Financial Linkages, Transparency, and Systemic Risk*

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Abstract

A fundamental structural change of the financial system in the previous decade resulted in increased interconnectedness and opacity. We develop a model of an interconnected financial system and examine its consequences for systemic risk and macro-prudential transparency regulation. Our model features fire sales and contagious counterparty risk arising from interbank loans. We also describe a novel and stabilising effect arising from a joint liquidation market, characterising the conditions under which this effect reduces systemic risk. We demonstrate that enhanced transparency can increase systemic risk. Examining the relationship between financial linkages and opacity conducive to low systemic risk, we contribute to the debate on transparency within the Basel framework of banking supervision.

Keywords: contagion, fire sales, systemic risk, transparency

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1 Introduction

The financial system underwent a fundamental structural change in the previous decade. Three developments characterise this structural change: first, an increase in both direct linkages between financial intermediaries; second, an increase in indirect linkages; and third, a reduction in the transparency of the financial system epitomised by a dramatic increase in the market size of global over-the-counter derivatives markets.

The most prominent examples of direct interconnections are interbank loans, repurchase agreements, and credit default swaps. Interbank loans (defined as loans issued among monetary financial institutions (MFIs)) are of particular importance in the euro area because of both the size of the interbank loan market and the absence of collateralisation in lending. For instance, the amount of deposit liabilities between euro area MFIs depicted in Figure (1) doubled between 2000 and 2008, reaching a level of seven trillion euro. Furthermore, financial corporations' total financial assets outstanding increased from 51.9% in 1999 to 58.5% in 2008 (as a fraction of overall balance sheet volume. See European Central Bank (2012)). Absent seizable collateral, lending banks realise severe losses in case of a borrowing bank's insolvency. The substantial counterparty risk associated with interbank loans may trigger contagion between banks.[1]

Indirect connections can arise from similar specialised asset holdings. If a number of financial intermediaries with similar asset holdings come into distress when suffering from forced liquidity outflows, they need to sell some of their assets, possibly igniting a fire sale (see Shleifer and Vishny (1992)).[2] There is also substantial empirical evidence for the existence of fire sales surveyed in Shleifer and Vishny (2011). Fire-sales in equity markets are

[1]Common measures for the perceived counterparty risk of an individual financial intermediary is its CDS spread. Since interbank loans are the predominant form of direct interbank linkages within the euro area, the LIBOR-OIS and the EURIBOR-EUREPO spread are often used as a measure for the system's overall perceived counterparty risk. For the US, where direct linkages mainly arise in the form of collateralised repos, Gorton and Metrick (2011) use a haircut index as a proxy for counterparty risk. They show that changes in the LIBOR-OIS spread were strongly correlated with changes in credit spreads and repo rates for securitised bonds. All measures of counterparty risk tell the same story: perceived counterparty risk surged with the onset of the financial crisis in late 2007 and in particular with the insolvency of the US investment bank Lehman Brothers in September 2008.

[2]The natural buyers of an asset are financial intermediaries that hold similar assets. When they are faced with similar liquidity problems, the asset is sold to general investors who value the asset less because of their lower degree of specialisation. Prices depreciate further and, faced with deteriorating asset values, a growing number of intermediaries is forced to sell of their asset holdings.

analysed by Coval and Stafford (2007), showing that fire-sales may even occur in highly liquid markets. They analyse sales by open-ended money market funds that face severe liquidity outflows and are forced to liquidate a share of their assets. The authors find significantly negative abnormal returns and the typical fire-sale shape. Campbell et al. (2012) demonstrate the existence of fire-sales in the residential housing market and report a 27% average reduction in house value after a forced house sale due to bankruptcy. Preventing ongoing fire sales was the focus of several ex-post policy interventions. In December 2009, the US Secretary of the Treasury Timothy Geithner emphasised that *"none of [the biggest banks] would have survived a situation in which we had let that fire try to burn itself out"*.[3]

Securitisation and financial innovation enhanced risk sharing. At the same time, derivatives and other financial products became increasingly complex and difficult to understand. Subsequently, the financial system as a whole has become less transparent. According to Acharya and Bisin (2011), opacity is a key feature of over-the-counter (OTC) markets. They show that opacity can lead to excess leverage that induces counterparties to take on short OTC positions, increasing the level of default risk above their ex-ante efficient level. The importance of transparency, and the lack thereof, is underlined by the size of global OTC derivatives markets depicted in Figure (2). This market increased more than five-fold over the period from 1998 to 2007, peaking at around 500 trillion US dollar in 2007.

Are financial crises an inevitable consequence of the fundamental structural change of the financial system? That is, do increasing levels of both direct and indirect financial linkages together with a decreasing amount of transparency result in higher levels of systemic risk that can manifest themselves in a large-scale financial crisis? In addition, is there a level of transparency that helps contain the effects on systemic risk? This paper addresses these questions by developing a model of financial interconnectedness that features all three key ingredients mentioned: direct linkages, indirect linkages, and transparency.

[3]Quoted by Robert Schmidt, "Geithner Slams Bonuses, Says Banks Would Have Failed (Update2)", Bloomberg, December 4, 2009; cited in National Commission on the Causes of the Financial and Economic Crisis in the United States (2011).

Each form of financial linkage constitutes an externality. First, counterparty risk poses a non-pecuniary externality that leads to possible contagion effects as described in Allen and Gale (2000). Second, joint access to a liquidation market poses a pecuniary externality that results in possible fire-sales. In addition to the fire-sale effect, we study a novel and stabilising aspect of a joint liquidation market labeled a *calm-before-the-storm* effect.

We examine the emergence of systemic risk, defined as the joint default of both banks, and analyse conditions under which a higher level of transparency is *un*desirable. For instance, we derive the social planner's allocation as a benchmark for comparing systemic risk across four cases (a baseline case without linkages, indirect linkages only, direct linkages only, and both linkages). We show that the introduction of indirect linkages always reduces system risk relative to the baseline case for any level of transparency. Transparency amplifies the reduction in systemic risk (Proposition 1). Next, the introduction of direct linkages has an ambiguous effect on systemic risk relative to the baseline case, balancing insurance with potential contagion. More transparency results in greater systemic risk (Proposition 2).

A main result of our analysis demonstrates that introducing indirect linkages in a model of financial contagion (e.g. Allen and Gale (2000)) may reduce systemic risk. In particular, the introduction of indirect linkages *always* reduces systemic risk if the effects of indirect linkages dominate the effects of direct linkages (Proposition 4). Moreover, a higher level of opacity *reduces* systemic risk if interbank contagion dominates (Proposition 3).

Our setup is as follows. There are three dates and two regions, each of which with a representative financial intermediary (called bank) and a continuum of depositors (called households). The household's liquidity preference is as in Diamond and Dybvig (1983): households are endowed with one unit of a universal investment and consumption good and are initially uncertain about the timing of their consumption. Early households value consumption at the interim date only, while late households value consumption at the final date only. The fraction of early households is constant yet unknown in a given region. Banks collect deposits and invest into storage or into a risky, illiquid, long-term investment project. The timing is summarised in Figure (3). Our notion of households and banks is broad and not limited to the traditional case of retail depositors and commercial banks but incorporates, for instance, money market funds (households) and investment banks (banks).

Direct linkages in the form of interbank loans arise from negatively correlated liquidity shocks, as in Allen and Gale (2000). Interbank loans are paid at the interim date from the liquidity surplus bank to the liquidity shortage bank upon materialisation of the observed liquidity shock. Interbank loans are repaid with interest at the final date, provided the debtor bank remains solvent. Indirect linkages result from the existence of a joint liquidation market, in which the long term project may be liquidated at the interim date. The liquidation price depends on the amount liquidated, capturing weak economic conditions of the specialised assets' potential buyers (Shleifer and Vishny (1992)), limited participation (Allen and Gale (1994)), or financial constraints of arbitrageurs (Gromb and Vayanos (2002)). Thus, liquidation proceeds will be low if both banks sell their illiquid investment projects, corresponding to a fire sale.

