# A detrimental feedback loop: deleveraging and adverse selection

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**Abstract**

Market distress can lead to a deleveraging wave, as in the 2007/08 financial crisis. This paper demonstrates how market distress and deleveraging can fuel each other in the presence of adverse selection in opaque asset markets. A detrimental feedback loop emerges: investors reduce their reliance on opaque markets by decreasing their leverage which in turn amplifies adverse selection. In the extreme, trade breaks down. Asymmetric information together with incomplete markets is at the root of two inefficiencies: investors' leverage choices are distorted and investors' liquidity management exhibits under-investment in cash. I discuss policy implications and the ambiguous role of transparency.

*Keywords:* Endogenous borrowing constraints, financial crisis, liquidity, fire sales, opacity, private information, central bank policy.

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# 1 Introduction

At the start of the financial crisis in July 2007, interbank market spreads shot up and subprime asset markets experienced a large drop. Temporarily important market segments dried up completely.[1] At the same time, a pronounced deleveraging wave in the financial sector began. US investment banks drastically cut leverage immediately after the crisis erupted. Data show that US commercial banks as well as EU and UK banks started heavily reducing leverage beginning in 2008. Financial market conditions were the main driver of this deleveraging in 2007 and 2008. Thereafter, the effect of financial market disorder on deleveraging was compounded by regulatory initiatives and a change in economic and policy conditions.[2] This paper focuses on the early crisis period and proposes a novel mechanism that draws a connection between liquidity risk, financial market distress, reflected in fire sales of opaque assets, and deleveraging.

There is a series of papers dedicated to the study of the underlying reasons for the market distress at the start of the crisis, and of potential policies that can positively affect economic outcomes in such a scenario. Arguably, credit risk played an important role due to solvency concerns related to the US subprime market. These concerns were fueled by the lack of transparency in the securitization process, highlighting the role played by asymmetric information (Gorton 2008). In addition, liquidity risk was an important contributor to the widening of interest rate spreads (Dick-Nielsen et al. 2012; Schwarz 2014) and was accompanied by hoarding behavior (Ashcraft et al. 2011; Acharya and Merrouche 2013), a mechanism that has been discussed in the theoretical literature (Heider et al. 2009; Gale and Yorulmazer 2013; Malherbe 2014).

The relationship between the exceptional deleveraging in the financial sector (Buttiglione et al. 2014) and the market distress at the start of the crisis still deserves more attention. Here lies the contribution of this paper. In particular, I establish a detrimental feedback loop between the intensity of adverse selection problems in an opaque asset market and financial sector deleveraging. Investors subject to idiosyncratic liquidity risk know that they may have to shed opaque assets in the future despite falling prices in order to

[1] The spread between LIBOR and the overnight Federal Funds rate for 3-month loans jumped from sub 20 basis point levels before July 2007 to elevated levels between 40 and 100 basis points (Cecchetti 2009, p. 58). A similar picture holds for Europe, where the spread between EURIBOR and the 3-month overnight index swap jumped from below 10 basis points to elevated levels fluctuating around 60 basis points during the year after August 2007. Then, the spread shot up to over 180 basis points in November 2008 (Heider et al. 2009, p. 8). US subprime markets for asset-backed securities and global high-yield corporate bonds were largely affected. In the year after August 2007, the US subprime index fell by over 80% and global high-yield corporate bond spreads climbed to over 60% (see Bank of England Financial Stability Report, April 2008).

[2] Feyen and González del Mazo (2013) provide a detailed account of the deleveraging wave. For US investment banks, leverage ratios (measured as weighted tangible assets over tangible common equity) dropped from around 40% in 2007 to under 30% in 2008, followed by a further drop to under 20% in 2009. Main factors contributing to the deleveraging wave in the initial crisis period till 2008 were the distress in interbank, subprime asset and high-yield corporate bonds markets.

obtain valuable cash. Fire sales are driven by adverse selection and the cash in the market. The anticipation of future distress in opaque markets due to adverse selection induces investors to reduce their reliance on funding from these markets. To do this, investors can reduce leverage in order to build up spare borrowing capacity that allows for a better future access to the prime market segment which is not prone to adverse selection. This precautionary behavior, in turn, amplifies the adverse selection problem in the opaque market, generating fire sale prices which, in the extreme, can lead to a breakdown of trade in the opaque market.

To understand the mechanism, I develop a model of liquidity provision that is augmented with an ex-ante leverage choice. This modeling choice reflects the view that liquidity management is conducted over a short horizon on a daily basis, while the leverage choice is part of the medium- to long-term business model and is only adjusted when lucrative investment opportunities arise that require financing or when the market outlook changes drastically. The model focuses on liquidity risk sharing in financial markets when there are limits to ex-ante risk-sharing arrangements. In particular, markets are incomplete and investors rely on segmented spot markets. First, an asset market that is prone to an adverse selection problem. Second, a prime market segment for collateralized credit that is not prone to adverse selection. However, investor's borrowing capacity in the prime market segment is limited by their initial leverage choice. A natural pecking order arises, because financing from the opaque market comes at higher cost if high quality assets are shed at a discount. When deciding about leverage and liquidity management, investors anticipate this market frictions. Nevertheless, externalities arise that can impede market functioning.

A lower level of leverage is tantamount to a higher level of borrowing capacity, which can entail a worsening of an Akerlof (1970) type adverse selection problem in the opaque asset market. In turn, anticipating future market distress may fuel the incentives to further reduce leverage in order to reduce, in expectation, the necessity to finance through the opaque market when asset prices are discounted. In sum, the deleveraging and the intensity of an Akerlof-type adverse selection problem are interconnected in a potentially detrimental way through a novel feedback mechanism that has yet to be studied in the existing literature. Furthermore, asymmetric information together with incomplete markets gives rise to both, inefficient leverage choices and an inefficient under-investment in cash.

More concretely, the model has four dates. There are investors and outside financiers with limited resources. The interest is in investors, while outside financiers only have the role to provide funding at all dates. At the initial date, each investor has a lucrative and safe investment opportunity that cannot be sold, but expanded by raising long-term funds from outside financiers. An ex-ante leverage choice pins down the size of investments, as well as the borrowing capacity left available for future trades. At the subsequent date, investors receive cash flows and have to decide on their liquidity management, knowing that they may face future liquidity needs. The alternative to storing cash is to invest into a long-term asset portfolio that can be thought of as a fully diversified portfolio consisting of risky mortgages or corporate loans. Thereafter, liquidity and return risk realize and are privately learned by investors. Ex-ante risk-sharing arrangements for the liquidity risk are not possible and investors have to rely on distinct spot markets.[3] Investors in need of cash can sell assets and borrow against their leveraged ex-ante investment, as far as their remaining borrowing capacity allows. Due to the asymmetric information on asset qualities, the asset market is opaque and prone to adverse selection. Contrastingly, lending against the safe ex-ante investment is risk-free. This setup captures in a stylized way the co-existence of market segments with a varying degree of opacity. Finally, the ex-ante investment and the long-term assets mature at the terminal date.

A first key feature of the model is that equilibrium spot prices are determined by the endogenous supply of cash-in-the-market (Shleifer and Vishny 1992; Allen and Gale 1994, 2004, 2007). The endogenous and, hence, imperfectly elastic supply of cash is key to the model mechanics. Both a higher level of cash and a higher level of leverage are genuinely beneficial for market liquidity. The notion of liquidity refers to the cost of converting expected future income into cash. The stronger the adverse selection problem in the opaque market and the less cash available in the economy, the higher the cost. As such, my model incorporates two key reasons for market breakdowns: adverse selection and insufficient financial muscle, both of which are discussed by Tirole (2011). A second key feature of the model is that cash is modeled as the most "liquid" mean for transactions. Hence, cash is not equal to negative debt (Acharya et al. 2007). This property arises because it is assumed that there is an epsilon-cost of issuing debt, which drives an arbitrarily small wedge between the return of investing cash and the cost of obtaining cash through collateralized credit. The minimal wedge ensures that leverage is only increased when there are positive gains doing so.

Taken together, these model features give rise to the detrimental feedback loop between deleveraging and the intensity of adverse selection problems in opaque asset markets. Empirically, the link between distress in subprime markets and adverse selection problems can be attributed to a substantial rise in counterparty risk and severe asymmetric information problems in subprime markets at the beginning of the crisis.[4] My model

[3] To capture the financial market distress during the financial crisis, the focus is on financial markets in liquidity risk sharing when there are limits to ex-ante risk-sharing arrangements.

[4] See Gorton (2008) amongst others. Lax screening incentives under the existing securitization procedures may have contributed to the emergence of substantial asymmetric information problems, as argued by Keys et al. (2010).

uses the same trigger for market distress. The model then links market distress in a novel way to the financial sector deleveraging wave witnessed during the crisis. Notably, the degree of deleveraging is in this paper measured relative to the borrowing constraint. Hence, I abstract from the debate on whether financial sector leverage was excessive prior to the crisis, since this question would be rather about the level of the borrowing constraint. Furthermore, the exclusive modeling of leverage in the private sector is stylized, but it mirrors the observed concentration of leverage in the financial sector. At the core of the mechanism is a strategic complementarity in leverage choices that can trigger a deleveraging wave after a small deterioration in the anticipated intensity of adverse selection in the opaque asset market. Deleveraging, which mirrors a quest for unencumbered high quality collateral, has systemic consequences because a reduction in leverage fuels the adverse selection problem.[5] Importantly, the novel feedback mechanism presented in this paper does not rely on portfolio constraints or margin requirements.[6] Instead, the effect is solely generated by investors' desire to shield themselves from the negative implications of adverse selection in the opaque market.

The strategic complementarity in leverage choices is also at the root of an inefficient leverage choice. Investors would in many cases be collectively better off if they chose not to reduce their leverage in anticipation of future market distress as this creates a welfare reducing breakdown of pooling in the opaque asset market. Furthermore, I uncover two layers of inefficiencies in the liquidity management. First, I find a tendency for inefficient under-investment in cash due to the private information friction together with the market incompleteness. Second, even absent a private information friction, the liquidity management affects ex-ante financing conditions which can also result in an inefficient under-investment in cash (Lorenzoni 2008). My result that the economy exhibits an under-investment in cash contradicts the prescription of models with adverse selection who predict over-investment in cash (e.g. Malherbe 2014). However, this result is in line with the cash-in-the-market pricing literature and is also consistent with Bhattacharya and Gale (1987) who find that moral hazard and asymmetric information are associated with under-investment in reserves.

In the light of the inefficiencies in the leverage choice and in the liquidity management, I discuss several policy implications. The inefficient under-investment in cash can be addressed by a Pigovian tax. Of more interest is, however, how a policy maker can prevent the emergence of an inefficient deleveraging wave that

[5]The emergences of a high demand for unencumbered high quality collateral that can be used for future trades has some features of a "flight to quality". However, the mechanism does not rely on Knightian uncertainty as in Caballero and Krishnamurthy (2008) but has more similarities with the mechanism in Guerrieri and Shimer (2014), which is based on fire sales.

[6]As it is, for instance, in Brunnermeier and Pedersen (2009) or Geanakoplos (2009).

triggers a breakdown of pooling in the opaque asset market segment. I find that a widening of collateral requirements by the central bank is an effective tool, as well as any policy that makes investors more reliant on financing through the opaque asset market. Allowing for the co-existence of an opaque and transparent asset market segment, I find that more opacity (a large size of the opaque market segment) can be good for market functioning and reduces the incentives for deleveraging.[7]

This paper is most closely related to Bolton et al. (2011) and Malherbe (2014). They find that the anticipation of adverse selection in the future leads to excessive early asset trading and liquidity hoarding, respectively. Unlike Malherbe (2014), the supply of cash is endogenous in my model. Hence, cash holdings do not present a negative externality. In contrast to Bolton et al. (2011) and Malherbe (2014), investors in my model anticipate future adverse selection problems and, as a result, seek to reduce their leverage today. This, in turn, can intensify adverse selection in the future and lead to stronger deleveraging today. Furthermore, a novel amplifying link between adverse selection and the intensity of fire sales emerges.

The focus is on an interplay between two frictions: a private information problem and endogenous collateral constraints. The interplay between these two frictions is also analyzed by Martin and Taddei (2013) and Boissay (2011). Unlike my paper, they consider an environment in which both frictions affect the same asset. Furthermore, Boissay (2011) focuses on self-fulfilling pessimistic beliefs to generate a liquidity dry-up. While Martin and Taddei (2013) find that limited pledgeability exacerbates adverse selection problems, the opposite result arises in my model with *endogenous* borrowing constraints. Nenov (2013) studies advantageous selection and endogenous leverage, highlighting a "debt quality" channel that generates a co-movement between asset prices, aggregate output and credit. Despite the different mechanism, also Nenov finds that more leverage is associated with higher asset qualities. In earlier work, Caballero and Krishnamurthy (2001, 2002) analyze the interplay between international and domestic collateral constraints. Unlike their work, the provision of high quality collateral plays a negative role in my model due to the adverse selection problem in sub-prime markets.

There are several related papers that examine adverse selection problems in macro models following the partial equilibrium model of Eisfeldt (2004). These include Kurlat (2009), Bigio (2014) and Taddei (2010). Kurlat (2009) and Bigio (2014) both extend the framework of Kiyotaki and Moore (2012) by introducing endogenous resaleability through asymmetric information. While Kurlat (2009) focuses on the relationship between liquidity and macroeconomic fluctuations as well as the amplification of shocks through learning,

[7] Other papers also found positive implications of opacity for market functioning (e.g. Dang et al. 2012).

Bigio (2014) adds a labor market friction and analyzes how dispersion shocks to capital quality affect the liquidity of assets and the macroeconomy. Taddei (2010) rationalizes the positive relationship between aggregate economic activity and the cross-firm divergence of bond yields. Their models contrast with mine in that they abstract from the role of a liquid asset that co-exists with illiquid assets prone to adverse selection problems, which is a key element of the mechanism presented in this paper.[8]

A separate strand of the literature examines adverse selection problems and liquidity in asset markets (Kirabaeva 2011) and in interbank credit markets (Freixas and Holthausen 2004; Heider et al. 2009; Heider and Hoerova 2009). Freixas and Holthausen (2004) is most closely related to this paper. They analyze a model with secured and unsecured credit which is similar to my model in which illiquid assets co-exist with high quality collateral. However, Freixas and Holthausen consider an *exogenous* change in the income structure that changes the composition between secured and unsecured credit, thereby affecting the intensity of adverse selection in interbank credit markets. More recently, Asriyan (2015) studies balance-sheet recessions in a model where the access to different market segments is endogenous. In particular, contracts with limited macro contingencies arise endogenously when the severity of macro shocks is low. Ma (2014) develops a model in which investors can limit their private information on asset qualities by investing in systemic risk assets, thereby generating a liquidity versus systemic risk trade-off.

The remainder of this paper is organized as follows. Section 2 describes the model. Section 3 proceeds with the equilibrium analysis. It establishes the existence of the detrimental feedback mechanism and contains the efficiency analysis for liquidity management and the leverage choice. Thereafter, section 4 provides a policy discussion based on these results. Section 5 concludes. All proofs and figures are in the Appendix.

## 2 The model

The model has four dates, indexed by $t = 0, 1, 2, 3$. It comprises a model of liquidity provision spanning over dates $t = 1, 2, 3$ and an ex-ante leverage choice at date $t = 0$.

