm}, c_2^{fm}) = (R/\mu, R)$ . This allocation, however, only coincides with the first-best if  $\eta \rightarrow 1$ , i.e., if  $u(c) = \ln(c)$ . This is reminiscent of the result of Diamond and Dybvig (1983).

Nonetheless, we need to make the investment restriction: If we allowed for the co-existence of financial markets and intermediaries, the incentive to conduct side trading would destroy the ability to implement the first-best via intermediaries, due to the same reasoning as in Jacklin (1987) and Farhi et al. (2009). If intermediaries offered the first-best demand-deposit contract, a consumer would have an incentive to invest his endowment in the productive technology and to consume the returns  $R > c_2^*$  if he turns out to be patient, or to trade with a patient depositor otherwise, thereby consuming  $c_1^*$  units.

## Appendix C Disciplining Demand Deposits and Shirking Equilibria

We want to argue that there exists a subgame-perfect Nash equilibrium in which the first-best consumption profile  $(c_1^*, c_2^*)$  is implemented by the intermediaries offering demand-deposit contracts that allow consumers to withdraw  $c_1^*$  units at  $t = 1$  or  $c_2^*$  units at  $t = 2$  and by managing liquidity by relying on investors to provide secured wholesale funding in  $t = 1$ .

Observe that in  $t = 0$ , intermediaries, due to perfect competition, must offer the best feasible contract,  $(c_1^*, c_2^*)$ , in exchange for the consumers' endowment. Otherwise, they would never receive funds in the first place. At date 1, consumers have the possibility to withdraw the promised amount of  $c_1^*$ , or to wait until date 2. Importantly, the intermediaries' investment decision  $I_{shirk}$  is not observable in  $t = 0$ , but becomes publicly observable before consumers make their withdrawal decision in  $t = 1$ .

Consider the following strategy of a consumer for the date-1 subgame: She withdraws if she turns out to be impatient or if the intermediary has chosen  $I_{shirk} > 0$ , and she does not withdraw if she turns out to be patient and the intermediary has chosen  $I_{shirk} = 0$ . We will now show that if all consumers use this strategy, this strategy profile constitutes a Nash equilibrium of the date-1 subgame for any investment decision of the intermediary, and the optimal strategy of the intermediary is to choose  $I_{shirk} = 0$ .

Assume that the intermediary has chosen  $I_{shirk} > 0$ . Because all other consumers withdraw, it is a best response to do so as well because the intermediary is already illiquid and insolvent in  $t = 1$ . Notice further that if  $I_{shirk}$  is large enough, withdrawing actually becomes a dominant strategy because the intermediary will be illiquid and insolvent in  $t = 2$  even without a run.

Now assume the intermediary has only invested in the productive technology, i.e.,  $I = 1$  and  $I_{shirk} = 0$ . Given that only impatient consumers withdraw, the intermediary will be able to serve all early consumers by selling  $L^*$  units of her investment to investors. Because  $A \geq \xi = \pi c_1^*$  by assumption, the investors' funds are sufficient to serve all early depositors. As  $c_2^* > c_1^*$ , it is a best response for patient consumers to wait.

### Shirking Equilibria

Note that there also exists a continuum of subgame-perfect Nash equilibria in which the bank chooses to invest a positive fraction in the shirking technology, but is not disciplined by the depositors up to this fraction.

There also exist subgame-perfect Nash equilibria in which that short-term debt is only partially disciplining. In fact, some investment in the shirking technology may be tolerated by depositors before they run. The reason is that if the intermediary has chosen some  $I_{shirk} \geq 0$  that is small enough, "running" is not the dominant strategy.