A solvency shock occurs at the end of the interim date when the value of the final-date investment project's profitability is realised. Transparency in our model refers to depositors learning about the profitability of the *other* region's investment project. Households receive a signal about the profitability of their region's investment project at the end of the interim date, whereas they only receive a signal about the other region's profitability with some probability. Based on their information, households form expectations about their final-date consumption levels (and the other region's action if there is no transparency) and may withdraw their funds at the end of the interim date. Late households, who may withdraw strategically, store their funds for consumption at the final date.

We turn to the impact of different financial linkages on systemic risk. A repayment of the interbank loan stabilises the creditor bank (i.e. the bank in the liquidity surplus region), while default of the debtor bank destabilises it. Effectively, interbank lending induces strategic complementarity in the late households' withdrawal decisions. In terms of the probability of a systemic crisis, only the destabilising effect of interbank loans is relevant, thus increasing systemic risk. Fire sales affect the liquidation payoff: the liquidation price is low if and only if the other bank liquidates. Therefore, fire sales induce strategic substitutability in the bank's liquidation decision.

There are two consequences of a joint liquidation market. The first consequence is the existence of an amplification effect commonly addressed in the literature (see e.g. Kiyotaki and Moore (1997)). Given that a bank has to liquidate, its proceeds are reduced if the other bank liquidates as well. Fire sales constitute an endogenous cost of a systemic crisis.[4] While fire sales exacerbate the incidence of a systemic crisis, the calm-before-the-storm effect reduces its probability.

Transparency is a source of amplification that intensifies the effects from both interbank loans and a joint liquidation market. That is, contagion arising from interbank loans, as well as stabilization arising from the calm-before-the-storm effect are amplified by more transparency. The overall effect on systemic risk will be determined by the relative strength of each form of financial linkages. If fire sales are relatively strong (weak), systemic risk will be reduced (increased). Hence, the level of transparency that implies the lowest level of systemic risk is high (low).

This paper is organised as follows. The model is described in section (2) and the equilibrium is characterised in section (3). All proofs are delegated to the Appendix (A). Section (4) discusses our results with particular reference to policy implications and concludes.

2 Model

The economy extends over three dates $t = 0, 1, 2$ and consists of two equally-sized regions $k = A, B$. There are many households and a bank in each region. Our notion of households is broad and not limited to the traditional case of retail depositors and commercial banks but incorporates, for instance, money market funds (households) and investment banks (banks). There is a single physical good used for consumption and investment.

[4]Other (exogenous) costs of a systemic crisis are the occurrence of a credit crunch and the deadweight loss associated with bankruptcy.

2.1 Investment opportunities

Two investment opportunities, storage and an investment project, are publicly available in each region at date 0. Storage is risk-free and matures after one period with a zero net return. A risky long-term investment project matures after two periods and yields a regional return of $\widetilde{R}_k$. Its expected net return is positive, $\mathbb{E}[\widetilde{R}_k] > 1$, ensuring that some investment into the project is made in equilibrium. We follow Goldstein and Pauzner (2005) in assuming a convenient bivariate regional investment return $\widetilde{R}_k$:

$$\widetilde{R}_k = \begin{cases} R > 1 & \text{w.p. } p(\theta_k) \\ 0 & \text{w.p. } 1 - p(\theta_k) \end{cases} \tag{1}$$

where the success probability p is strictly increasing in the regional fundamental θ_k, $p'(\cdot) > 0$. A convenient special case is $p(\theta) = \theta$, where the constraint on the positive expected net return simplifies to $R > 2$.

Premature liquidation of a fraction $x \in [0, 1]$ in the interim period results in an inferior return $\beta \in [0, 1)$, reflecting liquidation costs.[5] The payoffs are summarized as follows:

Asset	$t = 0$	$t = 1$	$t = 2$
Storage $(0 \to 1)$	-1	1	0
Storage $(1 \to 2)$	0	-1	1
Project $(0 \to 2)$	-1	$x\beta$	$(1 - x)\widetilde{R}$

We capture the notion of fire sales by assuming that banks may be linked via a joint liquidation market. Hence, the liquidation value for one bank is reduced if the other bank liquidates as well: $\beta \in \{\underline{\beta}, \overline{\beta}\}$ with $0 < \underline{\beta} < \overline{\beta} \leq 1$. This can be motivated with cash-in-the-market pricing that originates from limited market participation. Allen and Gale (1994) develop a model where investors endogenously decide on whether or not to participate in an asset market. In such a setting, there are two equilibria. One features an asset price that is determined by future returns, while the asset price in the other equilibrium is determined by the number of investors participating in the market. Contrary to Allen and Gale (1994), however, we assume the existence of two regions and one outside

[5] As in Eisenbach (2011), we assume an alternative use of resources, such as in a different industry. Hence, there will be a positive liquidation value even if the fundamental is at its lowest possible level.

investor with an inelastic demand for the long asset.[6] Other motivations for cash-in-the-market pricing are possible. Gale and Yorulmazer (2011) develop a model where illiquid banks try to sell a fraction of their long assets at a discount price while liquid banks, instead of purchasing these assets, are clinging on to their cash because of a (related, but not identical) speculative and a precautionary motive. Banks expect even further price discounts in the future and are hence unwilling to purchase the asset at the given market price. At the same time, liquid banks cannot be certain that they will not face a liquidity shortage in the next period and are hence saving cash to protect themselves against this case.

2.2 Households and Banks

Each region has ex-ante identical households of mass one. The liquidity preference of households is as in Diamond and Dybvig (1983): a household can be either *early* or *late*, thus wishing to consume at date 1 or 2, respectively. The ex-ante probability of being an early consumer is identical across consumers and given by $\lambda_k \in (0,1)$, which is also the share of early consumers in that region by the law of large numbers. Households do not know their liquidity preference at date 0 but learn it privately at the beginning of date 1. The household's period utility function $u(c)$ is twice continuously differentable, strictly increasing, weakly concave and satisfies the Inada conditions, giving rise to the following depositor utility function:

$$U(c_1, c_2) = \begin{cases} u(c_1) & \lambda \\ & \text{w.p.} \\ u(c_2) & 1-\lambda \end{cases}, \tag{2}$$

$$\mathbb{E}[U(c_1, c_2)] = \lambda u(c_1) + (1-\lambda) u(c_2) \tag{3}$$

where c_t is the household's consumption at date t and $\mathbb{E}$ is the expectation operator. Households in each region are endowed with one unit at date 0 to be invested or deposited in the bank. Late households prefer to invest in the investment project.

[6] Following Diamond and Rajan (2011) one alternatively can assume that the long asset has a limited set of potential buyers only. The example given by Diamond and Rajan are mortgage backed securities that can accurately be priced only by a small number of specialized firms.

There is a role for a bank as provider of liquidity insurance. This arises from the smaller volatility of regionally aggregate liquidity demand compared with individual liquidity demand. The bank offers demand deposit contracts to households that specify withdrawals (d_1, d_2) if funds are withdrawn at the interim or final date. Liquidity insurance for risk-averse households implies $d_1 > 1$. The non-observability of the idiosyncratic liquidity shock prevents the deposit contract between the bank and the household from being contingent on the household's liquidity shock.