**Agents** There are two types of agents: *investors* and *outside financiers*. Investors can be thought of as banks who face idiosyncratic liquidity risk and engage in leveraged investments. Outside financiers can be thought of as fixed income funds or insurers who provide financing to banks.

[8] More recently, Cui and Radde (2014) developed a version of Kiyotaki and Moore (2012) with a liquid asset and search frictions in illiquid asset markets. However, they abstract from adverse selection and focus on the pro-cyclicality of asset liquidity.

*Investors:* There is a continuum of ex-ante identical investors with unit mass who are born at $t = 0$ and consume at $t = 2$ and $t = 3$. Similar to Diamond and Dybvig (1983), investors are ex-ante uncertain about whether they prefer to consume *early* or *late*. The likelihood of an individual investor being either of early or late type is given by $\lambda$ and $(1 - \lambda)$, respectively. Let $c_{ti}$ be the consumption of a type $i$ investor at date $t$. The preferences are represented by:[9]

$$u(c_{2i}, c_{3i}) = \beta_i \, log(c_{2i}) + (1 - \beta_i) \; log(c_{3i}).$$

A higher relative valuation of consumption at $t = 2$ by early types is reflected in the parameter restriction $1 > \beta_E > \beta_L = 0$.[10] Different to Diamond and Dybvig, early types face a trade-off between consuming at $t = 2$ or $t = 3$ because $\beta_E < 1$. This is a key ingredient for the main mechanism of the paper to work.

*Outside financiers:* There are outside financiers who do not face preference risk. They maximize their payoff at $t = 3$, do not discount time and act as if risk-neutral (i.e. they can fully diversify their return risk).

**Technology and endowments** Both investors and outside financiers have access to a risk-less storage technology at each date. Outside financiers are endowed with $m_0 > 0$ units of cash at $t = 0$. Investors are endowed with an illiquid long-term investment project that can be leveraged and expanded at $t = 0$. In addition, investors receive one unit of cash endowment at $t = 1$ and no additional endowment thereafter.

**The leveraged investment at date t=0** At the initial date, investors are each endowed with a long-term investment project of size $\kappa > 0$, which yields a deterministic date $t = 3$ return of $\rho > 1$ per unit invested (i.e. constant returns to scale). The long-term investment project cannot be sold at $t = 0$, but it can be expanded by raising long-term funds from outside financiers at the *endogenous* interest rate $r_0$, where $\rho \geq r_0 \geq 1$. However, only a fraction $0 < \gamma < 1$ of the date $t = 3$ income from the investment project is pledgeable and, hence, leverage is limited.[11] Let $\theta_0 \geq 0$ be the amount of *spare borrowing capacity*, consisting of the pledgeable return that has not been pledged at $t = 0$ and, hence, can be used for future periods. Given $\theta_0$

[9] Log-utility is used to ensure analytical tractability. More generally, a CRRA utility is needed.
[10] Setting $\beta_L = 0$ simplifies the analysis without affecting the key insights.
[11] The assumption of limited pledgeability can, for instance, be justified by a moral hazard problem (Holmström and Tirole 2010) or by the inalienability of human capital (Hart and Moore 1994).

and $r_0$, the leveraged investment's return, say $G(\theta_0, r_0)$, is:

$$G(\theta_0, r_0) \equiv \quad \rho \overline{\Upsilon}(\theta_0, r_0) - \gamma\rho \left[ \overline{\Upsilon}(\theta_0, r_0) - \frac{\theta_0}{\gamma\rho} \right], \tag{1}$$

where $\overline{\Upsilon}(\theta_0, r_0) \equiv \frac{k-\theta_0/r_0}{1-\gamma\rho/r_0}$ is the maximum investment scale. If it is costly not to fully lever up (if $\rho > r_0$), then the signs of $\frac{\partial G}{\partial \theta_0} < 0$ and $\frac{\partial G}{\partial r_0} < 0$ are as expected.

**The model of liquidity provision spanning over dates t=1,2,3** The leverage choices are assumed to be *common knowledge* at $t = 1$. Investors each receive an endowment of one unit of cash at $t = 1$ and can raise additional funds from outside financiers or from other investors at dates $t = 1, 2$. The $t = 1$ decision problem for each investor is to either become an *illiquid investor* who invests all resources in long-term assets, or a *liquid investor* who stores cash. Hence, investors have a discrete liquidity management problem at $t = 1$.[12]

Long-term assets pay off at $t = 3$ and can be thought of as a fully diversified portfolio consisting of risky mortgages or corporate loans. At $t = 2$ each individual loan turns out to be of *bad quality* with probability $0 < \alpha < 1$ and of *good quality* with probability $(1-\alpha)$. In the latter case, the per unit payoff at $t = 3$ is $R_G > 1$. In the former case, it is $R_B < R_G$. Let the individual long-term asset returns in each portfolio be independently distributed and independent of investors' preferences.

At $t = 2$, long-term asset portfolios can be prematurely liquidated using a *private liquidation technology* that yields $\ell_G < R_G$ for *good* loans and $\ell_B = R_B$ for *bad* loans.[13] Alternatively, investors can securitize their portfolio of risky long-term loans and partially or fully sell them on the asset market described below.

**Information structure** There are two layers of private information. First, investors learn privately at the beginning of date $t = 2$ whether they are of the early or late type. Second, an exogenous fraction $0 \leq q \leq 1$ of each illiquid investor's long-term asset portfolio turns out to be *opaque*, whereas the fraction $(1-q)$ turns out to be *transparent* (i.e. *non-opaque*). The fundamental value of each individual loan ($R_G$ or $R_B$) in the transparent portfolio is learned *publicly* at the beginning of $t = 2$, while the value of each individual loan in the opaque portfolio of an illiquid investor is learned *privately*. For simplicity, learning is perfect.

[12] Investors can either store all their available resources, or instead, fully invest them in a long-term asset portfolio. Indivisibility of investments at $t = 1$ is a strong assumption and has the character of an occupational choice, which allows to derive all results analytically. In practice, the indivisibility could for instance be the result of fixed costs for investments in a loan portfolio. Importantly, the key insights of the paper prevail in an economy where investors can select mixed portfolios at $t = 1$.

[13] The private liquidation technology captures the idea of a costly premature project liquidation (Heider et al. 2009). This technology could be understood as the physical liquidation of loans, which allows to recover only a fraction of the investment.

**Market institutions** The focus is on risk sharing in financial markets when there is no scope for ex-ante risk-sharing arrangements. Hence, markets are assumed to be incomplete and investors have to rely on competitive spot markets. This can be justified by the inability of investors to borrow against future cash endowments[14] and by non-observable and non-verifiable project initiation.[15]

At dates $t = 0, 1$, there exists only a collateralized credit market because long-term assets are not yet initiated. Differently, at $t = 2$, there are two distinct spot markets in which trades take place simultaneously.

*The asset market at date $t = 2$:* The market for long-term assets is an anonymous and competitive spot market, where investors can securitize and sell their risky long-term loans. The market is comprised of two segments. First, the transparent segment where good and bad assets are traded at the endogenous prices $p_G$ and $p_B$, respectively, and, second, the opaque segment where illiquid investors have private information about the asset quality. Since buyers cannot distinguish between opaque assets, all are traded at a uniform endogenous price $p$. Due to the private information problem, illiquid investors can potentially gain from trading on private information by securitizing their opaque loans of bad quality and selling the "lemons" irrespective of their liquidity needs.[16]

*The collateralized credit market at dates $t = 0, 1, 2$:* In this market, investors can obtain credit up to their predetermined borrowing capacity. The borrowing constraint of an investor is given by $\frac{\theta_{t-1}}{r_t}$ at dates $t = 1, 2$. Instead, $\theta_{-1}$ at $t = 0$ is predetermined and, for a given $\theta_0$ and $r_0$, the borrowing constraint is given by:

$$\frac{\theta_{-1}}{r_0} = \rho \, \frac{\gamma \overline{\Upsilon}(\theta_0, r_0)}{r_0}.$$

## 2.1 Key parameter assumptions

The model is summarized in figure 1 in Appendix A. The model section closes with an overview over the parameter assumptions behind the key results of the paper.

**Assumption 1:** $R_G > 1 > \ell_G > R_B = \ell_B \geq 0$.

**Assumption 2:** $ER \equiv \alpha R_B + (1-\alpha) R_G > 1$.

[14]Future cash are hard to pledge as they are, by their definition, hard to seize. In a richer model future endowments may be stochastic and, hence, hard to observe and verify.

[15]This prevents investors from pre-empting the realization of private information by selling assets to outsiders at $t = 0, 1$ who cannot invest on the investors' behalf or by committing to bundle future asset sales.

[16]It is assumed that buyers in the opaque market segment do not face risk because they purchase a portfolio with a fundamental value corresponding to the average quality traded. This assumption is maintained for analytical tractability and common in the literature. It is justified if buyers can purchase from multiple sellers simultaneously and could also be implemented via an intermediary.

Assumption 1 ensures that the possibility of a breakdown of pooling in the opaque market is entertained by allowing for the possibility that the average quality of assets traded can fall short of the return $\ell_G$ earned from privately liquidating a good quality asset. Instead, Assumption 2 guarantees that investments in long-term assets are not dominated by cash. Otherwise, the problem is trivial.

**Assumption 3:** There is an epsilon-cost, $\varepsilon > 0$, of issuing collateralized debt.

The epsilon-cost of issuing debt drives an arbitrarily small wedge between the return of investing cash and the cost of obtaining cash in the prime market segment of collateralized credit, reflecting the nature of cash as the most liquid means of transaction. As said earlier, the existence of this wedge ensures that leverage is only increased when there are strictly positive gains doing so.

# 3 Equilibrium analysis

The model is solved backwards. At $t = 2$, illiquid and liquid investors face the realization of idiosyncratic liquidity risk. They can use two distinct spot markets at $t = 2$: trade long-term assets against cash (in both the opaque and transparent market segment); borrow or lend against safe collateral in the credit market. At $t = 1$, investors face the liquidity management problem. They also decide on how much to borrow or lend in the collateralized credit market. Finally, investors decide on leverage at $t = 0$.

First, I provide an equilibrium definition in section 3.1. Thereafter, section 3.2 analyzes the model of liquidity provision spanning dates $t = 1,2,3$. Section 3.3 provides an efficiency analysis of the $t = 1$ liquidity management, taking the leverage choice as given. Finally, section 3.4 examines the leverage choice at $t = 0$. With asymmetric information, a detrimental feedback can arise and I discuss in section 4 how a planner may prevent excessive (inefficient) deleveraging.

## 3.1 Equilibrium definition and classification of equilibria

Let $a$ denote the average quality of assets traded in the opaque segment at $t = 2$ and let $0 \leq f \leq 1$ be the measure of liquid investors at $t = 1$.

**Definition 1.** ***A competitive equilibrium consists of*** *(i) asset prices at $t = 2$ in the transparent market segment, $p_G^*$ and $p_B^*$, an asset price and an average quality of assets traded in the opaque market, $p^*$ and $a^*$, interest rates $r_0^*, r_1^*, r_2^*$ at which markets clear at dates $t = 0,1,2$ that are consistent with the equilibrium* *measure of liquid investors, $f^*$, and the leverage choices, (ii) type-dependent decision rules at $t = 2$ as functions of $p^*_G$, $p^*_B$,$p^*$, $a^*$, $r^*_2$, and the leverage choices, (iii) investment decisions and financing choices at $t = 1$ as functions of $r^*_1$ and expected future prices, which map into equilibrium measures of liquid (illiquid) investors $f^*$ $(1 - f^*)$, and (iv) leverage choices at $t = 0$ as a function of $r^*_0$ and expected future prices.*

In the remainder, I refer to a *pooling equilibrium* if *early type* illiquid investors are willing to sell their *good quality* long-term assets at $t = 2$ in the opaque market segment, given the equilibrium asset prices. If, instead, the equilibrium asset price is sufficiently low such that illiquid investors are only willing to sell *bad quality* long-term asset, then I refer to a *breakdown* of pooling in the opaque asset market.

## 3.2 Liquidity management at t=1 & liquidity provision at t=2

This section focuses on liquidity management and liquidity provision. Specifically, I analyze the liquidity management at $t = 1$ and market functioning at $t = 2$, taking the leverage choice at $t = 0$ as given. That is, I consider an investors' decision problem at $t = 1$ and her trading decisions at $t = 2$ for all $\theta^j_0 \in [0, \gamma\rho\kappa]$. Since the leverage choice at $t = 0$ can potentially differ depending on whether investors expect to become liquid or illiquid investors at $t = 1$, it is indexed with the superscripts $j = L$ for liquid ($j = I$ for illiquid).

First, section 3.2.1 analyzes trading decisions at $t = 2$. Then section 3.2.2 derives the average quality of assets traded in the opaque market segment and the market-clearing prices $(p_G, p_B, p)$ at $t = 2$ for given leverage and liquidity choices, establishing a link between leverage and market functioning at $t = 2$. Thereafter, I consider the liquidity management problem at $t = 1$ in section 3.2.3 and present the results on equilibrium existence and characterization.

### 3.2.1 Trading decisions at date t=2 and supply & demand schedules

Investors enter $t = 2$ with a predetermined leverage choice summarized in $\theta^j_1$.[17] At the beginning of $t = 2$, investors learn privately if they are of the early or late type. Moreover, the quality of individual assets in the transparent portfolio becomes publicly known, while it is learned privately for the opaque portfolio.

[17] In section 3.2.2 it will be argued that $\theta^j_1 = \theta^j_0$ for all $j = L, I$.

**No-arbitrage**

No-arbitrage requires that investments yield the same return across all markets:

$$r_2 = \frac{R_G}{p_G} = \frac{R_B}{p_B} = \frac{a}{p}, \tag{2}$$

meaning that one unit of cash invested in the collateralized credit market yields the same return as if invested in the transparent or opaque asset market segment at $t = 2$.

**Liquid investors**

Let us start with the decision problem of a *liquid investor*. She enters the period with one unit of cash and may be of either early or late type. Her problem is to decide on how much cash to consume at $t = 2$ and on how to invest the remainder. Investments in financial markets are preferred over storage whenever $r_2 > 1$. Formally, the problem of a *liquid investor* of type $i$ at $t = 2$ writes:

$$\begin{array}{ll} \underset{0 \le s^L_{2i} \le 1, -r_2 \le b^L_{2i} \le \theta^L_1}{max} & \left\{ \beta_i \, log\left(c^L_{2i}\right) + (1-\beta_i) \; log\left(c^L_{3i}\right) \right\} \\ s.t. & c^L_{2i} = \left(1 + \frac{b^L_{2i}}{r_2}\right)\left(1 - s^L_{2i}\right) \\ & c^L_{3i} = \left(1 + \frac{b^L_{2i}}{r_2}\right) \; s^L_{2i} \, r_2 - b^L_{2i} + G\left(\theta^L_0, r_0\right), \end{array} \tag{3}$$

where the choice variable $s^L_{2i}$ captures the fraction of available cash resources supplied to the market. The choice variable $b^L_{2i}$ captures the amount borrowed in the collateralized credit market, which takes on a negative value if liquid investors want to lend. The collateral constraint is given by $\frac{\theta^L_1}{r_2}$. As a result, the net supply of cash to the market by a liquid investor is $s^L_{2i}\left(1 + \frac{b^L_2}{r_2}\right) - \frac{b^L_2}{r_2}$. Notice that the consumption at $t = 3$ includes the return on the leveraged long-term investment project given by $G\left(\theta^L_0, r_0\right)$.