Assume the contract  $(c_1^*, c_2^*)$  has been promised. We can ask what level of  $I_{shirk}$  the intermediary can choose before consumers will run, irrespectively of the behavior of others at date 1. The date-2 budget constraint in case only impatient consumers withdraw is given by

$$(1 - \pi)c_2 = (1 - I_{shirk})R - \mu L_1,$$

where  $\pi c_1^* = L_1$ . After observing  $I_{shirk}$ , running is a dominant strategy whenever

$$c_2 = \frac{1}{1-\pi} [R - I_{shirk}(R - R_{shirk})\mu\pi c_1^*] < c_1^* \quad (35)$$

$$\Leftrightarrow I_{shirk} > 1 - \frac{R_{shirk} - \mu\pi c_1^* - (1-\pi)c_1^*}{R - R_{shirk}} \equiv I_x. \quad (36)$$

Therefore, there exist multiple subgame-perfect Nash equilibria in pure strategies which differ in the extent of the discipline that they ensure. In particular, for any  $\psi \in [0, \min[1, I_x]]$ , there exists an equilibrium in which each consumer runs if and only if  $I_{shirk} > \psi$ , and intermediaries choose  $I_{shirk} = \psi$ . In the main part of our analysis, we ignore such equilibria, which is equivalent to assuming that the intermediaries can only invest in either the productive or the shirking technology, i.e.,  $I_{shirk} \in \{0, 1\}$ .

## Appendix D Optimal Contract with Capital Requirement

Assume a capital requirement is in place as discussed above, i.e.,

$$e_0 = \frac{B}{\rho - B}, \quad e_2 = \rho e_0$$

Maintaining the assumption that the investors' capital  $A$  is not scarce, the following constraints are binding:

$$\begin{aligned} \pi c_1 &= (1 + e_0 - I) + Lp, \\ (1 - \pi)c_2 &= (I - L)R - e_2, \\ p &= R/\mu, \\ I &= 1 + e_0. \end{aligned}$$

The maximization problem is reduced to

$$\begin{aligned} &\max_{(c_1, c_2, L)} \pi u(c_1) + (1 - \pi)u(c_2), \\ &\text{subject to } \pi c_1 = LR/\mu, \\ &\quad (1 - \pi)c_2 = (1 + e_0 - L)R - \rho e_0, \\ &\quad e_0 = \frac{B}{\rho - B}. \end{aligned}$$

The FOC can be rewritten as

$$c_1 = \mu^{-\frac{1}{\eta}} c_2,$$

and the two budget equations yield the following consumption levels:

$$c_1 = \frac{RL}{\pi\mu}, \quad \text{and}$$

$$c_2 = \frac{1}{1-\pi} \left[ \left(1 + \frac{B}{\rho-B} - L\right)R - \rho \frac{B}{\rho-B} \right].$$

Solving for  $c_1$  and  $c_2$ ,  $I$ , and  $L$ , we arrive at

$$I^{**} = 1 + \frac{B}{\rho-B} \quad \text{and} \quad L^{**} = \frac{\pi\mu^{1-\frac{1}{\eta}} R - \frac{B}{\rho-B}(\rho-R)}{R(1-\pi) + \pi\mu^{1-\frac{1}{\eta}}}, \quad (37)$$

and the optimal consumption is given by

$$c_1^{**} = \mu^{-\frac{1}{\eta}} \frac{R - \frac{B}{\rho-B}(\rho-R)}{(1-\pi) + \pi\mu^{1-\frac{1}{\eta}}} \quad \text{and} \quad c_2^{**} = \frac{R - \frac{B}{\rho-B}(\rho-R)}{(1-\pi) + \pi\mu^{1-\frac{1}{\eta}}}. \quad (38)$$

## Appendix E Liquidity Guarantees

Until this point, we have restricted attention to intermediaries becoming either regulated banks or unregulated shadow banks. An interesting question is how our results change when banks and shadow banks are interdependent not only via effects on secondary markets, but if they are operated by the same intermediary. As described in Section 2, this had been practice prior to the recent financial crisis, as documented by Acharya et al. (2013), and has been targeted by post-crisis reforms.

To this end, we analyze a version of our model in which intermediaries operate a bank and a shadow bank at the same time. We investigate under which conditions intermediaries may have incentives to use funds from their regulated banking branch to support their shadow-banking activities in case of distress. We will thus analyze the effect of explicit contractual linkages.