A bank pays out deposits d_1 in in the interim period as long as it has liquidity. Late households are labeled patient when holding their deposits until the final date and impatient otherwise. Sufficient withdrawals of impatient households lead to the illiquidity of the bank and triggers liquidation and default on interbank liabilities if present. In case of default, the bank pays an equal amount to all demanding depositors (pro-rata). Hence, non-withdrawing depositors receive nothing if the bank declares insolvency. There is free entry to the banking sector. Thus, a bank chooses its portfolio (by holding an amount of liquidity $y \geq \lambda$ and investing the remainder into the investment project) and the interim withdrawal payment to maximize a depositor's expected utility. Under free entry, all depositors deposit in full, given the alignment of interest between the bank and its depositors and the fact that the bank can access the same investment opportunities as the depositor.

2.3 Regional liquidity shocks and interbank insurance

Regional liquidity shocks are negatively correlated.[7] Excess liquidity in one region is associated with liquidity shortage in the other region, with an equal probability of being the high liquidity demand region. We study negatively correlated liquidity shocks of equal size to exclude bank runs that are merely driven by aggregate liquidity surplus or shortage.

probability	region A	region B
$\frac{1}{2}$	$\lambda_A = \lambda_H$	$\lambda_B = \lambda_L$
$\frac{1}{2}$	$\lambda_A = \lambda_L$	$\lambda_B = \lambda_H$

[7] Freixas et al. (2000) motivate this assumption by allowing for interregional travel of depositors who learn the location of their liquidity demand at the beginning of the first period one. See also Allen and Gale (2000) and Dasgupta (2004).

Note that $\lambda_H \equiv \lambda + \eta$ and $\lambda_L \equiv \lambda - \eta$ denote high and low liquidity demand, respectively, where $\eta \geq 0$ is the size of the regional liquidity shock.

Banks insure against regional liquidity shocks. At date 0, they agree on liquidity insurance such that the bank in the liquidity shortage region receives an amount $0 \leq b \leq y$ from the bank in the liquidity surplus region at the beginning of period 1. If the bank in the high liquidity demand region remains solvent, it repays this loan in the final period with interest ($\phi > 1$). Special cases are actuarially fair insurance, in which the interest payment balances the risk of default, and a deposit swap: $\phi = \widetilde{R}_H$. Because of counterparty risk, it is never optimal to hold more interbank insurance than the liquidity shock, $b \leq \eta$. We make the common assumption of seniority of interbank loans at the final date only, see for example Dasgupta (2004). Non-defaulted interbank claims may be liquidated at rate β.[8]

2.4 Information structure

All prior distributions are common knowledge. The regional fundamental is uniformly distributed:

$$\widetilde{\theta}_k \sim U[0,1] \tag{4}$$

At date 1 households receive a perfectly revealing signal about their regional fundamental θ_k. In addition, households receive a signal about the *other* region's fundamental θ_{-k}. This signal is perfectlt revealing with probability $q \in [0,1]$ and pure noise with probability $1-q$.[9] The timeline of the model is depicted in Figure (3).

Remark 1 *The availability of information about the other region can be interpreted as* ***transparency****. The probability of (perfect) revelation of the other region's fundamental, q, is then a measure of transparency. The cases of full and no revelation, respectively, are referred to as informative and uninformative.*

[8] As liquidation is a modelling device for an outside investor willing to purchase investment projects at a discount, claims to physical goods are treated as physical goods themselves. That is, the bank in L may liquidate the interbank loan in the case it is repaid only.

[9] A differetnt information structure is considered in Ahnert and Nelson (2012). Regional investment returns are positively but imperfectly correlated and each depositor receives one signal. Given the correlation between fundamentals, the signal is also informative about the other region.

A number of papers have analysed the effect of transparency in financial systems. Following Diamond and Dybvig (1983), Parlatore-Siritto (2011) assumes a long-term risky asset whose return depends not only on the period in which it is liquidated, but also on the state of the world. In the low state of the world, the asset pays off less than in the high state, giving depositors more incentives to withdraw prematurely. This assumption is motivated as the result of a fire-sale that, however, is not modelled explicitely. Depositors receive a private signal about the return of the long-term asset. This signal, however, will give the depositor the state of the world only with probability $p \geq \frac{1}{2}$. The probability is then interpreted as a measure of the banks' transparency. Compared to the perfect information case, imperfect information about the state of the world decreases the incentive to withdraw prematurely for depositors with low signals, while it increases the incentives for depositors with high signals. Strategic complementarities exist for some values of deposit contract and bank portfolio, while they are absent for others. This leads to a possible multiplicity of equilibria, even in the global games framework used. In this case, the bank holds beliefs about the equilibrium the depositors will coordinate on. Under the optimistic assumption that banks believe that households will always coordinate on the best equilibrium, Parlatore-Siritto (2011) shows that increasing transparency can make the bank more susceptible to runs and decrease welfare.

Babus (2011) develops a model of strategic relationships in over-the-counter markets where agents with an investment opportunity can issue either an observable, non-verifiable financial derivative or a collateralized fixed-payoff security to agents with liquidity surplus. The agents with investment opportunity can decide to not pay promised investment returns to agents with liquidity surplus. In this case they are excluded from future trades. Agents can endogenously decide with whom to form financial linkages. Two linked agents gain access to their respective payment history and can verify whether their counterparty has ever neged on a payment. Transparency in this setup is modelled as access to payment history and perfect market transparency is achieved if the network of agents is perfectly connected.

2.5 Payoffs

The households' payoff depends on the withdrawal decision in both regions. Households receive a signal about the return in their own region and, in the case of transparency, about the return in the other region. Following Freixas et al. (2000), we assume the existence of a coordination device for late households in a given region. That is, late households coordinate on a common action upon the receipt of the signals. Appendix (A.1) relaxes this assumption by allowing households to coordinate on any aggregate withdrawal share $n \in [0, 1]$. If the fundamental is linear in the success probability, late households find it never optimal to coordinate on partial withdrawals.[10]

For a sufficiently bad signal the payoff received from not withdrawing is smaller than the payoff from withdrawing, irrespective of the proportion of impatient households. Thus, there exists a dominant strategy for late households to withdraw, avoiding a zero payoff at the final date. Each household receives the liquidation payoff

$$d_\beta \equiv y + (1 - y)\beta \tag{5}$$

If the signal is sufficiently good, households do not have a strictly dominant strategy. Then, they coordinate on the optimal withdrawal proportion $n \in \{0, 1\}$. If late households decide to not withdraw prematurely, the bank has funds worth $(1 - y)\widetilde{R}_k + (y - \lambda d_1)$ available at the final date, where $(y - \lambda d_1)$ denotes excess liquidity. Each late household receives

$$\widetilde{c}_{2,k} = \frac{(1 - y)\widetilde{R}_k + (y - \lambda d_1)}{1 - \lambda} \tag{6}$$

The focus of the present paper is on the interaction of several channels of systemic risk and on the effect of transparency on this interaction. Therefore, we address the issue of co-ordination between late households by assuming the existence of a co-ordination device available to late households provided they do not possess a strictly dominant strategy. In particular, additional co-ordination failure between patient households would add another component and tends to work against our results. As the co-ordination problem would

[10] An alternative modelling device for the strategic behaviour of late households in a given region is the theory of global games, pioneered by Carlsson and van Damme (1993) and famously used by Morris and Shin (2000, 2003). The main results of our analysis hold for different modelling choices for the strategic interaction between late households.

intensify as several systemic risk channels interact, our results could be interpreted as a lower bound on the interaction effect between systemic risk channels.

3 Equilibrium

Interbank connections can be either direct or indirect. Direct interbank connections arise from insurance against regional liquidity shocks ($\eta > 0$). Indirect connections stem from fire-sales when liquidation values are jointly and symmetrically depressed. We first consider a baseline case without direct or indirect linkages. Then, the pure fire-sale and pure interbank contagion cases are studied in turn. We finally analyze a unified model of systemic risk with both direct and indirect linkages. In each case we explore the role of transparency on equilibrium systemic risk. Final-date consumption levels in the four cases are denoted by subscripts.