Solving the problem in (3) reveals that liquid investors are indifferent as to how they finance their consumption and investments. Hence, fixing $b^L_{2i} = 0$ leads to:[18]

$$s^L_{2i} = (1-\beta_i) - \beta_i \, G\left(\theta^L_0, r_0\right) \; r_2^{-1}. \tag{4}$$

Different to models with Diamond Dybvig-type preferences, the supply of cash is not fixed at $t = 2$, but endogenous. It increases in the return from investing, $r_2$, and decreases in the utility weight on early con-

[18] Assumption 3 assures that investing borrowed money at $t = 2$ is not attractive, i.e. $\frac{b^L_{2i}}{r_2+\varepsilon} \, r_2 < b^L_{2i}$.

sumption, $\beta_i$. The positive dependency of the supply of cash on $r_2$ is at the core of an amplification link between adverse selection and the intensity of fire sales that is discussed in section 3.2.2.

**Illiquid investors**

*Illiquid investors* must decide at $t = 2$ on how many individual long-term loans to securitize and sell in the opaque and transparent market segment (or to privately liquidate) to obtain funding, and on how much to borrow in the collateralized credit market. The problem of an *illiquid investor* of type $i$ writes:

$$\max_{\substack{0 \leq s_{2i}^I \leq 1, b_{2i}^I \leq \theta_1^I, 0 \leq d_{2i}^I \leq 1 \\ 0 \leq d_{2iG}^I \leq 1, 0 \leq d_{2iB}^I \leq 1}} \left\{ \beta_i \, log\left(c_{2i}^I\right) + (1-\beta_i) \, log\left(c_{3i}^I\right) \right\} \tag{5}$$

$$\begin{aligned} s.t. \quad c_{2i}^I &= \left( (1-q) \, \tfrac{ER}{r_2} \, d_{2i}^I + \tfrac{b_{2i}^I}{r_2} + q \left( \alpha d_{2iB} \, \check{p}_B + (1-\alpha) \, d_{2iG} \, \check{p}_G \right) \right) \left(1 - s_{2i}^I\right) \\ c_{3i}^I &= \begin{pmatrix} \frac{c_{2i}^L}{1-s_{2i}^I} \, s_{2i}^I \, r_2 + (1-q) \, ER \left(1 - d_{2i}^I\right) - b_{2i}^I + G\left(\theta_0^I, r_0\right) \\ +q\left(\alpha \left(1 - d_{2iB}^I\right) R_B + (1-\alpha)\left(1 - d_{2iG}^I\right) R_G\right) \end{pmatrix}, \end{aligned}$$

where $\check{p}_G \equiv max\left\{p = \frac{a}{r_2}, \ell_G\right\}$ and $\check{p}_B \equiv max\left\{p = \frac{a}{r_2}, \ell_B\right\}$. The choice variable $s_{2i}^I$ captures the fraction of available cash resources supplied to the market by an illiquid investor. The choice variable $d_{2ih}^I$ captures the fraction of opaque long-term assets of quality $h = B, G$ that are sold or privately liquidated by an illiquid investor with preferences $i = E, L$. Similarly, $d_{2i}^I$ captures the fraction of transparent long-term assets that are sold. Finally, the choice variable $b_{2i}^I$ captures the amount borrowed in the collateralized credit market.

Given that illiquid investors have the option to either sell or privately liquidate their assets, one has to distinguish between two cases. If $p > \ell_G$, they are willing to sell the *opaque* long-term assets of good quality in the market to raise $pd_{2iG}^I = \frac{a}{r_2} d_{2iG}^I$ units of cash. Instead, if $p \leq \ell_G$, they weakly prefer private liquidation and raise $\ell_G d_{2iG}^I$ units of cash. For simplicity, it is assumed that good quality opaque assets are privately liquidated as opposed to securitized and sold in the market if $p = \ell_G$.[19] Hence, pooling in the opaque market cannot be supported if $p \leq \ell_G$.

The first-order necessary condition associated with the problem in (5) and further derivations can be found in Appendix B.1. Suppose there exists a pooling equilibrium, i.e. $p > \ell_G$, which requires that $d_{2EG}^I$ is

[19] This simplification rules out the existence of equilibria with *partial* pooling, where good types are indifferent whether to sell or not. The key insights of the paper are not affected by this simplification. See Bertsch (2012) for a discussion of equilibria with partial pooling in a related model.

interior. Then there is a natural pecking order. Early types prefer to finance through markets not affected by asymmetric information where they do not face a discount. Hence, $d^I_{2EB} = d^I_{2E} = 1$, $b^I_{2E} = \theta^I_1$ and:

$$d^I_{2EG} = \frac{\beta_E \left( q + \frac{G\left(\theta^I_0, r_0\right) - \theta^I_1}{R_G} \right) - q\alpha - (1-\beta_E) \left( (1-q)\ \frac{ER}{a} + \frac{\theta^I_1}{a} \right)}{q(1-\alpha)}. \tag{6}$$

Early types shed more opaque assets if $\beta_E$ increases. Interestingly, $d^I_{2EG}$ is independent of the average quality traded if $\theta^I_1 = 0$. Interiority of $d^I_{2EG}$ and $s^L_{2i}$ requires that the trade-off between consuming at dates $t=2$ and $t=3$ is preserved for both liquid and illiquid investors of early type. Accordingly, $\beta_E$ and $G\left(\theta^I_0, r_0\right)$ cannot be too large. Condition 1 assures that $s^L_{2i} > 0\ \forall i = E, L$ and $d^I_{2EG} < 1$. Lemma 2 provides a necessary condition for a pooling equilibrium to exist, which also constitutes a sufficient condition for $d^I_{EG} > 0$.

**Condition 1:** $\beta_E < \min\left\{ \frac{1}{1+G(0,1)}, \frac{1-q(1-\alpha)}{1+G(0,1)/R_G} \right\}$.

Similarly, it can be shown for late types that $d^I_{2LB} = 1$ and $d^I_{2LG} = d_{2E} = 0$. Recall the epsilon-cost associated with borrowing (Assumption 3). Hence, late types do not access the collateralized credit market and select $b^I_{2E} = 0$ and $s^I_{2E} = q\,\alpha \frac{a}{r_2}$.

#### 3.2.2 Financial market equilibria at date t=2

The interest of this paper is to analyze under which conditions a pooling equilibrium exists. Notwithstanding, (welfare inferior) equilibria with a breakdown of pooling always co-exists, as it is usual in adverse selection models. Under pooling, the average quality of assets traded in the opaque market segment at $t=2$ is defined as follows.

**Average quality of assets**

$$a = \frac{\alpha\, R_B + \lambda(1-\alpha)\, R_G\, d^I_{2EG}}{\alpha + \lambda(1-\alpha)\, d^I_{2EG}}. \tag{7}$$

Equation (7) implicitly defines the average quality as a function of $\theta^I_1$, $\theta^I_0$, and $r_0$.[20] Interestingly, $a = a\left(\theta^I_1, \theta^I_0, r_0\right)$ does not depend on $t=2$ prices and the aggregate level of cash in the economy provided $a \geq p > \ell_G$. This contrasts with models in which short-term funding is perfectly elastic, such as in Malherbe (2014). In Lemma 1 of Malherbe (2014), the author employs a model with a perfectly elastic supply of cash and demonstrates that investments in storage present a negative externality. This contrasts with my model

[20]Equation (7) has more than one solution of which the one with the higher value is relevant, since the interest is in a scenario with a pooling equilibrium where $a\left(\theta^I_1, \theta^I_0, r_0\right) > \ell_G$.

with cash-in-the-market pricing where the demand for cash is inelastic for prices above $\ell_G$, while the supply of cash is imperfectly elastic (equation (4)) leading to a novel amplification of fire sales, which is discussed at the end of this section. Here higher aggregate cash holdings do not pose a negative externality. On the contrary, they are beneficial due to under-investments in cash (Proposition 6).

In the subsequent analysis, it is critical to understand how the average quality of assets traded depends on the borrowing constraint and key exogenous parameters of the model. Of particular interest is the dependency of $a$ on the tightness of the borrowing constraint. One can show that $a$ tends to decrease in $\theta_1^I$, $\theta_0^I$ and $r_0$. Conversely, $a$ tends to increase in $q$ and $R_B$. These results are intuitive: a better ability of illiquid investors to borrow reduces the sales of good quality opaque assets and thereby amplifies the adverse selection problem. In the extreme, if the average quality of traded assets is depressed by too much, then a pooling equilibrium cannot exist. The results are summarized formally in Lemma 2.

**Lemma 2.** (Average quality of assets traded in the opaque market segment)

**(a)** *A necessary condition for a pooling equilibrium to exist is given by:*

$$\frac{\alpha R_B+\lambda(1-\alpha)R_G\, d_{2EG}^I\big|_{a=\ell_G}}{\alpha+(1-\alpha)\lambda\, d_{2EG}^I\big|_{a=\ell_G}} > \ell_G. \tag{8}$$

**(b)** *The partial derivatives are* $\frac{\partial a}{\partial \theta_0^I} < 0$, $\frac{\partial a}{\partial \theta_1^I} < 0$, $\frac{\partial a}{\partial r_0} < 0$, $\frac{\partial a}{\partial q} > 0$, *and* $\frac{\partial a}{\partial R_B} > 0$ *provided* $\alpha$ *is sufficiently small, or if* $q$ *is sufficiently large and* $R_G \leq 2\ell_G$.

*Proof.* See Appendix B.2.

Result *(b)* of Lemma 2 prescribes that $\frac{\partial a}{\partial \theta_0^I} < 0$. This result shows to be a crucial element of the detrimental feedback loop between deleveraging and adverse selection. Intuitively, a better access to alternative markets makes illiquid investors less reliant on raising funding in the opaque market segment. Similarly, a lower quality of lemons (a smaller $R_B$) and a larger size of the transparent market segment (a smaller $q$) also amplifies the adverse selection problem. Notably, the sufficient conditions (either $\alpha$ small or, instead, $q$ large and $R_G \leq 2\ell_G$) show to be mild and are satisfied for a large parameter range. Intuitively, they ensure that the adverse selection problem is not too strong and that the possibility of a breakdown of pooling has bite (i.e. a value of $\ell_G$ that is not too low relative to $R_G$).

**Market-clearing at date t=2** Taken together, the trading decisions derived in section 3.2.1 yield a market-clearing condition. Given the co-existence of different asset market segments, it is useful to express everything in terms of units of cash. For markets to clear, the supply of cash must be weakly larger than the demand: $S(p) \geq D(p)$. Both supply and demand depend on $f$, the endogenous fraction of liquid investors, and on $m_2$, the cash held by outside financiers at date $t = 2$:

$$\overbrace{m_2 + f\left[\lambda s_{2E}^L + (1-\lambda) s_{2L}^L\right]}^{\text{(net) supply of cash}} = \underbrace{(1-f)\lambda\left[(1-q)\frac{ER}{r_2}d_{2E}^I + q\frac{a}{r_2}\left(\alpha d_{2EB}^I + (1-\alpha) d_{2EG}^I\right) + \frac{b_{2E}^I}{r_2}\right]}_{\text{(net) demand for cash}} \tag{9}$$

After solving for $r_2$, the results can be summarized as follows.

**Lemma 3.** (Market-clearing at $t = 2$)

**(a)** *If a pooling equilibrium exists (i.e. Condition 1 holds and $a \geq p > \ell_G$), then the market-clearing interest rate is:*

$$r_2 = \frac{a}{p} = \max\left\{1, \frac{G\left(\theta_0^I, r_0\right)\frac{a}{R_G} + \left(1 - \frac{a}{R_G}\right)\theta_1^I + qa + (1-q)ER + \frac{f\,G\left(\theta_0^L, r_0\right)}{1-f}}{(m_2 + f(1-\lambda\beta_E))/(\lambda\beta_E(1-f))}\right\}. \tag{10}$$

**(b)** *If the solution is interior (i.e. $a > p > \ell_G$), then the partial derivatives are $\frac{\partial r_2}{\partial \theta_0^I} < 0$, $\frac{\partial r_2}{\partial \theta_0^L} < 0$, $\frac{\partial r_2}{\partial \theta_1^I} > 0$, $\frac{\partial r_2}{\partial r_0} < 0$, $\frac{\partial r_2}{\partial q} < 0$, $\frac{\partial r_2}{\partial R_B} = 0$, and $\frac{\partial r_2}{\partial a} > 0$. Provided $m_2$ is sufficiently small, then:*

$$\begin{cases} \frac{\partial r_2}{\partial f} < 0,\ \frac{\partial p}{\partial f} > 0 & if\ p \in [\ell_G, a) \\ \frac{\partial r_2}{\partial f}, \frac{\partial p}{\partial f} = 0 & if\ p = a. \end{cases}$$

*Proof.* Equation (10) follows from (9) after plugging in the demand and supply schedules. If the solution to the pricing function is such that $p = \frac{a}{r_2} > a \Leftrightarrow r_2 < 1$, then the market-clearing prices are given by $r_2 = 1 \Leftrightarrow p = a$ (corner). Instead, if $p \leq \ell_G$, then a pooling equilibrium cannot be supported because $d_{2EG}^I = 0$. See Appendix B.3 for the proof of result *(b)* when $p(r_2, a) > \ell_G$.

Figure 2 in Appendix A gives a graphical illustration of the market-clearing at $t = 2$ under pooling (left graph). Notice that the demand for cash is increasing in $p$ as the (constant) fraction of assets sold is more valuable. Conversely, the supply of cash is decreasing in $p$. Furthermore, when $p$ falls short of $\ell_G$ the supply vanishes for all $p \in (R_B, \ell_G]$. This is because no good quality opaque assets are traded if $p \leq \ell_G$.

Following Allen and Gale (2007), I refer to cash-in-the-market pricing (CIMP) when the equilibrium asset prices are below the "fundamental values" of assets (i.e. if $p < a$) due to an aggregate shortage of cash.[21] CIMP manifests itself because the cash available in the economy is endogenous and, therefore, the supply of short-term funding is limited (low elasticity; bounded supply). Characteristically for CIMP, the interest rate is inversely related to the aggregate supply of cash, i.e $\frac{dr_2}{df} < 0$. Again, the sufficient condition shows to be mild and satisfied for a large parameter range. Intuitively, the level of cash $m_2$ held by outside financiers at date $t = 2$ cannot be too large, in order to preserve CIMP. Otherwise, there would be no incentive for a private liquidity supply by investors (i.e. $f = 0$ and $r_2 = 1$).

A novelty is the amplifying link between adverse selection and the intensity of fire sales. To see this, recall the dependency of the supply of cash on $r_2$ (equation (4)). Notice from equation (10) that a deterioration in $a$ causes, ceteris paribus, a downward pressure on the price $p$ in the opaque market due to an endogenous reduction of the market supply of cash, thereby amplifying fire sales. Such a link would not arise in a standard model without an inter-temporal trade-off for early types, i.e. if $\beta_E = 1$.

### 3.2.3 Liquidity management at date t=1

Next, consider the liquidity management at $t = 1$. Investors decide whether they want to become *liquid investors*, who (together with the outside financiers) will be the natural providers of cash at $t = 2$, or *illiquid investors,* who will be the natural demanders of cash at $t = 2$. The focus is on rational expectations equilibria in which investors form correct perceptions about future prices and the average quality of assets traded in the opaque market segment at $t = 2$. First, I characterize the equilibrium for the benchmark case $q = 0$ without the opaque market segment. Thereafter, the general case with $q > 0$ is analyzed.