### Private optimality of liquidity guarantees

In the previous section, we assumed that a systemic run on the whole shadow banking sector is a sunspot phenomenon that occurs with a probability  $q$ . We now analyze a situation in which shadow banks experience idiosyncratic sunspot runs: With a probability  $q_i$ , each individual shadow bank experiences a run, and the realization at each shadow bank is independent of that at other shadow banks. Again we keep the contracts offered fixed: A commercial bank offers the contract  $(c_1^b, c_2^b)$ , and a shadow bank  $(c_1^{sb}, c_2^{sb})$ .

Given that there is a run on the shadow bank with probability  $q_i$ , the intermediary may now have an incentive to guarantee the liquidity of her shadow bank to protect her from idiosyncratic, i.e., non-systemic, runs. Observe that even in the presence of a

coordination device like a sunspot, runs cannot occur if the best response to all other depositors running is not to run. Thus, idiosyncratic sunspot runs can be eliminated if a regulated branch of an intermediary provides a credible liquidity guarantee for its unregulated operations. Moreover, observe that it is optimal to provide this support guarantee for each institution, as it makes the offered contract more attractive and will thus attract more consumers.

The liquidity guarantee is credible if the bank can serve all its impatient bank customers as well as all those who own a shadow bank contract by selling all its assets. The regulated banking sector has conducted an initial investment of  $(1 - \sigma)(1 + e_0^*)$ , and the shadow banking an investment of  $\sigma$ . In total, the bank can thus raise an amount of liquidity  $R/\gamma(1 + (1 - \sigma)e_0^*)$  at date 1. The funds raised by selling all assets need to be sufficient to satisfy the claims of all impatient consumers of the regulated bank,  $(1 - \sigma)c_1^b$ , and of all consumers of the shadow bank,  $\sigma c_1^{sb}$ . A liquidity guarantee is thus credible whenever

$$\sigma \leq \frac{R/\gamma(1 + (1 - \sigma)e_0^*) - \pi c_1^b}{c_1^{sb} - \pi c_1^b}$$

A guarantee can thus only be credible if the shadow banking operations are not too large compared to the regulated banking activities.

### Systemic runs

While it is optimal from the perspective of a single institution to provide a liquidity guarantee, it leads to an increased parameter space for runs on the aggregate level. In case of a run, commercial banks have to provide an amount of  $\sigma c_1^{sb}$  to shadow banks. In addition, they require an amount of  $(1 - \sigma)\pi c_1^b$  to satisfy their own impatient customers. Therefore, a run is systemic whenever  $\sigma c_1^{sb} + (1 - \sigma)\pi c_1^b > A$ .

**Proposition 8.** *Assume that intermediaries can operate a regulated bank and a shadow bank at the same time and that liquidity guarantees are credible for the case of idiosyncratic runs. It is privately optimal for each intermediary to guarantee the liquidity for her shadow bank branch by using funds from her regulated bank. In turn, this decreases the threshold size above which the shadow banking sector becomes systemic: A systemic run can occur and affect regulated banks if  $\sigma \geq \sigma^{guar}$ , where*

$$\sigma^{guar} = \frac{A - \pi c_1^b}{c_1^{sb} - \pi c_1^b} < \bar{\sigma}.$$

Without liquidity guarantees, systemic runs are only possible if the shadow banking sector's size exceeds  $\bar{\sigma}$ . With liquidity guarantees, this is already true for a sector size

of  $\sigma \geq \sigma^{guar} < \bar{\sigma}$ . The underlying mechanism is as follows: while liquidity guarantees are optimal from the individual intermediary's perspective, they increase the number of assets sold in case of a systemic run in the shadow banking sector. This shows that there is a clear benefit of preventing direct contractual linkages via regulation, as it reduces the parameter space in which systemic runs may take place. However, as shown in the earlier section, it may not be sufficient to rule out adverse effect for regulated banks entirely.