3.1 Baseline case

There are no links between regions. Interregional liquidity shocks and direct linkages are absent ($\eta = 0$), which excludes interbank contagion. Banks have separate regional access to liquidation markets ($\widetilde{\beta} = \beta$), precluding a fire-sale externality. Transparency only plays a role in the presence of interregional linkages.

Consider the withdrawal decision of households. Early households always withdraw, while late households compare keeping and withdrawing their funds. Let $c_1^G \equiv \frac{(1-y)R+(y-\lambda d_1)}{1-\lambda}$ and $c_1^B \equiv \frac{(y-\lambda d_1)}{1-\lambda}$ denote the final-date consumption of late households in the good and bad state, respectively. Late households' indifference between withdrawing (yielding $u(d_\beta)$) and keeping funds (yielding $p(\overline{\theta}_1)u(c_1^G) + [1 - p(\overline{\theta}_1)]u(c_1^B)$) implies a withdrawal threshold

$$\overline{\theta}_1 \equiv p^{-1}\left(\frac{u(d_\beta) - u(c_1^B)}{u(c_1^G) - u(c_1^B)}\right) \tag{7}$$

The right-hand side of equation (7) is strictly increasing in the fundamental θ, while the left-hand side is independent of it. The right-hand side converges to $u(c_1^B) < u(d_\beta)$ as the fundamental worsens, whereas it converges to $u(c_1^G) > u(d_\beta)$ with improving fundamental. Continuity and strict monotonicity imply a unique intersection $\overline{\theta}_1$.

Households withdraw if and only if the regional fundamental is smaller than the implied threshold ($\theta < \overline{\theta}_1$), which happens with probability $\overline{\theta}_1$. Thus, systemic risk in the baseline case is:

$$SR_1 = (\overline{\theta}_1)^2 \tag{8}$$

We next explore how changes to the bank contract, the portfolio choice, and the exogenous paramters of the model affect the withdrawal threshold $\overline{\theta}_1$. First, a higher payment R in the case of success rewards keeping your funds in the bank and thus lowers the withdrawal threshold. A lower liquidation share β makes liquidation less appealing, lowering the threshold as well. More early consumers λ reduces the available resources at date 1, which is detrimental to late consumers. However, they also need to share the remaining resources with fewer people at the final date, which is beneficial to late consumers. The second effect dominates and the threshold is reduced if there are sufficiently few early consumers ($\lambda \leq \frac{1}{2}$).

Next, a higher withdrawal payment d_1, which provides more insurance for early households, unambiguously increases the withdrawal threshold $\overline{\theta}_1$. Intuitively, a larger payment at the interim date implies that fewer resources are vailable at the final date, lowering the incentive to keep the funds in the bank. This trade-off between higher insurance and greater financial fragility is studied by Goldstein and Pauzner (2005) in a setup with a single bank.

Finally, consider an increase in the share of the safe asset y that has three effects. It (i) raises the payoff in case of default (higher d_β), leading to an increasing in the threshold; (ii) lowers consumption in the good state (lower c_1^G) as $R > 1$, leading to an increase in the threshold; and (iii) increases the payoff in the bad state (higher c_1^B), implying a decreasing threshold. Thus, the overall effect is ambiguous.

The shown in Appendix (A.3), the withdrawal threshold in the baseline case $\overline{\theta}_1$ depends positively on the promised interim payment d_1, negatively on the investment payoff in the good state R and the liquidation share β, whereas its dependence on the share of early consumers λ and the amount of liquidity y are non-monotonic.

Social planner allocation. To build intuition, we consider the social planner allocation and compare the implied systemic risk across the four cases. The planner faces the same technological constraints as private households (see also Lorenzoni (2008)). First, note that the planner will undo the liquidity shocks by rearranging liquidity between regions at the interim date. Thus, the planner holds the same amount of (average) liquidity in both regions. Second, the planner will always hold a sufficient amount of liquidity $y^{SP} \geq \lambda d_1^{SP}$ as liquidation is costly, such that the liquidity constraint never binds at the interim date. Third, the final-date payment is given by the resource constraint $(1-\lambda)d_2 = y - \lambda d_1 + (1-y)Rp(\theta)$. Taken together, the planner's problem is stated as:

$$\max_{y,d_1} \lambda u(d_1) + (1-\lambda)\mathbb{E}_\theta \left[u\left(\frac{y - \lambda d_1 + (1-y)Rp(\theta)}{(1-\lambda)} \right) \right] \tag{9}$$

The associated first-order conditions are

$$y: \quad \mathbb{E}_\theta \left[u'(d_2^{SP})(1 - Rp(\theta)) \right] = 0 \tag{10}$$

$$d_1: \quad \mathbb{E}_\theta \left[u'(d_2^{SP}) \right] = u'(d_1^{SP}) \tag{11}$$

For specificity, let the success probabilty function be linear ($p(\theta) = \theta$) and the the utility function be logarithmic ($u(c) = ln(c)$), allowing us to determine closed-form solutions. The first-order conditions simplify to:

$$0 = \int_0^1 \frac{(1-R\theta)(1-\lambda)}{y - \lambda d_1 + (1-y)R\theta} d\theta \tag{12}$$

$$\frac{1}{d_1} = \int_0^1 \frac{(1-\lambda)}{y - \lambda d_1 + (1-y)R\theta} d\theta \tag{13}$$

and integration yields:

$$\mathbb{E}_\theta \left[u'(d_2^{SP})(1-R\theta) \right] = -\frac{1-\lambda}{1-y} + \frac{(1-\lambda)(1-\lambda d_1)}{(1-y)^2 R} \ln\left(\frac{y - \lambda d_1 + (1-y)R}{y - \lambda d_1} \right) \tag{14}$$

$$\mathbb{E}_\theta \left[u'(d_2^{SP}) \right] = \frac{(1-\lambda)}{(1-y)R} \ln\left(\frac{y - \lambda d_1 + (1-y)R}{y - \lambda d_1} \right) \tag{15}$$

Solving for d_1^{SP}, one obtains $d_1^{SP} = 1$. This intuitive result reflects the exact cancellation of the income and substitution effects of higher future consumption for log-utility as the elasticity of intertemporal substitution is unity. The planner's liquidity and investment level given by the interior solution $y^{SP} \in (\lambda, 1)$ simplify to the following equation:

$$\exp\left(\frac{(1-y)R}{(1-\lambda)}\right) = 1 + \frac{(1-y)R}{y-\lambda} \tag{16}$$

Note that an interior solution always exists if and only if $R > 2$, which ensures that the investment project is not dominated by storage.

3.2 Fire sales

In the case of pure fire sales, banks are linked via a joint liquidation market only. Relative to the baseline case, this affects the (expected) utility from withdrawing. We proceed by defining the equilibrium in the informed and uninformed case, solve for the withdrawal threshold of late households, and determine systemic risk in both cases. We also demonstrate that increasing transparency can reduce the systemic risk originating from fire sales.

The informative case, where signals about the other regions' returns are fully revealing, occurs with probability q. A formal definition of the equilibrium is provided in Definition (1).

Definition 1 *In the informed case, late households in different regions know the signals* (θ_A, θ_B) *and thus play a complete information withdrawal game. A collection of binary withdrawal actions constitutes a (Nash) equilibrium if the withdrawal action in each region maximizes the expected utility of late households, taking the other region's late households withdrawal action as given.*

Note that the need for taking expectations does not arise from the strategic uncertainty about the other region's equilibrium behaviour but from the exogenous uncertainty about the investment project return.