**The benchmark case when all assets are transparent: q=0** Here the individual qualities of all assets are publicly know. Thus, there is no adverse selection and the $t = 2$ problem of illiquid investors simplifies.

Given Assumption 3, the early types finance exclusively through the asset market. Therefore, $b^j_{2i} = 0 \; \forall i, j$ and $d^I_{2E} = \beta_E \left(ER + G\left(\theta^I_0, r_0\right)\right) ER^{-1}$. Hence:

$$\begin{aligned} c^I_{3E} =& \quad (1-\beta_E)\left(ER + G\left(\theta^I_0, r_0\right)\right) = (1-\beta_E)\, c^I_{3L} = \beta_E^{-1}(1-\beta_E)\, c^I_{2E}\, r_2 \\ c^L_{3E} =& \quad (1-\beta_E)\left(r_2 + G\left(\theta^L_0, r_0\right)\right) = (1-\beta_E)\, c^L_{3L} = \beta_E^{-1}(1-\beta_E)\, c^L_{2E}\, r_2. \end{aligned}$$

[21] Cash-in-the-market pricing means that long-term assets trade at a discount when compared to their expected return in the final period, which is itself determined by the average quality of assets traded ("fundamental value").

As a result, the unique interest rate making investors indifferent at $t = 1$ whether to become liquid or illiquid investors is $r_2^* = ER$. In equilibrium, it must be true that $r_1 = r_2$.[22] Hence, from market-clearing $f$ solves:

$$f^* = \quad (1-f)\,\lambda\beta_E\left(ER+G(\theta_0^I,r_0)\right)ER^{-1}+f\lambda\beta_E\left(ER+G(\theta_0^L,r_0)\right)ER^{-1}-m_2,$$

which takes on an interior solution provided that $m_2 = m_1$ is sufficiently small. For given $t = 0$ choices, the $t = 1$ equilibrium is both *unique* and *efficient*. This results change drastically when an opaque market segment is introduced (Proposition 6).

**The general case: q>0** For the general case, the $t = 1$ problem of investors needs to be examined more carefully. Investors face a discrete choice at $t = 1$ described by $x \in \{0,1\}$. They either become *liquid investors* and store their entire endowment ($x = 0$) or they become *illiquid investors* and fully invest their resources at $t = 1$ in risky long-term assets ($x = 1$). In other words, investors operate at the extensive margin and the problem mirrors an occupational choice. Consistent with the occupational choice character, it is assumed that illiquid investors must fully invest their available resources at $t = 1$ in risky long-term assets, which precludes a partial repayment of credit, i.e. $b_1^I \geq 0$.[23] As a result, the $t = 1$ problem can be simplified by setting $b_1^I = 0$. This is because $b_1^I > 0$ would result in an undesirable increase in the exposure of illiquid investors to utility-reducing illiquid investments.

The simplified investors' maximization problem reads:

$$\max_{x\in\{0,1\},b_1^L\leq\frac{\theta_0^L}{r}} \left\{x\,V\left(c_{2E}^I,c_{3E}^I,c_{3L}^I\right)+(1-x)\;W\left(c_{2E}^L,c_{3E}^L,c_{3L}^L\right)\right\} \tag{11}$$

s.t.

$$V(\cdot)=\lambda\left[\beta_E\;log\left(c_{2E}^I\right)+(1-\beta_E)\;log\left(c_{3E}^I\right)\right]+(1-\lambda)\;log\left(c_{3L}^I\right)$$
$$W(\cdot)=\lambda\left[\beta_E\;log\left(c_{2E}^L\right)+(1-\beta_E)\;log\left(c_{3E}^L\right)\right]+(1-\lambda)\;log\left(c_{3L}^L\right)$$

Recall that the superscripts $j = I, L$ correspond to *illiquid* and *liquid investor*s, respectively. Preferences are

[22] If $r_1 > r_2$ then both outside financiers and investors do not want to hold any cash at $t = 1$. Conversely, if $r_1 < r_2$, then the $t = 1$ credit market does not clear because outside financiers would like to borrow unbounded amounts.

[23] This assumption follows directly from the restriction to the occupation choice-type problem at $t = 1$. A modeling approach chosen to simplify the analysis without affecting the key insight. Absent this additional assumption illiquid investors could overcome the restriction imposed by the occupation choice problem by (partially) repaying their credit from $t = 0$ and, thereby, effectively varying their portfolio liquidity continuously.

Note that in a model with continuous portfolio choice this issue does not arise. Here the equilibrium interest rate is such that investors are indifferent (at the intensive margin) between investing more into long-term assets or cash. Given such an interest rate nobody would want to partially repay credit from date $t = 0$, provided collateralized credit comes at $\varepsilon$ cost while storage is costless.

captured by the subscripts $i = E, L$. The supply and demand schedules ($s_E^L$, $d_{iG}^I$) are derived in section 3.2.1. After plugging in the consumption terms $b_1^L$ drops out. Hence, we can simply set $b_1^L = 0$, which implies that all the cash carried over into $t = 1$ by outside financiers can be made available for $t = 2$, i.e. $m_1 = m_2$. At $t = 1$, $\theta_0^L$ and $\theta_0^I$ are predetermined and taken as given. They can potentially differ for investors who expect to become an *illiquid* or *liquid investor* at $t = 1$.[24] Thus, we can set $\theta_1^L = \theta_0^L$ and $\theta_1^I = \theta_0^I$.

In a pooling equilibrium, investors have to be indifferent between becoming an *illiquid* or *liquid investor*. The equilibrium fraction of *liquid investors* $f$ solves:

$$V(r_2(f)) = W(r_2(f)). \tag{12}$$

Let $\widehat{f}$ be the solution to equation (12).

**Lemma 4.** (Uniqueness) *Provided $\alpha$ or $\beta_E$ is sufficiently small and provided that a pooling equilibrium in the date $t = 2$ market exists (i.e. $a \geq p > \ell_G$), then the solution $\widehat{f}$ to equation (12) is unique.*

*Proof.* See Appendix B.4.

The proof rests on a single-crossing property. Illiquid investors gain from a higher level of liquidity in the economy, while liquid investors loose, i.e. $\frac{\partial V}{\partial f} > 0$ and $\frac{\partial W}{\partial f} < 0$. As before, the result is guaranteed to hold if either $\alpha$ or $\beta_E$ is sufficiently small. The sufficient condition is mild and satisfied for a large parameter range.

Three types of equilibria can be distinguished: *(i)* a *"pooling equilibrium"*, where both *good* and *bad types* sell in the opaque market segment, i.e. $\ell_G < p \leq a$. Their existence requires that the pricing function in (10) yields an internal solution when evaluated at $\widehat{f}$. Moreover, there *always* exists either *(ii)* equilibria characterized by a *"breakdown"* of pooling where the good types prefer to privately liquidate their high quality assets instead of selling them in the opaque market, i.e. $p \leq \ell_G$, or *(iii)* equilibria characterized by *"liquidity hoarding"* where all investors store cash, i.e. $f^* = 1$.

**Proposition 5.** (Equilibrium at $t = 1$: existence and characterization) *For given $\theta_0^j$, $G\left(\theta_0^j, r_0\right)$ and $m_1$ there:*

**(a)** *exists a pooling equilibrium if and only if $\ell_G < p = \frac{a\left(\theta_1^I, \theta_0^I, r_0\right)}{r_2\left(a, \hat{f}; \theta_1^I, r_0, \theta_0^I, \theta_0^L\right)} \leq a\left(\theta_1^I, \theta_0^I, r_0\right)$; provided $\alpha$ or $\beta_E$ sufficiently small, it is characterized by $f^* = \widehat{f}$ and $p_G^* = p_B^* \frac{R_G}{R_B} = \frac{R_G}{r_2\left(a, \hat{f}; \theta_1^I, r_0, \theta_0^I, \theta_0^L\right)} \leq R_G$, which holds with strict inequality if $p < a$*

[24] This is because investors can correctly anticipate at $t = 0$ what their desired liquidity choice will be at $t = 1$ and, thus, adjust their leverage choice accordingly depending on their type $j$. Notably, the potential heterogeneity in $\theta s$ does not arise in an alternative setup with a continuous portfolio choice at $t = 1$. However, the key insights are unaffected.

**(b)** *exists a liquidity hoarding equilibrium if* $\frac{a\left(\theta_1^I,\theta_0^I,r_0\right)}{r_2\left(a,\hat{f};\theta_1^I,r_0,\theta_0^I,\theta_0^L\right)} > a\left(\theta_1^I,\theta_0^I,r_0\right) \geq \ell_G$*, characterized by* $f^* = 1$ *and* $p_G^* = p_B^* \frac{R_G}{R_B} = R_G$

**(c)** *always exists an equilibrium where pooling in the opaque asset market segment breaks down, characterized by* $f^* \in [0,1]$ *and* $p^* \in [0, R_B]$,

*where* $a = a\left(\theta_1^I,\theta_0^I,r_0\right)$ *is implicitly defined by equation (7).*

*Proof.* The proof of result *(a)* follows from Lemma's 2, 3 and 4. See Appendix B.5 for the proof of results *(b)* and *(c)*.

This concludes the discussion of the existence and characterization of $t = 1$ equilibria. Notably, a liquidity hoarding equilibrium is unlikely to occur and becomes impossible when $q$ is small. This is because investors typically rely on market liquidity provision even in the event when one market segment breaks down. In what follows, I analyze the efficiency of the liquidity management for the general case $q > 0$.

### 3.3 Efficiency at date t=1: a second-best benchmark

This section constructs a second-best benchmark to analyze efficiency for the general case $q > 0$. That is, the efficiency of the liquidity management at $t = 1$ for a given leverage choice at $t = 0$. From before we know that the $t = 1$ equilibrium is efficient for the special case when $q = 0$. In what follows, I consider the problem of a constrained planner who can manipulate $f$ at $t = 1$ but who cannot infer with markets. Using an envelope-type argument, I examine whether a constrained planner would select a level of $f$ different from the one found in the decentralized equilibrium. The result is summarized in Proposition 6 and builds on Lemma 3.

**Proposition 6.** (Efficiency at $t = 1$) *For a given leverage choice at date* $t = 0$ *that satisfies* $\theta_0^L \leq \theta_0^I$*, pooling equilibria are characterized by an inefficient under-investment in cash.*

*Proof.* See Appendix B.6.

**Intuition** Equilibria characterized by pooling in the opaque market segment are inefficient relative to the second-best benchmark. The private information problem, in combination with incomplete ex-ante risk markets, is at the root of this inefficiency.[25] Due to a trading-on-private-information motive, illiquid investors with bad quality assets can gain from private information even if they do not have a liquidity need. Instead, liquid and illiquid investors with a liquidity need loose. The direction of the inefficiency depends crucially on the comparison between these gains and losses. A tendency for inefficient under-investment in cash prevails. This result holds under the conjecture that $\theta_0^L \leq \theta_0^I$, which will be verified in the next section, where also the efficiency of the leverage choice will be discussed.

### 3.4 Leverage choice at date t=0

This section discusses the leverage choice at $t = 0$ and includes the main results of the paper. The aim is to understand the interplay of this leverage choice with the intensity of adverse selection in the opaque asset market segment at $t = 2$. In section 3.4.1, I start with a discussion of the special case where all long-term assets are transparent, i.e. $q = 0$. Thereafter, I move to the general case, i.e. $q > 0$, and discuss intuitively (section 3.4.2) and analytically (section 3.4.3) how incentives emerge for selecting a positive spare borrowing capacity at $t = 0$, which creates a tension between leverage and adverse selection. Thereby, paving the way for section 3.4.4, which establishes the existence of a detrimental feedback loop between deleveraging and adverse selection.

#### 3.4.1 The benchmark case when all assets are transparent: q=0

The main results on the efficiency of the $t = 0$ leverage choice are summarized in Proposition 7. Interestingly, the inefficient under-investment in cash at the interim stage that was established in Proposition 6 for the general case $q > 0$ can be enforced when leverage is taken into account. This is because an increase in $f$ reduces not only future interest rates but also $r_0$, thereby, increasing the size of the leveraged investment $G$. Proposition 7 analysis this effect in isolation by focusing on the special case $q = 0$ where individual long-term asset qualities are publicly know.

**Proposition 7.** (Existence, uniqueness and efficiency of a $t = 0$ equilibrium if $q = 0$) *Provided Condition 1 holds and:*

$$\frac{\gamma\rho\kappa}{ER-\gamma\rho} \leq m_0 < \frac{\gamma\rho\kappa}{ER-\gamma\rho} + \lambda\beta_E \ (ER + G(O,ER))\, ER^{-1} \tag{13}$$

[25] See also Gale and Yorulmazer (2013) or Bertsch (2012) for related papers featuring a constrained inefficient liquidity choice due to incomplete ex-ante risk markets and private information.

*is satisfied, then there exists a unique equilibrium characterized by* $\theta_0^{L,I*} = 0$*,* $r_2^* = ER$*, and* $f^* < 1$*. While the leverage choice* $\theta_0^{L,I*} = 0$ *is always efficient, the liquidity management is constraint efficient under the sufficient condition:*

$$\left[\frac{\rho^2\ (1-\gamma)}{(1-\gamma\rho)^2}\ \frac{ER^2}{\lambda\beta_E\ (1-\lambda\beta_E)(ER+G(0,r_0))}\right]\gamma\kappa \leq ER-1. \tag{14}$$

*Proof.* See Appendix B.7.

There exists a unique equilibrium where all investors (efficiently) lever up to the constraint at $t = 0$ provided Condition 1 and inequality (13) hold. Condition 1 ensures the existence of an inter-temporal trade-off for illiquid investors of the early type at $t = 2$. Furthermore, the right-hand side of inequality (13) ensures a scarcity of cash in the aggregate (cash-in-the-market pricing) while the left-hand side of (13) ensures that the resources of outside financiers are sufficient to finance all investments at $t = 0$. Hence, investors face an *inter-temporal trade-off* and a *liquidity trade-off.* Notice that $f^* < 1$ is guaranteed from Condition 1. If $m_1 = m_2 = m_0 - \frac{\gamma\rho\kappa}{ER-\gamma\rho}$ is large, implying that the supply of cash by outside financiers is abundant, then inequality (13) is violated and $f^* = 0$. It is in this way, that my model nests models with a perfectly elastic supply of cash à la Malherbe (2014).

Consider a constrained planner who can subsidize or tax investments at dates $t = 0,1$ by honoring a balanced intra-period budget. The equilibrium is constrained efficient if the leveraged investments are not too large. Inequality (14) reveals that this is the case if $\gamma\kappa$ is sufficiently small relative to the loss, $ER-1$, from forgone investments in long-term assets at $t = 1$ due to the increase in $f$. Conversely, if inequality (14) is violated, then a tendency for an inefficient under-provision of liquidity prevails. The inefficiency arises due to the inability of investors to borrow against future endowments. Constrained investors do not internalize at $t = 1$ how their individual liquidity management affects the financing conditions at $t = 0$, which depend on the endogenous interest rate (Lorenzoni 2008, Korinek 2012).

Interestingly, the results of Proposition 7 on the leverage choice change drastically when $q > 0$. This is discussed in the subsequent sections.