## Appendix F Optimal Contracts with Sunspot-Induced Runs

If runs on shadow banks occur with a probability  $q(p(\sigma))$ , then the optimal contracts depend on the sector size  $\sigma$  directly through the fire-sale price and indirectly through the probability of sunspots. In order to solve the problem, we switch the setup slightly and assume that the cost of deposit insurance is not subtracted from the consumption levels, but rather enters additively separable with the functional form  $v(DI(\sigma))$ , where  $v$  is strictly increasing and twice continuously differentiable.

### Regulated Banks

The only change in the problem of regulated banks is that the cost of equity is increasing in  $q$ . We can distinguish three cases: First, if  $\sigma$  is so low such that  $p(\sigma) = R/\mu$ , banks offer the old contract. Second, for a small range of  $\sigma$ s, the equity is partly wiped out in a run. Third, the equity is completely wiped out in case of a systemic run.

Given that the bank equity is wiped out with some probability  $q$ , the equity holders' promised rate of return has to be increased to  $\rho/(1-q)$  in order to reimburse them for the default risk. That is, we have that  $e_2 = \frac{\rho}{1-q}e_0$  and  $e_0 = \frac{B}{\rho/(1-q)-B}$ .

$$\begin{aligned} & \max_{(c_1, c_2, L) \in \mathbb{R}_+^3} \pi u(c_1) + (1-\pi)u(c_2) - (1-q(p(\sigma)))v(DI(\sigma)), \\ & \text{subject to } \pi c_1 = LR/\mu, \\ & (1-\pi)c_2 = (1+e_0-L)R - \rho e_0, \\ & e_0 = \frac{B}{\rho/(1-q)-B}. \end{aligned}$$

The bank thus offers a contract with

$$c_1^b(q) = \mu^{-\frac{1}{\eta}} \frac{R - \frac{B}{\rho/(1-q)-B}(\rho/(1-q) - R)}{(1-\pi) + \pi\mu^{1-\frac{1}{\eta}}} \quad \text{and} \quad c_2^b(q) = \frac{R - \frac{B}{\rho/(1-q)-B}(\rho/(1-q) - R)}{(1-\pi) + \pi\mu^{1-\frac{1}{\eta}}}. \quad (39)$$

It holds that  $c_1^b(q)$  and  $c_2^b(q)$  are decreasing in  $q$ .

## Shadow Banks

The optimization problem for shadow banks changes as shadow banks may desire to invest in storage. The expected utility in the shadow banking sector is given by

$$EU^{sb}(c_1, c_2, I|\sigma) = (1-q(p))[\pi u(c_1) + (1-\pi)u(c_2)] + q(p(\sigma))[u(1+I(p(\sigma)-1)) - v(DI(\sigma))].$$

The optimization problem for a representative shadow bank is:

$$\max_{c_1, c_2, I, L} EU^{sb}(c_1, c_2, I|\sigma)$$

$$\text{subject to} \quad \pi c_1 = 1 - I + L_1,$$

$$(1 - \pi)c_2 = IR - \mu L_1,$$

$$I \leq 1.$$

We first substitute for  $c_2$  and fix  $I$ , then we can solve for the optimal “response function”  $c_1^*(I)$ . We yield a function  $EU^{sb}(I, c_1^*(I)|\sigma)$ , and we take the total derivative wrt.  $I$  and evaluate it at  $I = 1$ . If this is positive, then  $I^* = 1$ .

It is clear that in the good state (no run),  $I$  has an unambiguously positive effect; it increases consumption at both dates. In the bad state (run), the effect is negative if  $p(\sigma) < 1$ . However, the positive effect outweighs the negative effect as long as the probability of a run is sufficiently small.

$$EU^{sb}(c_1, I|\sigma) = (1-q(p)) \left[ \pi u(c_1) + (1-\pi)u\left(\frac{IR - \mu(\pi c_1 - 1 - I)}{1-\pi}\right) \right] + q(p(\sigma))[u(1+I(p(\sigma)-1)) - v(DI(\sigma))].$$