Since actions are known in equilibrium, late households know whether or not the bank in the other region liquidates, which only happens in case of default. The other bank's decision is labeled N for "no default" and D for "default". If the other bank liquidates, the liquidation value will be low $\widetilde{\beta} = \underline{\beta}$, implying a low liquidation threshold $\overline{\theta}_2^{\mathrm{i,D}}$ given by equation (7) with $\beta = \underline{\beta}$. Likewise, if the other bank does not liquidate, the liquidation value is high and the withdrawal threshold $\overline{\theta}_2^{\mathrm{i,N}}$ is given by equation (7) with $\beta = \overline{\beta}$. Note that $\overline{\theta}_2^{\mathrm{i,D}} < \overline{\theta}_2^{\mathrm{i,N}}$.

Two effects arise from the introduction of fire sales. First, there is an amplification effect in times of crisis: if it rains, it pours. If a given bank's fundamental is bad ($\overline{\theta}_2^{\mathrm{i,D}}$) and it has to liquidate its assets and detrimentally affects the liquidiation value of the other bank. While joint liquidation adversely affects the incidence of a systemic crisis, the probability of the occurence of such a crisis is unaffected. A second effect is at work for interim fundamentals ($\overline{\theta}_2^{\mathrm{i,D}} \leq \theta \leq \overline{\theta}_2^{\mathrm{i,N}}$). Given that the other bank liquidates, the liquidation value will be low and it is optimal for late depositors not to withdraw and thus for the bank not to liquidate. Hence, late depositors' optimal behaviour exhibits *strategic substitutability.*

The equilibrium behaviour of late households is symmetric across regions. In case of extreme fundamentals, the households' withdrawal decision is independent from the other region. Late households keep their funds at the bank if fundamentals are good ($\theta \geq \overline{\theta}_2^{\mathrm{i,N}}$) and withdraw their funds if fundamentals are bad ($\theta \leq \overline{\theta}_2^{\mathrm{i,D}}$). There is strategic substitutability in the withdrawal decision of late households across regions for interim fundamentals ($\overline{\theta}_2^{\mathrm{i,D}} \leq \theta \leq \overline{\theta}_2^{\mathrm{i,N}}$). This leads to multiple equilibria (in pure strategies) if both regions' fundamentals are in the interim region.[11]

The equilibrium behaviour is summarised in Figure 4. If both regions' fundamentals are worse than the lower threshold $\overline{\theta}_2^{\mathrm{i,D}}$, a systemic crisis occurs. None of the pure-strategy multiple equilibria contribute to systemic risk. We label this stabilizing effect as a *calm before the storm.* Systemic risk in the informed case is thus:

$$SR_2^{\mathrm{i}} = (\overline{\theta}_2^{\mathrm{i,D}})^2 \tag{17}$$

In the uninformed case, which occurs with probability $1-q$, depositors have no information about the other region's fundamental. The appropriate equilibrium concept is a Bayesian Nash equilibrium:

Definition 2 *In the uninformed case, late households know their own signal θ_k only and*

[11] We focus on pure strategy equilibria throughout.

thus play an incomplete information withdrawal game. A strategy is a mapping from the signal θ_k into the binary withdrawal action. A collection of strategies constitutes a (Bayesian Nash) equilibrium if the strategy in each region maximizes the expected utility of late households, taking the other regions' late households strategy as given.

Note that the need for taking expectations arises from both the exogenous uncertainty about the investment project return and, crucially, the strategic uncertainty about the other region's type. We now determine late households' expected utility from withdrawing and waiting, respectively. Fire sales only affect the expected utility of liquidation relative to the baseline case:

$$\mathbb{E}[u(\widetilde{d}_\beta)] = \underbrace{\overline{\theta}^{\text{u}}_{-k} u(\underline{d}_\beta)}_{\text{-k withdraws}} + \underbrace{(1-\overline{\theta}^{\text{u}}_{-k}) u(\overline{d}_\beta)}_{\text{-k waits}} \tag{18}$$

where $\widetilde{d}_\beta \equiv y + (1-y)\widetilde{\beta} \in \{\underline{d}_\beta, \overline{d}_\beta\}$. We maintain the assumption of symmetric transparency such that k is uninformed if and only if $-k$ is. Thus, the equilibrium withdrawal threshold is symmetric $\overline{\theta}^{\text{u}}_{-k} = \overline{\theta}^{\text{u}}_{k} \equiv \overline{\theta}^{\text{u}}$ and given by:

$$\overline{\theta}^{\text{u}} = p^{-1}\left(\frac{\overline{\theta}^{\text{u}} u(\underline{d}_\beta) + (1-\overline{\theta}^{\text{u}}) u(\overline{d}_\beta) - u(c_1^B)}{u(c_1^G) - u(c_1^B)}\right) \tag{19}$$

For the special case of linear success probability ($p(\theta) = \theta$), we obtain a closed-form expression for the withdrawal threshold:

$$\overline{\theta}^{\text{u}} = \frac{u(\overline{d}_\beta) - u(c_1^B)}{u(c_1^G) - u(c_1^B) + u(\overline{d}_\beta) - u(\underline{d}_\beta)} \tag{20}$$

The probability of a systemic crisis is thus:

$$SR_2^{\text{u}} = (\overline{\theta}^{\text{u}})^2 \tag{21}$$

Comparing the withdrawal thresholds of the informed and uninformed cases, we find the following ranking:

$$\overline{\theta}_2^{\text{i,N}} > \overline{\theta}^{\text{u}} > \overline{\theta}_2^{\text{i,D}} \tag{22}$$

The results are intuitive as the uninformed case is the average over both informed cases.

Having determined the equilibrium behaviour and threshold ranking, we are now ready to describe the overall systemic risk in the case of pure interbank contagion. Overall systemic risk is the weighted average of systemic risk in the informed and uninformed cases, where weight is given by the transparency parameter q:

$$SR \equiv qSR^{\mathrm{i}} + (1-q)SR^{\mathrm{u}} \tag{23}$$

When transparency increases, the informed case becomes relatively more important. Since systemic risk in the informed case is lower than in the uninformed case because of the threshold ranking, overall systemic risk decreases. Hence, more transparency lowers systemic risk in the model with pure fire sales. While the effect of transparency on systemic risk is unambiguous, its effect on individual default probabilities is less clear.

Comparison of systemic risk across cases. We close by comparing the thresholds and the induced level of systemic risk in the case of pure fire sales with the baseline case, evaluated at the social planner allocation. The liquidation value is high in the absence of fire sales ($\beta = \overline{\beta}$), implying that the baseline-case liquidation proceeds equal the high liquidation proceeds in the fire-sale case ($d_\beta = \overline{d}_\beta$). Subsequently, the the threshold in the baseline case equals the no-deafult threshold ($\overline{\theta}_2^{\mathrm{i,D}} < \overline{\theta}_2^{\mathrm{i,N}} = \overline{\theta}_1$).

Proposition 1 *Systemic risk in the case of indirect linkages only is lower than in the baseline case for any level of transparency. Furthermore, more transparency leads to a greater reduction in systemic risk.*

3.3 Interbank contagion

Banks are linked via interbank insurance because of negatively correlated liquidity shocks ($\eta > 0$). When mutually insuring themselves, banks face a trade-off between liquidity insurance and interbank contagion. Faced with low liquidity demand at the interim date ($\widetilde{\lambda} = \lambda_L$), the bank pays b as agreed at the initial date. At the final date it receives ϕb if the other bank, which faced a high liquidity demand at the interim date ($\widetilde{\lambda} = \lambda_H$), survives. Dasgupta (2004) discusses two possible forms of contagion. Positive contagion occurs upon the failure of the creditor bank. Then, the debtor does not have to repay, leading to its stabilization. We exclude this form of contagion by assuming a liquidator for the defaulting bank to which the surviving bank has to repay its debt at the final date. This assumption is plausible as the liquidation of banks destroys value due to fire sales but not claims on viable institutions. Debtor contagion occurs if the debtor fails, causing the creditor to suffer a loss. There is an intermediate range of fundamentals for which the creditor bank survives if and only if the interbank loan is repaid.