### 3.4.2 The general case: q>0

Recall that the return on the leveraged long-term investment project is decreasing in the spare borrowing capacity and in the interest rate at $t = 0$. In a rational expectations equilibrium, investors correctly anticipate the future measure $f$ of liquid investors at $t=1$, as well as market prices and the average quality of assets traded at $t=2$. Furthermore, they anticipate their individual liquidity choice at $t=1$. As a result, investors who expect to become liquid investors at $t=1$ select $\theta_0^{L*}=0$ as long as Condition 1 holds. Instead, investors who expect to become illiquid investors may reduce leverage at $t=0$ because of future benefits from $\theta_0^I>0$. To see this, consider their problem at $t=0$:

$$\max_{\substack{0\leq\theta_0^I \\ \theta_0^I\leq\gamma\kappa\rho}} \left\{ \begin{array}{c} \lambda\beta_E\, log\left[\beta_E\chi\frac{a}{r_2}\right]+\lambda\left(1-\beta_E\right)\, log\left[\left(1-\beta_E\right)\chi R_G\right] \\ +\left(1-\lambda\right)\, log\left[G\left(\theta_0^I,r_0\right)+\left(1-q\right)ER+q\left(\alpha a+\left(1-\alpha\right)R_G\right)\right] \end{array} \right\} \tag{15}$$

where $\chi\equiv\frac{R_G-a}{R_G}\frac{\theta_0^I}{a}+\frac{G\left(\theta_0^I,r_0\right)}{R_G}+\frac{qa+(1-q)ER}{a}$. The payoffs are the same as in section 3.2.3.

**Key trade-off** The payoff of early types is increasing in $\theta_1^I$ if $1-\frac{a}{R_G}+\partial G/\partial\theta_0^I>0$. Hence, illiquid investors install spare borrowing capacity at $t=0$, i.e. select $\theta_0^I>0$, when the appropriately weighted benefit of reducing leverage, $1-\frac{a}{R_G}>0$, outweighs the cost, $\partial G/\partial\theta_0^I<0$. Lemma 8 presents a formal condition.

### 3.4.3 Results on leverage

**Lemma 8.** (Leverage choice) *Provided the sufficient conditions of Lemma 2(b) are met, and provided a pooling equilibrium exists at date $t=2$, then, for a given $r_0$, individual investors optimally select $\theta_0^I>0$ whenever the cost of reducing leverage is not too high, i.e. if:*

$$-\frac{\partial G\left(0,r_0\right)}{\partial\theta_0^I}\leq\frac{\lambda\left(1-\frac{a(0,0;G(0,r_0))}{R_G}\right)}{1-\lambda\left(1-\frac{a(0,0;G(0,r_0))}{R_G}\right)}, \tag{16}$$

*where $a\left(0,0;G\left(0,r_0\right)\right)$ is implicitly defined by equation (7).*

*Proof.* See Appendix B.8.

Observe that the sufficient condition in Lemma 8 is more relaxed, the higher the value of $\lambda$. Intuitively, a higher likelihood of being the early type makes it more important for illiquid investors to shield themselves against adverse selection in the opaque asset market segment by holding spare borrowing capacity. As said earlier, the term $1 - \frac{a}{R_G}$ captures the benefit from being able to reduce high quality asset sales in the opaque market by having better access to alternative financing. Notice that $r_0$ in inequality (16) is determined from the problem at $t = 1$ and from market clearing, after imposing $\theta_0^I = \theta_0^L = 0$.

It turns out that the incentive for an individual illiquid investor to select a positive spare borrowing capacity is increasing in the leverage choice of other investors. In other words, I find a strategic complementarity in leverage choices which is stated formally in Proposition 9. Let $\hat{\theta}_{0,n}^I\left(\theta_{0,-n}^I\right)$ be the optimal $\theta_{0,n}^I$ chosen by investor $n$ as a function of other investors' choice $\theta_{0,-n}^I$.

**Proposition 9.** (Strategic complementarity in leverage choices) *Provided a pooling equilibrium exists at date $t = 2$, and provided the inequality in Lemma 8 holds, then there is a strategic complementarity in leverage choices, i.e.:*

$$\begin{cases} \frac{d\hat{\theta}^I\left(\theta_{-n}^I, k_{-n}^I\right)}{d\theta_{-n}^I} > 0 & \forall\ \hat{\theta}^I < \theta_{max}^I \equiv \gamma\kappa\rho \\ \frac{d\hat{\theta}^I\left(\theta_{-n}^I, k_{-n}^I\right)}{d\theta_{-n}^I} = 0 & if\ \hat{\theta}^I = \theta_{max}^I \end{cases} \tag{17}$$

*if $\kappa$, $\beta_E$ sufficiently small, $q$ sufficiently large, and $R_G \leq 2\ell_G$.*

*Proof.* See Appendix B.9.

The idea of the proof is to establish the existence of a strategic complementarity in leverage choices that builds on the results from Lemmas 2, 3 and 8. Although the proof is analytically involved, the set of sufficient conditions allows for a very intuitive explanation of the underlying mechanism. For the desired result to arise, a sufficiently high intensity of the adverse selection problem is needed in order to provide incentives for investors to deleverage. This is achieved with the help of the restrictions on $\kappa$, $\beta_E$ and $q$. A sufficiently large value of $q$ ensures that the opaque market segment is sufficiently large and, hence, future distress (a low average quality and, hence, a low price) is a relevant concern for investors at $t = 0$. Furthermore, small values of $\kappa$ and $\beta_E$ lower the quantity of high quality assets sold, $d_{2EG}$, and, hence, guarantee that the adverse selection problem is sufficiently strong. Finally, the possibility of a breakdown of pooling in the opaque market needs to be entertained, which is ensured by $R_G \leq 2\ell_G$.

The strategic complementarity in leverage choices lays the foundations for an inefficiency that is distinct from section 3.4.1. Individuals reduce leverage by too much and do not take into account that this can lead to a breakdown of pooling in the opaque market. How such a scenario can arise is discussed next.

#### 3.4.4 Deleveraging and the severity of adverse selection at date t=2

Based on the previous results, I can establish the main insight of this paper on the existence of a detrimental feedback loop between deleveraging and the intensity of adverse selection in the opaque asset market segment. I find that a more severe adverse selection causes a reduction in leverage, provided the existence of the strategic complementarity in leverage choices established in Proposition 9. The result is formally stated in Proposition 10 below and the focus is on symmetric equilibria, i.e. equilibria where $\theta^I_{0,n} = \theta^I_{0,-n} = \theta^I_0$ for all $n$. The set of conditions is the same as for Proposition 9 and the same interpretation applies. Notably, the stated conditions are sufficient but not necessary for the result in Proposition 10 to hold.

**Proposition 10.** (Detrimental deleveraging) *Consider a pooling equilibrium and suppose that the adverse selection in the opaque asset market segment worsens due to a reduction in $R_B$. A lower $R_B$ causes a:*

**(a)** *reduction in leverage, i.e. $\frac{d\theta^{I*}}{dR_B} < 0$, which further amplifies the adverse selection provided that $\kappa$, $\beta_E$ sufficiently small, $q$ sufficiently large, and $R_G \leq 2\ell_G$, and provided that the inequality in Lemma 8 holds after the reduction of $R_B$.*

**(b)** *breakdown of pooling for a sufficiently strong amplification of adverse selection. Formally, if the p solving market-clearing, when evaluated at $\theta^{I*}$, falls short of $\ell_G$.*

*Proof.* See Appendix B.10.

Proposition 10 demonstrates that the anticipation of a stronger adverse selection in the opaque market due to a decrease in $R_B$ causes deleveraging. However, the deleveraging itself triggers a further reduction in the average quality of assets traded, as shown in Lemma 2(a). This in turn amplifies deleveraging and creates downward pressure on the price of opaque assets, because the relative return for investors purchasing opaque assets has to be sufficiently attractive, when compared to the return on investing in non-opaque assets (see equation (2)).

In the extreme, this detrimental feedback mechanism can lead to a breakdown of pooling in the opaque market when the price falls short of $\ell_G$. The pooling equilibrium ceases to exist due to a drastic deleveraging, causing a substantial welfare loss. In other words, deleveraging intensifies adverse selection and can make it impossible to support a pooling equilibrium that would exist absent deleveraging.[26] In such a scenario,

[26]Recall that the interest of this paper is to analyze under what conditions a pooling equilibrium can exist. However, provided a pooling equilibrium exists, it is always the case that a welfare inferior equilibrium without pooling co-exists (coordination failure). This is due to the adverse selection problem and the strategic complementarity in leverage choices.

the leverage choice is clearly constrained inefficient. Appendix section C provides a numerical example.

The above mechanism can explain how a deterioration in the quality of subprime mortgage-backed securities triggered both a breakdown in opaque subprime markets and a deleveraging wave in the financial crisis of 2007/08. After realizing that subprime markets may come under distress, banks started to adjust their business models. In search of unencumbered high quality collateral, banks began to deleverage. This enabled them to reduce their dependency on refinancing through opaque markets. However, the simultaneous exit further amplified the distress and fire sales in those markets. In the light of these mechanics, section 4 discusses how a policy maker may intervene and prevent a detrimental deleveraging.

# 4 Policy implications

The tension between leverage and adverse selection arises because markets are incomplete and investors have to rely on spot markets. If a policy maker were able to complete markets, the detrimental deleveraging could be avoided. In fact, the first-best allocation could be reached by fully insuring market participants against idiosyncratic risk. However, given the market incompleteness that can be justified by the inability of investors to borrow against future cash endowments and by non-observable and non-verifiable project initiation, a policy maker has to resort to policies that aim at achieving the second-best allocation. Markedly, the policies considered in this section are part of the usual toolkit of central banks and financial regulators. During the financial crisis of 2007/08 several of these policies have been employed to address the breakdown in opaque subprime markets and to mitigate the financial sector deleveraging wave.

In particular, the equilibrium analysis reveals several immediate policy implications. Firstly, a policy maker can counteract the inefficient liquidity management (Proposition 6) by manipulating $f$ through taxing investments in risky long-term assets. Secondly, a policy maker can prevent an inefficient detrimental deleveraging spiral that arises due to a deterioration in the asset quality (Proposition 10) by making deleveraging less attractive at $t = 0$. Thirdly, a policy maker can intervene at $t = 2$ and provide liquidity to markets by purchasing long-term assets trading at fire sale prices.

While the computation of a Pigovian tax to counteract the inefficient liquidity management is standard,[27] the relevant policies to influence the leverage choice at $t = 0$ and to provide public liquidity at $t = 2$ demand further discussion. Of particular interest is how a policymaker who faces a deleveraging wave, can prevent

[27] Liquidity regulation has been discussed extensively in the literature. See Perotti and Suarez (2011) for a Pigovian approach.

the emergence of the detrimental feedback loop described in section 3.4.3? In the remainder, I present three different options available to the policy maker that all aim to increase the costs of reducing leverage, with the goal of preventing excessive deleveraging (as a reaction to anticipated future market distress, which in turn amplifies distress in the opaque market segment).

First, the policy maker can widen the collateral requirements for refinancing at $t = 0$. This policy was used by leading central banks when stepping up their liquidity provision at the beginning of the crisis.[28] In the model such a policy amounts to an increase in $\gamma$, which increases the individual costs of deleveraging $-\frac{\partial G(0,r_0)}{\partial \theta^I_{0,n}}$ and, thereby, discourages deleveraging. From equation (23) in the Proof of Lemma 8, a necessary and sufficient condition that prevents deleveraging is given by:

$$\begin{aligned} \frac{\partial}{\partial \theta^I_{0,n}}\Big|_{\theta^I_{0,n}=0} = \quad & \lambda \, \frac{\frac{R_G - a(0,0;G(0,r_0))}{a(0,0;G(0,r_0))} + \frac{\partial G(0,r_0)}{\partial \theta^I_{0,n}}}{G(0,r_0) + qR_G + (1-q)ER\,\frac{R_G}{a(0,0;G(0,r_0))}} \\ & + (1-\lambda)\,\frac{\frac{\partial G(0,r_0)}{\partial \theta^I_{0,n}}}{G(0,r_0) + q(\alpha\, a(0,0;G(0,r_0)) + (1-\alpha)R_G) + (1-q)ER} < 0. \end{aligned} \tag{18}$$

The first-order effect of an increase in the cost of deleveraging, $\frac{\partial G(0,r_0)}{\partial \theta^I_{0,n}} > 0$, works in favor of inequality (18). However, the second-order effects via general equilibrium prices and the quality of assets traded, as well as the effects through $\frac{\partial G(0,r_0)}{\partial \gamma} > 0$, are more difficult to assess. In the framework of the numerical example from Appendix section C, the first-oder effects prevail. To see this, consider the case of $R'_B = 0$ where the pooling equilibrium ceases to exist. Now, consider a widening of collateral requirements from $\gamma = 1/3$ to $\gamma' = 1/2$. Such an intervention restores pooling by preventing the detrimental feedback loop from materializing: $r^* \approx 1.24$, $a^* \approx 0.96$ and $p^* \approx 0.77 > \ell_G = \frac{2}{3}$.

Second, if the policy maker has any means by which to reduce either the asymmetric information problem at $t = 2$ or the number of lemons in the market,[29] then a credible commitment to achieving these goals can prevent a detrimental deleveraging wave. Again, this is because deleveraging at $t = 0$ is discouraged (see equation (16) in Lemma 8) as the benefit from installing a positive spare borrowing capacity is smaller, the higher $a$. The first-order effect of such a policy is a decrease in $\frac{R_G - a}{a}$, which works in favor of inequality (24). Again, second-order effects via general equilibrium prices are difficult to assess. However, in the framework of the numerical example from Appendix section C, the first-oder effect prevails. To see this, consider the case of $R'_B = 0$ and an increase in the size of the opaque market segment from $q = \frac{9}{10}$ to $q' = 1$.

[28] See, for example, Cecchetti (2009)'s description of the Federal Reserve's Term Auction Facility.
[29] E.g. with the help of public bank stress tests and asset purchases like during the Troubled Asset Relief Program in 2008/09.

Again, the pooling equilibrium is restored by preventing the detrimental feedback loop from materializing: $r^* \approx 1.24$, $a^* \approx 0.95$ and $p^* \approx 0.76 > \ell_G = \frac{2}{3}$. This highlights the ambitious role played by transparency. Here, more opacity is beneficial, as it helps to restore a pooling equilibrium. This contrasts with the negative implications of opacity related to the constrained inefficiency of the liquidity management (Proposition 6).

Third, the policy maker can also discourage deleveraging by influencing market prices (i.e. by reducing $r_0$ and thus increasing $-\frac{\partial G(0,r_0)}{\partial \theta_{0,n}^I}$) through liquidity provisions at dates $t = 0$ or $t = 2$. If fully anticipated, the timing of such a liquidity provision is not relevant. However, observe that any public liquidity provision is exactly offset by a reduction in private liquidity provision. Since $dV(f)/df > 0$ and $dW(f)/df < 0$, any public liquidity provision must trigger an increase in the number of illiquid investors that completely offsets the intervention. Consequently, a central bank can only restore market functioning if it fully crowds out the private liquidity supply, thereby "becoming in effect the lender of first resort" (Gale and Yorulmazer 2013, page 291).