As usual, optimality requires that  $c_1^*(I)$  satisfies the FOC  $u'(c_1) = \mu u'(c_2)$ . We obtain the consumption level functions

$$c_1^*(I) = \mu^{-\frac{1}{\eta}} \frac{I(R-1) + 1}{(1-\pi) + \pi\mu^{1-\frac{1}{\eta}}}, \quad \text{and} \quad c_2^*(I) = \frac{I(R-1) + 1}{(1-\pi) + \pi\mu^{1-\frac{1}{\eta}}}.$$

The total derivative of the expected utility is given by

$$\begin{aligned} \frac{dEU^{sb}(c_1, I|\sigma)}{dI} &= (1-q(p)) \frac{R-I}{1-\pi} \underbrace{\left[ \pi \mu^{-\frac{1}{\eta}} u'(c_1^*(I)) + (1-\pi) u'(c_2^*(I)) \right]}_{>0} \\ &\quad + q(p(\sigma)) \underbrace{(p(\sigma)-1) u'(1+I(p(\sigma)-1))}_{<0 \text{ if } p(\sigma) < 1}. \end{aligned}$$

## Appendix G Proof of Proposition 3

We want to show that there exists  $\hat{q}$  and  $\bar{q}$  such that for  $q(p(1)) > \hat{q}$  and  $q(p(0)) < \bar{q}$ , it holds that

$$\sigma^* \in (\bar{\sigma}, 1).$$

Moreover, whenever  $q(p(1)) \leq \hat{q}$ , it holds that  $\sigma^* = 1$ , and there are only shadow banks; whenever  $q(p(0)) \geq \bar{q}$ , it holds that  $\sigma^* = 0$ , and there are only regulated banks.

*Proof.* We first analyze the second part of the proposition. For  $\sigma = 1$  to be an equilibrium, it must hold that

$$EU^b(1) < EU^{sb}(1)$$

Observe that at  $\sigma = 1$  it holds that  $DI(1) = 0$  and  $EU^b(1) = qU(c_1^{sb}, c_2^{sb}) + (1-q)u(p(1))$  and  $EU^{sb}(1) = U(c_1^b c_2^b)$ . Thus, in order for  $EU^b(1) < EU^{sb}(1)$  to hold, we must have that given all parameters:

$$\hat{q} = \frac{U(c_1^{sb}, c_2^{sb}) - U(c_1^b c_2^b)}{U(c_1^{sb}, c_2^{sb}) - U(c_1^b c_2^b) + U(c_1^b, c_2^b) - u(p(1))}.$$

Likewise, for  $\sigma = 0$  to be an equilibrium, it must hold that

$$EU^b(0) > EU^{sb}(0)$$

Again, we have that  $\sigma = 0$  implies that  $DI(0) = 0$  and  $EU^b(0) = (1-q)U(c_1^{sb}, c_2^{sb}) + qu(R/\mu)$  and  $EU^{sb}(0) = U(c_1^b c_2^b)$ . Thus in order for  $EU^b(0) > EU^{sb}(0)$  to hold, we must have that given all parameters:

$$\bar{q} = \frac{U(c_1^{sb}, c_2^{sb}) - U(c_1^b c_2^b)}{U(c_1^{sb}, c_2^{sb}) - u(R/\mu)}$$

Finally, observe that  $EU^{sb}(0) = EU^{sb}(\bar{\sigma})$  by definition. Therefore, whenever  $q(p(1)) > \hat{q}$  and  $q(p(0)) < \bar{q}$ , it holds that

$$\sigma^* \in (\bar{\sigma}, 1).$$

□

## Appendix H Proof of Proposition 4

*Proof.* Approach: Show that for all  $\sigma \notin [\bar{\sigma}, \sigma^*)$ , it holds that  $W(\sigma) < W(\bar{\sigma})$ .