We start by determining the payoffs and the optimal withdrawal decision in the high liquidity demand region ($\widetilde{\lambda} = \lambda_H$). As there is no effect of region L's behaviour on region H's depositor payoffs, the following derivation is valid for both the informed and uninformed case. We compare the bank run case in which all households withdraw with the case of no withdrawals. In the case of a bank run, all funds are liquidated and the interbank loan is not repaid. Thus, the impatient households' payoff is $y + \beta(1-y) + b = d_\beta + b$. In the case of no bank run, the patient households' payoffs in the good and bad states are:

$$c_{3H}^G = \frac{(1-y)R + y - \lambda_H d_1 - (\phi - 1)b}{1 - \lambda_H} \tag{24}$$

$$c_{3H}^B = \frac{y - \lambda_H d_1 - (\phi - 1)b}{1 - \lambda_H} \tag{25}$$

The withdrawal threshold $\overline{\theta}_{3,\mathrm{H}}$ in the high liquidity demand region is obtained from the indifference between being patient with payoff $p(\bar{\theta}_{3H})u(c_{3H}^G) + [1 - p(\bar{\theta}_{3H})]u(c_{3H}^B)$ and impatient with payoff $u(d_\beta + b)$:

$$\overline{\theta}_{3,\mathrm{H}} \equiv p^{-1}\left(\frac{u(d_\beta + b) - u(c_{3H}^B)}{u(c_{3H}^G) - u(c_{3H}^B)}\right) \tag{26}$$

Given the uniform distribution of the fundamental, the probability of default in region H is identical to the withdrawal threshold $\overline{\theta}_{3,\mathrm{H}}$.

The bank in the low liquidity demand region L has excess liquidity at the interim date and pays b to the bank in the high liquidity demand region. In the case of a bank run in L, all assets including the financial claim on the other region are liquidated, yielding a payoff $d_\beta - b + \beta\phi\widetilde{b}$. The repayment of the interbank claim $\widetilde{b}$ is uncertain. It yields b if H repays, which happens with survival probability $(1 - \overline{\theta}_{3,\mathrm{H}})$, and zero otherwise. The liquidation value of the interbank claim is positive in case of repayment only. Patient households receive:

$$c_{3L}^{GN} \equiv \left(\frac{R(1-y)+(y-\lambda_L d_1)+(\phi-1)b}{1-\lambda_L}\right) \tag{27}$$

$$c_{3L}^{GD} \equiv \left(\frac{R(1-y)+(y-\lambda_L d_1)-b}{1-\lambda_L}\right) \tag{28}$$

$$c_{3L}^{BN} \equiv \left(\frac{(y-\lambda_L d_1)+(\phi-1)b}{1-\lambda_L}\right) \tag{29}$$

$$c_{3L}^{BD} \equiv \left(\frac{(y-\lambda_L d_1)-b}{1-\lambda_L}\right) \tag{30}$$

where superscripts (G, B) denote success and failure of the investment project and (N, D) denote survival and default of the bank in the high liquidity demand region.

In the uninformed case households in the low liquidity demand region know their fundamental θ_L only and take expectations over all possible fundamentals in region H. The expected payoff from being patient is the sum of two terms: (i) with probability $\overline{\theta}_{3,\mathrm{H}}$ the bank in region H defaults and patient households in region L receive $[p(\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}})u(c_{3L}^{GD})+(1-p(\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}})u(c_{3L}^{BD})]$; (ii) with probability $(1-\overline{\theta}_{3,\mathrm{H}})$ the bank in region H survives and patient households in region L receive $[p(\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}})u(c_{3L}^{GN})+(1-p(\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}})u(c_{3L}^{BN})]$. The expected payoff from being impatient is $u(d_\beta - b)$. The withdrawal threshold $\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}}$ is again determined by the indifference of late households between both options:

$$\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}} \equiv p^{-1}\left(\frac{\overline{\theta}_{3,\mathrm{H}}[u(d_\beta-b)-u(c_{3L}^{BD})]+(1-\overline{\theta}_{3,\mathrm{H}})[u(d_\beta-b[1-\beta\phi])-u(c_{3L}^{BN})]}{\overline{\theta}_{3,\mathrm{H}}[u(c_{3L}^{GD})-u(c_{3L}^{BD})]+(1-\overline{\theta}_{3,\mathrm{H}})[u(c_{3L}^{GN})-u(c_{3L}^{BN})]}\right) \tag{31}$$

The withdrawal decision of late households in region H affects the withdrawal decision of late households in region L, such that $\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}} = \overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}}(\overline{\theta}_{3,\mathrm{H}})$. That is, the impatience of late households in region H constitutes a negative externality on the payoffs of late households in region L (interbank contagion). In particular, the withdrawal threshold of uninformed households in the low liquidity demand region is strictly increasing in the withdrawal threshold of uninformed households in the high liquidity demand region ($\partial\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}}/\partial\overline{\theta}_{3,\mathrm{H}} > 0$). This result is obtained by direct differentiation and the derivative is stated in Appendix (A.2.1).

In the informed case depositors in L know the fundamental in region H and thus whether or not there is a default. The equilibrium withdrawal thresholds $\overline{\theta}^{\mathrm{i,N}}_{3,\mathrm{L}}$ and $\overline{\theta}^{\mathrm{i,D}}_{3,\mathrm{L}}$ are special cases of the uninformed threshold $\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}}$. The threshold in region L is obtained for $\overline{\theta}_{3,\mathrm{H}} \to 0$ if the bank in region H survives and for $\overline{\theta}_{3,\mathrm{H}} \to 1$ if it defaults. As in the case of pure fire sales, the withdrawal thresholds are ranked:

$$\overline{\theta}^{\mathrm{i,N}}_{3,\mathrm{L}} < \overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}} < \overline{\theta}^{\mathrm{i,D}}_{3,\mathrm{L}} \tag{32}$$

Similar to Dasgupta (2004) there is a region of fundamentals $[\overline{\theta}^{\mathrm{i,N}}_{3,\mathrm{L}}, \overline{\theta}^{\mathrm{i,D}}_{3,\mathrm{L}}]$ for which the bank in region L defaults if and only if the the bank in region H defaults. Systemic risk in the informed and uninformed case, respectively, is given by:

$$SR^{\mathrm{u}}_3 = \overline{\theta}_{3,\mathrm{H}}\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}} \tag{33}$$

$$SR^{\mathrm{i}}_3 = \overline{\theta}_{3,\mathrm{H}}\overline{\theta}^{\mathrm{i,D}}_{3,\mathrm{L}} > SR^{\mathrm{u}}_3 \tag{34}$$

where the ranking of systemic risks is a direct consequence of the threshold ranking. This implies that more transparency increases overall systemic risk in the model with pure interbank contagion.

Comparison of systemic risk across cases. We compare the thresholds and the induced level of systemic risk in the case of interbank contagion with the baseline case. As the households receive more funds in case of direct financial linkages than without any linkages, their incentive to default increases ($\overline{\theta}_{3,\mathrm{H}} > \overline{\theta}_1$). The effect on region L's households is unclear in general as may they gain if H repays but lose funds if H defaults. While the introduction of direct interbank linkages tends to increase systemic risk, its effect is in general ambiguous.

Proposition 2 *Systemic risk in the case of direct linkages may or may not be lower than in the baseline case. More transparency unambiguously increases systemic risk.*

3.4 Fire sales and interbank contagion

This section considers the joint presence of fire sales and interbank contagion. As before, we find the thresholds in the high and low liquidity demand region for the uninformed case and then derive the informed case as a limit. A description of the equilibrium behaviour and the associated systemic risk follows.