# 5 Conclusion

This paper presents a novel feedback mechanism which explains how deleveraging and the intensity of adverse selection in opaque asset markets can fuel each other, as in the global financial crisis of 2007/08. At the core of the mechanism is an interplay between adverse selection in opaque asset markets and the incentives to reduce leverage. These incentives for deleveraging arise because illiquid investors want to become less reliant on opaque asset markets for their liquidity management whenever the intensity of adverse selection is expected to be higher.

The model features both, an inefficient leverage choice and an inefficient under-investment in cash. I discuss several central bank policies that have been used during the crisis and analyze their effectiveness. Within the modeling framework of this paper, both a widening of collateral requirements and public liquidity provision can be effective in preventing the emergence of a detrimental feedback loop. Furthermore, I uncover the ambiguous role of market transparency. On one hand, a larger size of the transparent asset market segment has direct positive implications for liquidity risk-sharing and, hence, social welfare. On the other hand, it can also be harmful because it amplifies the adverse selection problem in the opaque market segment and, thereby, may provide incentives for investors to reduce leverage. For future research, a detailed welfare analysis of the role played by market transparency could be of interest.

The results of this paper show to be robust to several variations of the model. For tractability, I assumed throughout that the liquidity choice at $t = 1$ is binary, meaning that the investment decision at $t = 1$ is indivisible. When relaxing this assumption by allowing for mixed portfolios, the key qualitative insights appear to be unaltered. Similarly, the assumption that a private information problem only exists for the opaque asset market and not for the leveraged long-term investment project started at $t = 0$ can be relaxed without affecting the key insights. What matters is that there exist spot markets at $t = 2$ with a varying degree of adverse selection problems and that the adverse selection in the opaque asset market is strongest. Also, the fixed shares of investments in transparent and opaque assets is a model simplification that is not crucial for the key insight, which prevails even when the transparent market segment vanishes ($q = 1$).

Finally, the feature of a breakdown in pooling hinges on Assumption 1. A richer economy with more than two possible payoffs of the risky long-term asset (for instance a continuum approximation) would require a more complicated parameter assumption in order to generate a breakdown in pooling and preserve the existence of the detrimental feedback loop derived in Proposition 10. In particular, there must be a relatively large probability mass for low return realizations. For the application to the global financial crisis of 2007/08, this distributional feature is arguably realistic. The same is true for the private information on asset qualities. Prior to the crisis, financial market participants with superior information, such as US investment banks, were more than happy to off-load opaque bad quality subprime assets at high prices to less informed banks, such as the German Landesbanken.

# A Appendix: Figures

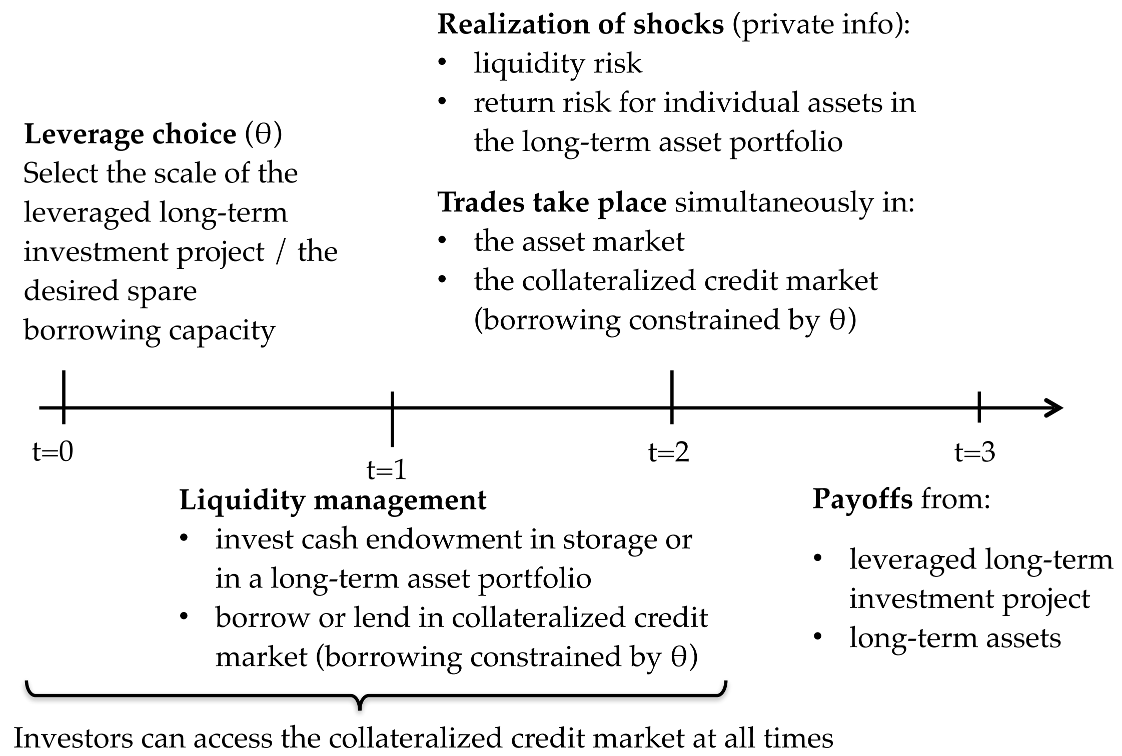


Figure 1: Timeline

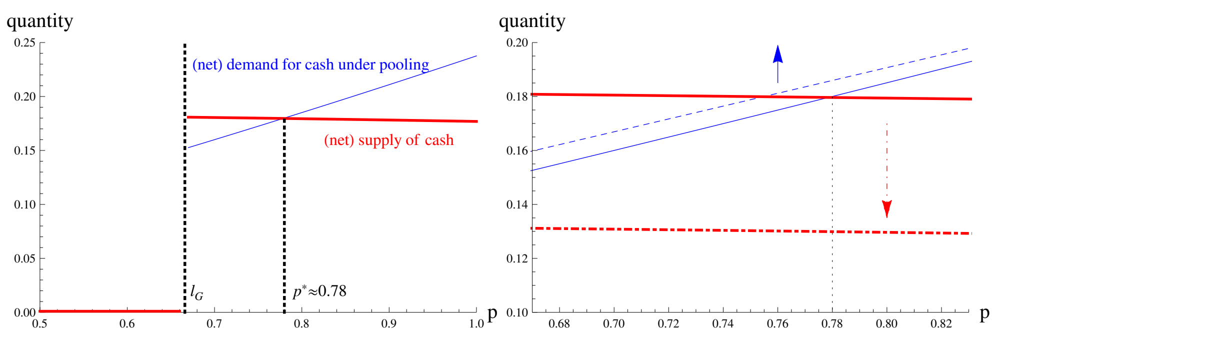


Figure 2: Market-clearing at $t = 2$: demand and supply from equation (9). Everything is expressed in terms of $p$. The parameters are the same as in the baseline example of Appendix section C. Left panel ($R_B = 0.2$): a (unique) pooling equilibrium exists. Right panel ($R_B' = 0$): the supply shifts down and the demand shifts up; no pooling equilibrium exists.

# B Appendix: Derivations

## B.1 Derivations of the trading decisions at date $t = 2$

The first-order necessary conditions associated with the problem in (5) write:

$$
\begin{array}{ll}
b_{2i}^I: & \frac{\beta_i}{c_{2i}^I}\frac{1-s_{2i}^I}{r_2}+\frac{1-\beta_i}{c_{3i}^I}\left(s_{2i}^I-1\right)-\mu_3=0 \\
d_{2i}: & \frac{\beta_i}{c_{2i}^I}\left(1-q\right)\frac{ER}{r_2}\left(1-s_{2i}^I\right)+\frac{1-\beta_i}{c_{3i}^I}\left(1-q\right)ER\left(s_{2i}^I-1\right)+\mu_8-\mu_9=0 \\
d_{2iG}: & \frac{\beta_i}{c_{2i}^I}q\left(1-\alpha\right)\check{p}_G\left(1-s_{2i}^I\right)+\frac{1-\beta_i}{c_{3i}^I}q\left(1-\alpha\right)\left(\check{p}_G r_2 s_{2i}^I-R_G\right)+\mu_4-\mu_5=0 \\
d_{2iB}: & \frac{\beta_i}{c_{2i}^I}q\alpha\check{p}_B\left(1-s_{2i}^I\right)-\frac{1-\beta_i}{c_{3i}^I}q\left(1-\alpha\right)\left(\check{p}_B r_2 s_{2i}^I-R_B\right)+\mu_7-\mu_8=0 \\
s_{2i}^I: & \left[-\frac{\beta_i}{c_{2i}^I}+\frac{1-\beta_i}{c_{3i}^I}r_2\right]\left(\left(1-q\right)\frac{ER}{r_2}d_{2i}^I+\frac{b_{2i}^I}{r_2}+q\left(\alpha d_{iB}^I\check{p}_B+\left(1-\alpha\right)d_{iG}^I\check{p}_G\right)\right)+\mu_1-\mu_2=0
\end{array}
$$

where $\mu_1$, $\mu_2$,...,$\mu_9$ are the multipliers on the first, second,..., ninth inequality constraint, respectively. Suppose $d_{2EG}^I$ is interior. From the third and fourth condition, $d_{2EB}^I = 1$ follows. The third first-order condition together with the first (second) condition implies, that $b_{2E}^I = \theta_1^I$ ($d_{2E}^I = 1$), and together with the fifth condition that $s_{2E}^I = 0$. Hence, equation (6) follows.

## B.2 Proof of Lemma 2

The results of Lemma 2 are proven in turn.

***(a)*** The left-hand side and the right-hand side of (7) are continuous and increasing in $a$. As a result, the larger root of (7) only exceeds $\ell_G$ if inequality (8) holds.

***(b)*** The average quality $a$ is implicitly defined by:

$$
\begin{aligned}
F_1\left(a;\theta_1^I,r_0,\theta_0^I\right) \quad & \equiv \alpha\left(R_B a-a^2\right)+\lambda\left(R_G-a\right)\cdot \\
& \left[\beta_E\left(a+\frac{G\left(\theta_0^I,r_0\right)-\theta_1^I}{qR_G/a}\right)-\frac{\left(1-\beta_E\right)\left(\left(1-q\right)ER+\theta_1^I\right)+\alpha aq}{q}\right]=0
\end{aligned}
$$

By application of the implicit function theorem $\frac{\partial F_1}{\partial \theta_0^I}<0$, $\frac{\partial F_1}{\partial \theta_1^I}<0$, $\frac{\partial F_1}{\partial r_0}<0$, $\frac{\partial F_1}{\partial q}>0$ and:

$$
\begin{aligned}
\frac{\partial F_1}{\partial R_B} &= \alpha a-\lambda\left(R_G-a\right)\left(1-\beta_E\right)\frac{1-q}{q}\alpha \\
\frac{\partial F_1}{\partial a} &= -\alpha a+\frac{\lambda\left(1-\beta_E\right)\left(\left(1-q\right)ER+\theta_1^I\right)}{q}+\lambda\left(R_G-2a\right)\left(\beta_E\left(1+\frac{G\left(\theta_0^I,r_0\right)-\theta_1^I}{qR_G}\right)-\alpha\right).
\end{aligned}
$$

Observe that $\frac{\partial^2 F_1}{\partial R_B \partial q}>0$ and $\frac{\partial F_1}{\partial R_B}\Big|_{q\to 1}>0$. By continuity and differentiability $\frac{\partial F_1}{\partial R_B}>0$ for a sufficiently large

$q$. Moreover, $\frac{\partial F_1}{\partial a} < 0$ for $q$ sufficiently large and $R_G \leq 2\ell_G$. Similarly, it can be shown that $\frac{\partial F_1}{\partial R_B} > 0$ and $\frac{\partial F_1}{\partial a} > 0$ for $\alpha$ sufficiently small. To see this, notice that $a \nearrow R_G$ for $\alpha \searrow 0$ and, hence, $\frac{\partial F_1}{\partial R_B} > 0$ and $\frac{\partial F_1}{\partial a} < 0$ for $\alpha \searrow 0$. As a result, $\frac{\partial a}{\partial \theta_0^I} < 0$, $\frac{\partial a}{\partial \theta_1^I} < 0, \frac{\partial a}{\partial r_0} < 0$, $\frac{\partial a}{\partial q} > 0$, and $\frac{\partial a}{\partial R_B} > 0$ provided $\alpha$ is sufficiently small or provided $q$ is sufficiently large and $R_G \leq 2\ell_G$. *(q.e.d.)*

## B.3 Proof of Lemma 3

Provided a pooling equilibrium exists, the market-clearing interest rate is implicitly defined by:

$$F_2\left(r_2, a, f; \theta_1^I, r_0, \theta_0^I, \theta_0^L\right) \equiv r_2 - \frac{\lambda\beta_E(1-f)}{m_2+f(1-\lambda\beta_E)} \cdot \left[\frac{G\left(\theta_0^I, r_0\right) - \theta_1^I + \left(qa+(1-q)ER+\theta_1^I\right)\cdot\frac{a}{R_G}}{R_G/a} + \frac{fG\left(\theta_0^L, r_0\right)}{1-f}\right] = 0$$

By application of the implicit function theorem $\frac{\partial F_2}{\partial \theta_0^I} > 0$, $\frac{\partial F_2}{\partial \theta_0^L} > 0$, $\frac{\partial F_2}{\partial \theta_1^I} < 0$, $\frac{\partial F_2}{\partial r_0} > 0$, $\frac{\partial F_2}{\partial q} > 0$, $\frac{\partial F_2}{\partial R_B} < 0$, $\frac{\partial F_2}{\partial r_2} = 1$, $\frac{\partial F_2}{\partial a} < 0$ and:

$$\frac{\partial F_2}{\partial f} = \frac{\lambda\beta_E\left[(m_2+1-\lambda\beta_E)\left(\frac{G\left(\theta_0^I, r_0\right)-\theta_1^I}{R_G/a} + qa + (1-q)ER + \theta_1^I\right) - m_2 G\left(\theta_0^L, r_0\right)\right]}{(m_2+f(1-\lambda\beta_E))^2}.$$

By continuity and differentiability, $\frac{\partial F_2}{\partial f} > 0$ provided that $m_2$ is sufficiently small. As a result, $\frac{\partial r_2}{\partial \theta_0^I} < 0$, $\frac{\partial r_2}{\partial \theta_0^L} < 0$, $\frac{\partial r_2}{\partial \theta_1^I} > 0$, $\frac{\partial r_2}{\partial r_0} < 0$, $\frac{\partial r_2}{\partial q} < 0$, $\frac{\partial r_2}{\partial R_B} = 0$, and $\frac{\partial r_2}{\partial a} > 0$. Moreover, $\frac{\partial r_2}{\partial f} < 0$ provided $m_2$ is sufficiently small.