Step 1a: Show that  $W(\sigma) < W(\bar{\sigma})$  for all  $\sigma > \sigma^*$

Step 1b: Show that  $W(\sigma) < W(\bar{\sigma})$  for all  $\sigma < \bar{\sigma}$

Step 2: Show that  $W(\sigma^*) < W(\bar{\sigma})$

It holds that

$$\begin{aligned} EU^b(\sigma^*) &< EU^b(\bar{\sigma}) \\ EU^{sb}(\sigma^*) &< EU^{sb}(\bar{\sigma}) \end{aligned}$$

Welfare

$$\begin{aligned} W(\sigma^*) &= (1 - \sigma^*)EU^b(\sigma^*) + \sigma^*EU^{sb}(\sigma^*) \\ &< (1 - \sigma^*)EU^b(\bar{\sigma}) + \sigma^*EU^{sb}(\bar{\sigma}) \\ &< (1 - \bar{\sigma})EU^b(\bar{\sigma}) + \bar{\sigma}EU^{sb}(\bar{\sigma}) \\ &= W(\bar{\sigma}) \end{aligned}$$

Step 3: It has to hold that  $\sigma^{SP} \in [\bar{\sigma}, \sigma^*)$ .

Remarks:

If  $\sigma^* = 1$ , then  $\sigma^{SP} \leq \sigma^* = 1$ .

If  $\sigma^* = 0$ , then  $\sigma^{SP} = \sigma^* = 0$ .

$\sigma^* \in (0, \bar{\sigma}]$  can only prevail if  $EU^{sb}(0) < EU^b(0)$ . In this case, all  $\sigma \in (0, \bar{\sigma}]$  constitute an equilibrium, and the social planner is indifferent between all of these. □

In order to gain deeper understanding of what it is that the social planner can do that agents cannot, we can analyze the corresponding FOC, which implies that  $\sigma^{SP}$  satisfies

$$\frac{EU^b(\sigma)}{EU^{sb}(\sigma)} = 1 + \Delta(\sigma)$$

in an interior solution to the problem, and where  $\Delta(\sigma)$  is given by

$$\begin{aligned} \Delta(\sigma) &= \frac{1}{EU^{sb}(\sigma)} q(p(\sigma)) \\ &\quad \cdot \left[ \sigma \left[ \underbrace{q'(p(\sigma))p'(\sigma)(U^{sb}(\sigma) - U(c_1^{sb}, c_2^{sb}))}_{\text{Extensive margin shadow banks}} \right] \right. \\ &\quad \left. + \underbrace{u'(p(\sigma) - DI(\sigma))[p'(\sigma) - DI'(\sigma)]}_{\text{Intensive margin shadow banks}} \right] \\ &\quad + (1 - \sigma) \left[ \underbrace{q'(p(\sigma))p'(\sigma)(U^b(\sigma) - U(c_1^b, c_2^b))}_{\text{Extensive margin banks}} + \underbrace{U_\sigma^b(\sigma)}_{\text{Intensive margin banks}} \right], \end{aligned}$$

and  $U^{sb}(\sigma) = u(p(\sigma) - DI(\sigma))$  and  $U^b(\sigma) = U(c_1^b - DI(\sigma), c_2^b - DI(\sigma))$  denote the utility in the two sectors in case of a run, and  $U_\sigma^b(\sigma)$  and  $U_\sigma^{sb}(\sigma)$  the respective derivatives with respect to  $\sigma$ .

Recall, in equilibrium, if the two sector coexists,  $\sigma^*$  is such that

$$\frac{EU^b(\sigma)}{EU^{sb}(\sigma)} = 1.$$

That is, the difference between the equilibrium and the social planner's preferred allocation is captured in  $\Delta(\sigma)$ .  $\Delta$  can be decomposed into three different components that the social planner internalizes, but agents do not. First, the social planner internalizes the effect of  $\sigma$  via the fire-sale price on an increased probability of sunspots  $q$ , referred to as the extensive margin effect. Second, he internalizes the effect of  $\sigma$  directly on the fire-sale price and thus the proceeds in case of a run in the shadow banking sector. Finally, he internalizes the effect of  $\sigma$  via the fire-sale price on the cost of the deposit insurance and thus the level of taxation across all agents. The latter two effects can be referred to as the intensive margin.

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