In the high liquidity demand region, consider first the uninformed case. Impatient households receive $\overline{d}_\beta + b$ if the bank in region L does not default and $\underline{d}_\beta + b$ if it does. Liquidation in region L takes place if the signal falls short of a threshold $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}}$ yet to be determined. Thus, the expected utility of impatient households in region H is:

$$\mathbb{E}[u(\widetilde{d}_\beta + b)] = \underbrace{\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}} u(\underline{d}_\beta + b)}_{\text{L defaults}} + \underbrace{(1 - \overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}}) u(\overline{d}_\beta + b)}_{\text{L survives}} \tag{35}$$

If households are patient, they receive c^G_{2H} and c^B_{2H}, depending on the investment project's success. The expected utility from being patient is $p(\bar{\theta}^u_{4H})u(c^G_{3H}) + [1 - p(\bar{\theta}^u_{4H})]u(c^B_{3H})$. Equating both options yields the high liquidity demand region's withdrawal threshold $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}} = \overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}(\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}})$, where the dependence on the low liquidity demand region arises from fire sales only. The threshold is defined by:

$$\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}} = p^{-1}\left(\frac{(1 - \overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}})u(\overline{d}_\beta + b) + \overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}} u(\underline{d}_\beta + b) - u(c^B_{3H})}{u(c^G_{3H}) - u(c^B_{3H})}\right) \tag{36}$$

The withdrawal decision exhibits strategic substitutability: the withdrawal probability in the high liquidity demand region decreases with increasing withdrawal probability in the low liquidity demand region ($\partial\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}/\partial\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}} < 0$).

The informed-case thresholds in region H are the limiting cases of the uninformed threshold: $\overline{\theta}^{\mathrm{i,D}}_{4,\mathrm{H}}$ is given by equation (36) as $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}} \to 1$ and $\overline{\theta}^{\mathrm{i,N}}_{4,\mathrm{H}}$ as $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}} \to 0$, respectively. As in the pure fire sale case, the threshold ranking in the high liquidity demand region is $\overline{\theta}^{\mathrm{i,D}}_{4,\mathrm{H}} < \overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}} < \overline{\theta}^{\mathrm{i,N}}_{4,\mathrm{H}}$.

In the low liquidity demand region we first consider the uninformed case. Impatient households' payoff is conditional on the withdrawal decision of late households in the high liquidity demand region. Impatient households in L receive $\overline{d}_\beta - b$ if the bank in region H survives and $\underline{d}_\beta - b$ if it defaults. Liquidation in region H takes place if the signal falls short of the threshold $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}$. Thus, the expected utility of impatient households in region L is $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}} u(\underline{d}_\beta - b) + (1 - \overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}})u(\overline{d}_\beta - b[1 - \beta\phi])$. This shows that the liquidation of the interbank claim amplifies the fire sale effect. Patient households' payoff depends on both the success of the investment project and the repayment of the interbank claim. Hence, they receive c_{3L}^{GN}, c_{3L}^{GD}, c_{3L}^{BN}, and c_{3L}^{BD}, respectively. The expected utility from being patient has two terms. If the investment project is successful, which happens with probability $p(\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}})$, patient households obtain $[\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}} u(c_{3L}^{GD}) + (1 - \overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}) u(c_{3L}^{GN})]$. Else, they receive $[\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}} u(c_{3L}^{BD}) + (1 - \overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}) u(c_{3L}^{BN})]$, which happens with probability $(1 - p(\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}}))$.

The uninformed-case withdrawal threshold in the low liquidity demand region region $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}} = \overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}}(\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}})$ is determined by the indifference between being patient and impatient:

$$\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}} \equiv p^{-1} \left(\frac{\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}[u(\underline{d}_{\beta} - b) - u(c_{3L}^{BD})] + (1 - \overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}})[u(\overline{d}_{\beta} - b[1 - \overline{\beta}\phi]) - u(c_{3L}^{BN})]}{\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}[u(c_{3L}^{GD}) - u(c_{3L}^{BD})] + (1 - \overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}})[u(c_{3L}^{GN}) - u(c_{3L}^{BN})]} \right) \tag{37}$$

The dependence of the threshold on the high liquidity demand region arises from both fire sales and interbank contagion, such that the the effect of $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}$ on $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}}$ is in general ambiguous. If the effects of fire sales dominate the effects of interbank contagion, the withdrawal threshold in region L is negatively associated with the withdrawal threshold in region H ($\partial\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}}/\partial\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}} < 0$). However, the association between thresholds is positive if the effects of interbank contagion dominate the effects of fire sales ($\partial\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}}/\partial\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}} > 0$), which is derived in Appendix (A.2.2).

The thresholds in region L for the informed case are again obtained as limiting cases: $\overline{\theta}^{\mathrm{i,D}}_{4,\mathrm{L}}$ is given by equation (37) as $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}} \to 1$ and $\overline{\theta}^{\mathrm{i,N}}_{4,\mathrm{L}}$ as $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}} \to 0$, respectively. The ranking of the withdrawal thresholds now depends on the relative strength of fire sales and interbank contagion: (i) if the effects of fire sales dominate the effects of interbank contagion, then $\overline{\theta}^{\mathrm{i,D}}_{4,\mathrm{H}} < \overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}} < \overline{\theta}^{\mathrm{i,N}}_{4,\mathrm{H}}$; (ii) if the effects of interbank contagion dominate the effects of fire sales, then $\overline{\theta}^{\mathrm{i,N}}_{4,\mathrm{H}} < \overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}} < \overline{\theta}^{\mathrm{i,D}}_{4,\mathrm{H}}$.

We now combine the individually optimal behaviour into the equilibrium outcomes. The equilibrium thresholds in the uninformed case, $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}$ and $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}}$, are jointly determined by equations (36) and (37), where existence and uniqueness are shown for the linear case

($p(\theta) = \theta$) in Appendix (A.2.2). Then, systemic risk in the uninformed case is:

$$SR_4^{\mathrm{u}} = \overline{\theta}_{4,\mathrm{H}}^{\mathrm{u}} \overline{\theta}_{4,\mathrm{L}}^{\mathrm{u}} \tag{38}$$

The equilibrium in the informed case is characterised by the following thresholds. Late households in H do not withdraw if the fundamentals are good ($\theta_H > \overline{\theta}_{4,\mathrm{H}}^{\mathrm{i,N}}$) and withdraw if the fundamentals are bad ($\theta_H < \overline{\theta}_{4,\mathrm{H}}^{\mathrm{i,D}}$). Because of strategic substitutability they withdraw if and only if late households in region L do not withdraw for interim fundamentals ($\overline{\theta}_{4,\mathrm{H}}^{\mathrm{i,D}} \leq \theta_H \leq \overline{\theta}_{4,\mathrm{H}}^{\mathrm{i,N}}$). A similar argument applies for late households in region L and we consider the two cases of dominant fire sale and interbank contagion effects in turn. If the effects of fire sales are dominant, $\overline{\theta}_{4,\mathrm{L}}^{\mathrm{i,D}} < \overline{\theta}_{4,\mathrm{L}}^{\mathrm{i,N}}$. Likewise, dominant effects of interbank contagion imply $\overline{\theta}_{4,\mathrm{L}}^{\mathrm{i,N}} < \overline{\theta}_{4,\mathrm{L}}^{\mathrm{i,D}}$. Late households that receive a signal above the larger of the two thresholds are always patient, while households that receive a signal below the smaller of the two thresholds are always impatient. As in the case of pure fire sales, there is multiplicity of equilibria for jointly interim fundamentals.