Let $\widetilde{f}$ be the solution to the pricing function. If it exceeds the maximum price paid by buyers, i.e. if $p(\widetilde{f}) > a$, then the market-clearing interest rate does not depend on $f$. This is because, first, from Lemma 2, the average quality $a$ does not depend on $f$ and, second, because of the pricing function $\frac{\partial r_2}{\partial f} < 0 \Leftrightarrow \frac{\partial p}{\partial f} > 0$. Hence, the solution remains non-interior for all $f > \widetilde{f}$. Instead, if the solution to the pricing function falls short of the minimum price accepted by sellers of opaque good quality assets, i.e. if $p(\widetilde{f}) \leq \ell_G$, then pooling cannot be sustained. *(q.e.d.)*

## B.4 Proof of Lemma 4

The proof consists of three steps. First, insert the demand and supply schedules derived in section 3.2.1 for the case of pooling:

$$V(r_2(f)) \equiv \begin{pmatrix} \lambda\beta_E log\left[\left(\beta_E\left(q+\frac{G\left(\theta_0^I,r_0\right)-\theta_0^I}{R_G}+\frac{(1-q)ER}{a}+\frac{\theta_1^I}{a}\right)a-\theta_1^I+b_{2E}^I\right)r_2^{-1}\right] \\ +\lambda\left(1-\beta_E\right)log\left[\frac{(1-\beta_E)\left(q+\frac{G\left(\theta_0^I,r_0\right)-\theta_0^I}{R_G}+\frac{(1-q)ER}{a}+\frac{\theta_1^I}{a}\right)a+\frac{\beta_E\theta_1^I-b_{2E}^L}{R_G/a}}{a/R_G}\right] \\ +(1-\lambda)\,log\left[G\left(\theta_0^I,r_0\right)+(1-q)ER+q\left(\alpha a+(1-\alpha)R_G\right)\right] \end{pmatrix}$$

$$W(r_2(f)) \equiv \begin{pmatrix} \lambda\beta_E\ log\left[\beta_E\left(r_2+G\left(\theta_0^L,r_0\right)\right)r_2^{-1}\right] \\ +\lambda\left(1-\beta_E\right)\ log\left[\left(1-\beta_E\right)\left(r_2+G\left(\theta_0^L,r_0\right)\right)\right] \\ +(1-\lambda)\ log\left[r_2+G\left(\theta_0^L,r_0\right)\right] \end{pmatrix}$$

where $b_{2E}^I=\theta_1^I=\theta_0^I$, provided there exists a pooling equilibrium in the date $t=2$ market. Recall that $b_1^L$ cancels out. Henceforth, we set $b_1^L=0$. Second, observe that $\frac{\partial V}{\partial f}>0$ and $\frac{\partial W}{\partial f}<0$. Third, given the results of Lemma 3 the function $W$ $(V)$ takes on its lowest (highest) value for the highest permissible value of $\widetilde{f}$ where $r_2(\widetilde{f})=1$. Provided $\alpha$ or $\beta_E$ is sufficiently small $V(r_2(\widetilde{f}))=1>W(r_2(\widetilde{f}))=1$. Given that $W(r_2)\big|_{r_2\to\infty}>V(r_2)\big|_{r_2\to\infty}$, it follows from differentiability and continuity that, for a given average quality of opaque assets traded, there exists a unique $\widehat{f}$ solving equation (12). The pooling equilibrium at date $t=2$ exists if $\frac{a}{r_2(\widehat{f})}>\ell_G$. *(q.e.d.)*

## B.5 Proof of Proposition 5

Results *(b)* and *(c)* of Proposition 5 are proven in turn. First, $\frac{a\left(\theta_1^I,\theta_0^I,r_0\right)}{r_2\left(a,\hat{f};\theta_1^I,r_0,\theta_0^I,\theta_0^L\right)}>a\left(\theta_1^I,\theta_0^I,r_0\right)\geq\ell_G$ implies that becoming a liquid investor is more attractive than becoming an illiquid investor, despite the interest rate in the date $t=2$ market being at its lower bound $r_2=1$. The previous inequality implies that $V(r_2=1)<W(r_2=1)$. Hence, it is optimal for all investors to become liquid investors, i.e. the outcome is a collective cash hoarding ($f^*=1$). This is true despite the absence of cash-in-the-market pricing, resulting in a high market valuation that reflects the fundamental value of assets traded in the opaque market segment. From no-arbitrage, $p_G^*=p_B^*\frac{R_G}{R_B}=R_G$ follows, concluding the proof of result *(b)*.

Second, it remains to be shown that there always exists an equilibrium where pooling in the opaque market segment breaks down, which is characterized by $f^* \in [0,1]$ and $p^* \in [0,R_B]$. This equilibrium can be constructed as follows. Suppose investors believe at $t=1$ that there will be a breakdown of pooling in the opaque market segment at $t=2$, i.e. they believe that $p \leq \ell_G$. Notice that at $t=2$ such an equilibrium can always be supported by any $p \in [0,R_B]$. The characterization of this breakdown equilibrium requires re-visiting market-clearing (equation (9)):

$$\begin{aligned} & m_2 + f\left(1-\lambda\beta_E\left(r_2+G\left(\theta_0^L,r_0\right)\right)r_2^{-1}\right)-(1-f)\lambda\frac{\theta_1^I}{r_2} \\ = \; & (1-f)\lambda\left((1-q)\frac{ER}{r_2}+q\left(\alpha\frac{R_B}{r_2}+(1-\alpha)\frac{\ell_G}{r_2}d_{2iG}^I\right)\right) \end{aligned} \tag{19}$$

where:

$$d_{2iG}^I\left(l_B,l_G\right) = \frac{\beta_E\left(q+\frac{G\left(\theta_0^I,r_0\right)-\theta_1^I}{R_G}\right)-q\alpha\left(\beta_E+(1-\beta_E)\frac{R_B}{\ell_G}\right)-(1-\beta_E)\frac{(1-q)ER+\theta_1^I}{\ell_G r_2}}{q(1-\alpha)}.$$

Let $\hat{r}_2(f)$ be the solution to equation (19). Then, the market clearing interest rate is given by $r_2^* = max\{1,\hat{r}_2(f)\}$. Similar to the pooling case, it can be shown that $\hat{r}_2(f)$ is decreasing in $f$. The liquidity choice problem at $t=1$ if investors anticipate a breakdown of pooling is constructed similarly to before. If an interior solution exists, then $f^* \in [0,1)$ and $p^* \in [0,R_B]$. At the corner solution, the breakdown equilibrium exhibits liquidity hoarding, i.e. $f^*=1$, with $r^*=1$ and $p^* \in [0,R_B]$. This concludes the proof of result *(c)*. *(q.e.d.)*

### B.6 Proof of Proposition 6

The proof proceeds by analyzing efficiency if the solution is interior ($\ell_G < p(\widehat{f}) \leq a$) and if the solution is in one of the corners.

***(a)*** Assuming an interior solution, the problem of the constrained planner reads:

$$\max_{0\leq f\leq 1} \quad \left\{(1-f)\;V\left(r_2(f)\right)+f\,W\left(r_2(f)\right)\right\}.$$

Given a pooling equilibrium exists, the derivative with respect to $f$ writes:

$$-V+W+\left\{\frac{-(1-f)\lambda\beta_E}{r_2}+f\frac{1-\lambda\beta_E\left(r_2+G\left(\theta_0^L,r_0\right)\right)r_2^{-1}}{r_2+G\left(\theta_0^L,r_0\right)}\right\}\quad\frac{\partial r_2(f)}{\partial f}. \tag{20}$$

Using an envelope-type argument equation (20) simplifies when evaluated at $\widehat{f}$:

$$\left\{-\frac{\lambda\beta_E}{r_2}+\frac{f}{r_2+G\left(\theta_0^L,r_0\right)}\right\} \left.\frac{\partial r_2(f)}{\partial f}\right|_{f=\widehat{f}}. \tag{21}$$

If equation (21) is strictly positive then the equilibrium is characterized by an inefficient under-investment in cash. The result is established in three steps.

First, recall that $m_1 = m_2$ and that $\widehat{f}$ is smaller (larger) when $m_2$ is larger (smaller). This is because from Lemma 4 there is only one price solving $V(r_2) = W(r_2)$, while we know from the pricing function that $f$ (supply of liquidity by investors) and $m_2$ (supply of liquidity by outside financiers) are substitutes. From market-clearing, we can derive an upper bound , say $\overline{f}$, after plugging in $m_2 = 0$:

$$\overline{f} = \lambda c_{2E}^I\left(1-\lambda\beta_E\left(r_2+G\left(\theta_0^L,r_0\right)\right)r_2^{-1}+\lambda c_{2E}^I\right)^{-1}.$$

Second, observe that $c_{2E}^I < \beta_E\left(r_2+G\left(\theta_0^L,r_0\right)\right)r_2^{-1}$ under the conjecture that $\theta_0^L \leq \theta_0^I$. This is because $c_{2E}^I < c_{2E}^L$ if $r_2 \geq ER$. Furthermore, $c_{3E}^I > c_{3E}^L$ if $r_2 < ER$ and, hence, $c_{2E}^I < c_{2E}^L$ since $V(r_2) = W(r_2)$. As a result, $\overline{f} < \lambda\beta_E\left(r_2+G\left(\theta_0^L,r_0\right)\right)r_2^{-1}$ under the conjecture that $\theta_0^L \leq \theta_0^I$.

Third, using the result form Lemma 3 *(b)* it follows, by continuity and monotonicity, that equation (21) evaluated at any $f < \overline{f}$ is strictly positive.

***(b)*** Next, assume a corner solution with $p\left(\hat{f}\right) > a$. Here, $f^* = f_{SP}^* = 1$. Finally, assume a corner solution with $p\left(\hat{f}\right) \leq \ell_G$, then $f^* = f_{SP}^* \in [0,1]$. Hence, the equilibrium is efficient. *(q.e.d.)*

## B.7 Proof of Proposition 7

The proof proceeds by analyzing the problems at dates $t = 0,1,2$ in three steps. Thereafter, the efficiency analysis follows. First, consider the trading decisions at date $t = 2$. The solution to the problem of liquid investors stays unaltered if $q = 0$. Suppose $d_{2E}$ takes on an interior solution, then:

$$\frac{\beta_E}{c_{2E}^I}\frac{ER}{r_2} = \frac{1-\beta_E}{c_{3E}^I}ER \quad\Leftrightarrow\quad \frac{\beta_E}{\frac{ER}{r_2}d_{2E}+\frac{b_{2E}^I}{r_2}}\frac{ER}{r_2} = \frac{1-\beta_E}{ER(1-d_{2E})-b_{2E}^I+G(\theta_1^I,r_0)}ER.$$

Illiquid investors are indifferent between borrowing or selling assets. Setting $b_{2E}^I = 0$ yields $d_{2E} = \beta_E\left(ER+G(\theta_1^I,r_0)\right)ER^{-1}$. Hence, the interiority of $d_{2E}$ is guaranteed if Condition 1 holds.

Second, consider the liquidity management problem at $t = 1$. The unique interest rate making investors indifferent is $r_2 = ER$. From market-clearing, the corresponding proportion of liquid investors $f$ solves:

$$f = \quad (1-f)\,\lambda\beta_E\left(ER + G(\theta_0^I, r_0)\right)ER^{-1} + f\lambda\beta_E\left(ER + G(\theta_0^L, r_0)\right)ER^{-1} - m_2.$$

Third, consider the leverage choice problem at $t = 0$. As there is no benefit from leaving spare borrowing capacity, investors fully lever up, i.e. they select $\theta_0^L = \theta_0^I = 0$. The resources of outside financiers are sufficient to finance all investments if $m_0 \geq \frac{\gamma\rho\kappa}{ER-\gamma\rho}$. Following the same argument as in section 3.2.3, it can be argued that $r_0 = r_1 = r_2 \equiv r$. Hence, $r = ER$ and $f = \lambda\beta_E\,(ER + G(0, ER))\,ER^{-1} - m_2$, where $f > 0$ requires that the second inequality of (13) holds. Taken together:

$$f^* = \quad \min\left\{0, \lambda\beta_E\ (ER + G(0, ER))\,ER^{-1} - \left(m_0 - \tfrac{\gamma\rho\kappa}{ER-\gamma\rho}\right)\right\} < 1. \tag{22}$$

The equilibrium if $q = 0$ is unique given the uniqueness of the interest rate that makes investors indifferent at date $t = 1$ (Lemma 4).

Finally, the equilibrium is constrained efficient if inequality (14) holds. To see this, observe that:

$$\frac{\partial r_2}{\partial f} = \quad -\lambda\beta_E \frac{ER\,m_2 + (ER + G(0, r_0))(1-\lambda\beta_E)}{(m_2 + f(1-\lambda\beta_E))^2} < 0$$

is smallest if $m_2 = 0$. If the constrained planner induces a higher $f$ by subsidizing cash holdings at $t = 1$, then the marginal benefit for investors is $\frac{dG(\theta, r_0)}{dr_0}\ \frac{\partial r_2}{\partial f}\big|_{f=f^*}$, while the social cost is $ER - 1$. On the other hand, taxing cash holdings at $t = 1$ is clearly welfare decreasing. Hence, constrained efficiency is guaranteed if inequality (14) holds. *(q.e.d.)*

## B.8 Proof of Lemma 8

The incentives to select a positive $\theta_0^I$ can be understood by analyzing the problem in (15). Recall that $\theta_0^I = \theta_1^I$ and $r_0 = r_1 = r_2$. The first-order condition of (15) writes:

$$\begin{aligned}\frac{\partial}{\partial\theta_{0,n}^I} = \quad & \lambda \frac{\frac{R_G-a}{a} + \frac{\partial G\left(\theta_{0,n}^I, r_0\right)}{\partial\theta_{0,n}^I}}{\frac{R_G-a}{a}\theta_1^I + G\left(\theta_{0,n}^I, r_0\right) + qR_G + (1-q)ER\frac{R_G}{a}} + \\ & (1-\lambda)\cdot\frac{\frac{\partial G\left(\theta_{0,n}^I, r_0\right)}{\partial\theta_{0,n}^I}}{G\left(\theta_{0,n}^I, r_0\right) + q(\alpha a + (1-\alpha)R_G) + (1-q)ER}.\end{aligned} \tag{23}$$

Provided the either of the conditions from Lemma 2(b) hold, a sufficient condition for the derivative of the objective function in (15) to be positive, i.e. $\frac{\partial}{\partial \theta_0^I} > 0$, is given by inequality (16). *(q.e.d.)*

### B.9 Proof of Proposition 9

This proof analyzes the change in the first-order condition of (15) when $\theta_{0,-n}^I$ increases:

$$\frac{\partial\left(\frac{\partial}{\partial\theta_{0,n}^I}\right)}{\partial\theta_{0,-n}^I} = \overbrace{\frac{\partial\left(\frac{\partial}{\partial\theta_{0,n}^I}\right)}{\partial a}}^{\equiv A}\frac{da}{d\theta_{0,-n}^I} + \overbrace{\frac{\partial\left(\frac{\partial}{\partial\theta_{0,n}^I}\right)}{\partial r_0}}^{\equiv B}\frac{dr_0}{d\theta_{0,-n}^I}. \tag{24}$$

A strategic complementarity in leverage choices exists if (24) has a positive sign. Sufficient conditions for this to be true are derived in the remainder of the proof. Evaluating the partial derivatives yields:

$$A = \left[\begin{array}{c} \frac{\lambda\cdot\frac{R_G}{a^2}\cdot\left(-\left(G\left(\theta_0^I,r_0\right)+qR_G+(1-q)ER\right)+\left(\theta_1^I+(1-q)ER\right)\frac{\partial G\left(\theta_0^I,r_0\right)}{\partial\theta_0^I}\right)}{\left(G\left(\theta_0^I,r_0\right)+\theta_1^I\left(\frac{R_G}{a}-1\right)+qR_G+(1-q)ER\frac{R_G}{a}\right)^2} \\ -\frac{(1-\lambda)q\alpha\frac{\partial G\left(\theta_0^I,r_0\right)}{\partial\theta_0^I}}{\left(G\left(\theta_0^I,r_0\right)+q(\alpha a+(1-\alpha)R_G)+(1-q)ER\right)^2}\end{array}\right]$$

$$B = \left[\begin{array}{c} \frac{\lambda\frac{\partial^2 G\left(\theta_0^I,r_0\right)}{\partial\theta_0^I\partial r_0}\left(G\left(\theta_0^I,r_0\right)+\theta_1^I\left(\frac{R_G}{a}-1\right)+qR_G+(1-q)ER\frac{R_G}{a}\right)-\left(\left(\frac{R_G}{a}-1\right)+\frac{\partial G\left(\theta_0^I,r_0\right)}{\partial\theta_0^I}\right)\frac{\partial G\left(\theta_0^I,r_0\right)}{\partial r_0}}{\left(G\left(\theta_0^I,r_0\right)+\theta_1^I\left(\frac{R_G}{a}-1\right)+qR_G+(1-q)ER\frac{R_G}{a}\right)^2} \\ +\frac{(1-\lambda)\left(\frac{\partial^2 G\left(\theta_0^I,r_0\right)}{\partial\theta_0^I\partial r_0}\left(G\left(\theta_0^I,r_0\right)+q(\alpha a+(1-\alpha)R_G)+(1-q)ER\right)-\frac{\partial G\left(\theta_0^I,r_0\right)}{\partial\theta_0^I}\frac{\partial G\left(\theta_0^I,r_0\right)}{\partial r_0}\right)}{\left(G\left(\theta_0^I,r_0\right)+q(\alpha a+(1-\alpha)R_G)+(1-q)ER\right)^2}\end{array}\right]$$

where $\frac{\partial G\left(\theta_0^I,r_0\right)}{\partial r_0} = \frac{\rho(1-\gamma)}{(r_0-\gamma\rho)^2}\left(\theta_0^I-\gamma\rho\kappa\right) = \frac{\partial^2 G\left(\theta_0^I,r_0\right)}{\partial\theta_0^I\partial r_0}\left(\theta_0^I-\gamma\rho\kappa\right) < 0$. Notice that $A$ is guaranteed to be negative provided that the result of Lemma 8 holds and $\kappa$ is sufficiently small, while $q$ is sufficiently large. Furthermore, $B$ is guaranteed to be positive for a sufficiently small $\kappa$ (which implies that $\frac{\partial G\left(\theta_0^I,r_0\right)}{\partial r_0}$ is small).

Suppose that $\frac{da}{d\theta_0^I} < 0$. Given that a $A$ is negative and $B$ is positive, the sign of (24) is positive if either $\frac{dr_0}{d\theta_0^I} > 0$ or $\frac{dr_0}{d\theta_0^I}/\frac{da}{d\theta_0^I} < \frac{-A}{B}$. The proof proceeds by deriving conditions such that $\frac{da}{d\theta_0^I} < 0$ and either $\frac{dr_0}{d\theta_0^I} > 0$ or $\frac{dr_0}{d\theta_0^I}/\frac{da}{d\theta_0^I} < \frac{-A}{B}$ holds.

First, the implicit function theorem for simultaneous equations is used to derive $\frac{da}{d\theta_0^I}$ and $\frac{dr_0}{d\theta_0^I}$ (recall that $\theta_0^I = \theta_1^I$ and $r_0 = r_1 = r_2$). In Lemmas 2 and 3, the two optimality conditions stemming from date $t = 2$ and the comparative statics are derived. It remains to analyze the optimality condition stemming from date

$t = 1$:

$$F_3\left(r_2, a, f; r_0, \theta_0^I, \theta_0^L\right) \equiv V\left(r_2\left(f\right)\right) - W\left(r_2\left(f\right)\right) = 0. \tag{25}$$

By application of the implicit function theorem $\frac{\partial F_3}{\partial \theta_0^L} > 0$, $\frac{\partial F_3}{\partial f} = 0$ and:

$$\frac{\partial F_3}{\partial \theta_0^I} = \left( \begin{array}{c} \frac{\lambda\left(\frac{\partial G\left(\theta_0^I, r_0\right)}{\partial \theta_0^I} + \left(\frac{R_G}{a} - 1\right)\right)}{G\left(\theta_0^I, r_0\right) + \theta_0^I\left(\frac{R_G}{a} - 1\right) + (1-q)ER\frac{R_G}{a} + qR_G} \\ + \frac{(1-\lambda)\frac{\partial G\left(\theta_0^I, r_0\right)}{\partial \theta_0^I}}{G\left(\theta_0^I, r_0\right) + (1-q)ER + q(\alpha a + (1-\alpha)R_G)} \end{array} \right) > 0 \; given \; (16)$$

$$\begin{aligned} \frac{\partial F_3}{\partial r_0} = & \frac{\lambda \frac{\partial G\left(\theta_0^I, r_0\right)}{\partial r_0}}{G\left(\theta_0^I, r_0\right) + qR_G + (1-q)ER\frac{R_G}{a} + \theta_1^I\left(\frac{R_G}{a} - 1\right)} + \\ & \frac{(1-\lambda)\frac{\partial G\left(\theta_0^I, r_0\right)}{\partial r_0}}{G\left(\theta_0^I, r_0\right) + (1-q)ER + q(\alpha a + (1-\alpha)R_G)} - \frac{1 + \frac{\partial G\left(\theta_0^L, r_0\right)}{\partial r_0}}{r_0 + G\left(\theta_0^L, r_0\right)} < 0 \; if \; \kappa \; suff. \; small. \end{aligned}$$

Furthermore:

$$\frac{\partial F_3}{\partial a} = \left( \begin{array}{c} \frac{\lambda \beta_E}{a} - \frac{\lambda\left((1-q)\frac{ER}{a} + \frac{\theta_1^I}{a}\right)\frac{R_G}{a}}{G\left(\theta_0^I, r_0\right) + (1-q)ER\frac{R_G}{a} + qR_G + \theta_0^I\left(\frac{R_G}{a} - 1\right)} \\ + \frac{(1-\lambda)q\alpha}{G\left(\theta_0^I, r_0\right) + (1-q)ER + q(\alpha a + (1-\alpha)R_G)} \end{array} \right) > 0 \; if \; q \; large \; and \; \kappa \; small.$$

As a result, provided inequality (16) (Lemma 8) holds then, by continuity and differentiability:

$$\frac{da}{d\theta_{0,-n}^I} = \frac{da}{d\theta_0^I} = \frac{|J_2|}{|J|} < 0 \; if \; \kappa \; small, \; q \; large \; and \; R_G \leq 2\ell_G.$$

Furthermore, provided (16) holds then, by continuity and differentiability:

$$\frac{dr_0}{d\theta_{0,-n}^I} = \frac{dr_0}{d\theta_0^I} = \frac{|J_1|}{|J|} < 0$$

if $\kappa$ small, $q$ large, $R_G \leq 2\ell_G$, and in addition $|J_1| = -\frac{\partial F_1}{\partial a}\frac{\partial F_2}{\partial f}\frac{\partial F_3}{\partial \theta_0^I} + \frac{\partial F_3}{\partial a}\frac{\partial F_2}{\partial f}\frac{\partial F_1}{\partial \theta_0^I} < 0$.

If $|J_1| \geq 0$, then the sign of (24) is positive provided $\kappa$ sufficiently small, $q$ sufficiently large, and $R_G \leq 2\ell_G$. Instead, if $|J_1| < 0$, then:

$$
\begin{aligned}
\frac{\frac{dr_0}{d\theta_0^I}}{\frac{da}{d\theta_0^I}} = \quad \frac{|J_1|/|J|}{|J_2|/|J|} &= \frac{-\frac{\partial F_1}{\partial a}\frac{\partial F_2}{\partial f}\frac{\partial F_3}{\partial \theta_0^I}+\frac{\partial F_3}{\partial a}\frac{\partial F_2}{\partial f}\frac{\partial F_1}{\partial \theta_0^I}}{-\frac{\partial F_1}{\partial \theta_0^I}\frac{\partial F_2}{\partial f}\frac{\partial F_3}{\partial r_2}+\frac{\partial F_3}{\partial \theta_0^I}\frac{\partial F_2}{\partial f}\frac{\partial F_1}{\partial r_2}} \\
&< \frac{-\left(\begin{array}{c}\frac{\lambda\beta_E}{a}-\frac{\lambda\left((1-q)ER+\theta_1^I\right)\frac{R_G}{a^2}}{G\left(\theta_0^I,r_0\right)+\theta_0^I\left(\frac{R_G}{a}-1\right)+qR_G+(1-q)ER\frac{R_G}{a}} \\ +\frac{(1-\lambda)q\alpha}{G\left(\theta_0^I,r_0\right)+q(\alpha a+(1-\alpha)R_G)+(1-q)ER}\end{array}\right)}{\left(\begin{array}{c}\frac{\lambda\frac{\partial G\left(\theta_0^I,r_0\right)}{\partial r_0}}{G\left(\theta_0^I,r_0\right)+\theta_1^I\left(\frac{R_G}{a}-1\right)+qR_G+(1-q)ER\frac{R_G}{a}} \\ +\frac{(1-\lambda)\frac{\partial G\left(\theta_0^I,r_0\right)}{\partial r_0}}{G\left(\theta_0^I,r_0\right)+q(\alpha a+(1-\alpha)R_G)+(1-q)ER}-\frac{1+\frac{\partial G\left(\theta_0^L,r_0\right)}{\partial r_0}}{r_0+G\left(\theta_0^L,r_0\right)}\end{array}\right)}
\end{aligned}
$$

Provided $\kappa$ is sufficiently small, the expression is arbitrarily close to a weakly negative value provided that $\beta_E$ is sufficiently small, which implies low values of $\alpha$ to assure that $0 < d_{2EG} < 1$ is satisfied. At the same time, $A$ and $B$ are not a function of $\beta_E$. Hence, $\left(\frac{dr_0}{d\theta_0^I}/\frac{da}{d\theta_0^I}\right) < \frac{-A}{B}$ is guaranteed to hold for a sufficiently small $\beta_E$ provided $\kappa$ sufficiently small, $q$ sufficiently large, and $R_G \leq 2\ell_G$. Under the same conditions $\frac{d\hat{\theta}^I}{d\theta_{-n}^I} = 0$ if $\hat{\theta}^I = \theta_{max}^I$. *(q.e.d.)*

## B.10 Proof of Proposition 10

The proof of Proposition 10 analyzes the change in the first-order condition of (15) when $R_B$ increases:

$$
\frac{\partial\left(\frac{\partial}{\partial\theta_{0,n}^I}\right)}{\partial R_B} = -\left[\begin{array}{c}\frac{\lambda\left[\left(\frac{R_G}{a}-1\right)+\frac{\partial G\left(\theta_{0,n}^I,r_0\right)}{\partial\theta_{0,n}^I}\right](1-q)\alpha\frac{R_G}{a}}{\left(G+\theta_1^I\frac{R_G-a}{a}+qR_G+(1-q)ER\frac{R_G}{a}\right)^2} \\ +\frac{(1-\lambda)\frac{\partial G\left(\theta_{0,n}^I,r_0\right)}{\partial\theta_{0,n}^I}(1-q)\alpha}{(G+q(\alpha a+(1-\alpha)R_G)+(1-q)ER)^2}\end{array}\right]+A\frac{da}{dR_B}+B\frac{dr_0}{dR_B}. \tag{26}
$$

Given the strategic complementarity in leverage choices from Proposition 9, a lower $R_B$ increases $\theta_0^I$ if (26) has a negative sign. Following the same analysis as in the Proof of Proposition 9, we find that:

$$
\begin{aligned}
\frac{dr_0}{dR_B} &= \frac{|J_1|}{|J|} > 0\; if\; \kappa\; small,\; q\; large\; and\; R_G \leq 2\ell_G \\
\frac{da}{dR_B} &= \frac{|J_2|}{|J|} > 0\; if\; \kappa\; small,\; q\; large\; and\; R_G \leq 2\ell_G.
\end{aligned}
$$

The sign of (26) is guaranteed to be negative if $\left(\frac{dr_0}{dR_B}/\frac{da}{dR_B}\right) < \frac{-A}{B}$. The result arises by application of the same argument as in the Proof of Proposition 9 provided that $\kappa$, $\beta_E$ sufficiently small, $q$ sufficiently large, and $R_G \leq 2\ell_G$. *(q.e.d.)*

# C Appendix: Numerical example

This section presents a numerical example to illustrate the mechanics behind the detrimental feedback loop derived in section 3.4 and to support the discussion of policy implications in section 4. Consider the model parameters given in table 1. The parameters are selected such that there exists a pooling equilibrium. In particular, the adverse selection problem is assumed to be relatively mild (a low $\alpha$), while the relative size of the opaque market segment is large (a high $q$).

| Variable | $\beta_E$ | $\lambda$ | $\alpha$ | $R_G$ | $R_B$ | $\ell_G$ | $\rho$ | $\kappa$ | $\gamma$ | $m_0$ | $q$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Value | $\frac{1}{2}$ | $\frac{2}{5}$ | $\frac{1}{10}$ | $\frac{7}{5}$ | $\frac{1}{5}$ | $\frac{2}{3}$ | $\frac{7}{5}$ | $\frac{1}{4}$ | $\frac{1}{3}$ | $\frac{3}{10}$ | $\frac{9}{10}$ |

Table 1: Model parameters

Given the result from Proposition 5, there exists a pooling equilibrium characterized by $\theta^* = \theta^{I,F*} = 0$, $r^* \approx 1.27$ and $a^* \approx 0.99$. The corresponding market-clearing prices are given by $p^* \approx 0.78$, $p_G^* \approx 1.10$ and $p_B^* \approx 0.16$, respectively. As long as adverse selection is relatively mild, investors do not have an incentive to install spare borrowing capacity at $t = 0$, i.e., to select a positive $\theta$. This changes when the adverse selection problem is stronger, as suggested by Proposition 10.

Let us examine what happens in a crisis scenario triggered by a deterioration in the quality of subprime assets. Consider an increase in the intensity of adverse selection caused by a small drop in the value of lemons from $R_B = 0.2$ to $R_B' = 0$. In this case, the expected return drops only slightly from $ER = 1.26$ to $ER' = 1.24$. However, there no longer exists a pooling equilibrium because the incentives to deleverage by selecting a strictly positive $\theta^I$ are growing too large (Lemma 8, Proposition 9). Intuitively, the more intense adverse selection incentivizes investors to increase $\theta^I$ which in turn amplifies adverse selection, eventually pushing $p$ below $\ell_G$. This is illustrated in figure 2 in Appendix A. With $R_B = 0.2$ a unique pooling equilibrium exists with $p^* \approx 0.78$ (left graph). When $R_B$ falls, adverse selection gets more intense and the supply of cash drops sharply (right graph). No pooling equilibrium can be supported. In summary, a detrimental feedback loop evolves, leading to a complete breakdown in the opaque market and a unique equilibrium characterized by $\theta^{I*} = \gamma\kappa\rho \approx 0.12$, $r^* \approx 1.13$, $f^* \approx 0.08$ and $p^* = 0$. Interestingly, the pooling equilibrium prevails, despite $R_B' = 0$, if a social planner forces investors to select $\theta^I = 0$. In the latter case, $r^* \approx 1.24$, $a^* \approx 0.91$ and $p^* \approx 0.73 > \ell_G = \frac{2}{3}$. This highlights the detrimental effect of deleveraging.

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