The interaction of interbank contagion and fire sales results in an ambiguous role of transparency for systemic risk described in Proposition (3):

Proposition 3 *Consider the unified model of systemic risk with both direct and indirect financial linkages. If the effect of indirect linkages (calm before the storm) dominate the effect of direct linkages (contagion), more transparency unambiguously reduces systemic risk. If effect of interbank contagion are sufficiently dominant, more transparency increases systemic risk.*

To prove Proposition (3), note that systemic risk is defined as $SR_4^{\mathrm{i}} \equiv \overline{\theta}_{4,\mathrm{L}}^{\mathrm{i,D}} \overline{\theta}_{4,\mathrm{H}}^{\mathrm{i,D}}$ in the informed case, and as $SR_4^{\mathrm{u}} \equiv \overline{\theta}_{4,\mathrm{L}}^{\mathrm{u}} \overline{\theta}_{4,\mathrm{H}}^{\mathrm{u}}$ in the uninformed case. Transparency shifts overall systemic risk from the uninformed to the informed case. Since $\overline{\theta}_{4,\mathrm{H}}^{\mathrm{i,D}} < \overline{\theta}_{4,\mathrm{H}}^{\mathrm{u}}$, the partial impact from region H always reduces systemic risk. By contrast, the partial impact from region L depends on the relative strength of the effects of fire sales and interbank contagion. Particularly, the partial impact from region L is negative if the effects of fire sales are dominant, whereas it is positive if the effects of interbank contagion are dominant. Hence, increasing transparency unambiguously reduces systemic risk if the effects of fire sales are dominant, while it increases systemic risk if the effects of interbank contagion are sufficiently dominant. A sufficient condition is derived for the latter case in Appendix (A.2.2), highlighting that the interbank contagion component dominates the fire sale components:

$$\underbrace{\frac{u(c_{3L}^{BN}) - u(c_{3L}^{BD})}{u(\underline{d}_\beta - b) - u(c_{3L}^{BD})}}_{\text{contagion effect in region L}} > \underbrace{\frac{u(\overline{d}_\beta + b) - u(\underline{d}_\beta + b)}{u(\underline{d}_\beta + b) - u(c_{3H}^{B})}}_{\text{fire sale effect in region H}} + \underbrace{\frac{u(\overline{d}_\beta - b(1-\beta\phi)) - u(\underline{d}_\beta - b)}{u(\underline{d}_\beta - b) - u(c_{3L}^{BD})}}_{\text{fire sale effect in region L}} \tag{39}$$

Comparison of systemic risk across cases. We now compare the system risk in the case of direct and indirect financial linkages to the case of pure direct linkages. Establishing a key result, we show that the introduction of indirect linkages may *lower* systemic risk. Moreover, we derive a condition under which it always lowers systemic risk.

We start by noting that the introduction of fire sales has a stabilising effect on region H because of the addition of strategic substitutability ($\overline{\theta}_{\mathrm{4,H}}^{\mathrm{i,D}} < \overline{\theta}_{\mathrm{4,H}}^{\mathrm{u}} < \overline{\theta}_{\mathrm{4,H}}^{\mathrm{i,N}} = \overline{\theta}_{\mathrm{3,H}}$). Two main effects are present in region L.[12] First, there is a similar fire-sale effect that reduces the liquidation value and thus tends to drive down the threshold. This effect is direct as results from the change in payoffs arising from fire sales. Second, there is an indirect effect arising from the reduction in region H's threshold. The sign of this effect is in general ambiguous and depends again on the relative strenght of fire sales and and interbank contagion. Taking the argument a step further, the introduction of fire sales *always* reduces systemic risk if fire sales are relatively strong, as given by the condition $A \leq 0$ derived in Appendix (A.2.2).

Proposition 4 *Systemic risk in the case of both direct and indirect linkages may be lower than in the case of pure (potentially contagious) direct linkages. In particular, systemic risk is always lower if the calm before the storm effect is strong relative to interbank contagion (*$A \leq 0$*).*

[12]There is weak third effect from concavity that tends to be small.

4 Policy implications and concluding remarks

This paper argues that the financial system fundamentally changed in the previous decade. Both direct and indirect linkages amongst financial intermediaries increased substantially. At the same time, the transparency of the financial system decreased, a development epitomised by the surge in over-the-counter derivatives market size. We develop a model of an interconnected financial system and examine its consequences for systemic risk and transparency regulation.

The first ingredient of our two-region model with depositors and a representative bank in each region are direct linkages such as interbank loans. They may result in a non-pecuniary counterparty-risk externality. The repayment of interbank loans stabilises the creditor bank, while a default of the debtor bank increases the chance of a creditor bank default (contagion). Thus, depositor withdrawals in the debtor region induce depositors in the creditor region to withdraw as well. Our second ingredient is a joint liquidation market as a form of indirect financial linkage. The joint liquidation market is associated with a well-understood pecuniary externality. If a bank is forced to liquidate, the liquidation price of its investments will be lower if the other bank also liquidates. Such fire sales occur after bad solvency shocks and constitute an endogenous cost of a systemic financial crisis.

A main contribution of our paper is the description of a novel effect of indirect linkages. A *calm-before-the-storm* effect is present for interim solvency shocks. Depositors only withdraw if the other region's depositors do not withdraw. This displays a strategic substitutability in late households' withdrawal decision that stabilises the financial system by reducing systemic risk. We examine the consequences of the *calm-before-the-storm* effect in a unified model of systemic risk with both direct and indirect financial linkages. We show that systemic risk may be reduced if the *calm-before-the-storm* effect is strong relative to the effect of interbank contagion.

Transparency, our third ingredient, is captured by how much less precise a depositor's signal about the other region's investment profitability is, relative to his own region. Transparency is an amplification mechanism in our model. A main result of our paper is that the overall impact of transparency on systemic risk is ambiguous. It depends on the relative strength of the effects from direct to indirect financial linkagess. In particular, transparency will reduce systemic risk if the effect of indirect linkage, the calm-before-the-storm effect, dominates. Thus, we demonstrate that financial crises are not an inevitable consequence of the three key developments that mark the fundamental structural change in the financial system. More generally, we study which combination direct and indirect linkages as well as transparency is conducive to systemic risk. Our model suggests that the recent financial crisis can be understood as a manifestation of systemic risk in times of substantial indirect linkages relative to interbank contagion and a low degree of transparency.

Our model has applications to the current debate on regulatory reform. The recently endorsed Basel III framework largely focuses on a reform of the first two pillars of the Basel II framework on banking supervision. The proposal includes stronger capital requirements, two liquidity ratios, and evaluating a leverage ratio. Few and only minor changes have been proposed to the third pillar, which is concerned with market discipline and transparency. By contrast, our paper recommends a much larger weight be put on this pillar. As we show, there is a combination of indirect linkages (joint liquidation market), direct linkages (interbank contagion), and transparency that achieves a low level of systemic risk. Thus, our model sheds light on the issue of which level of transparency minimizes systemic risk, given the relative strength of the respective financial linkages. Based on our findings, we argue for (i) an identification of the relative strength of financial linkages in a truly macroprudential framework and (ii) and a dynamic implementation of transparency rules within pillar three, as a high level of transparency may be conducive to systemic risk at some times.

A Appendix

A.1 Optimal withdrawal proportion of late households

The coordination device assumed in the model allows late households to coordinate on full withdrawals or no withdrawals at all in the absence of a strictly dominant strategy. This section considers the relaxation of this assumption by allowing late households to coordinate on any withdrawal proportion $n \in [0, 1]$.

To characterise the late household's incentives, the following two thresholds are helpful: a liquidation threshold n_0 and a solvency threshold $n_1 > n_0$. The solvency threshold is defined as the proportion of withdrawing late households that fully deplete the bank's asset under full liquidation and is given by:

$$d_1[\lambda + n_1(1-\lambda)] = y + \beta(1-y) \quad \equiv \quad d_\beta \tag{40}$$

$$\Rightarrow \frac{1}{1-\lambda}\left(\frac{d_\beta}{d_1} - \lambda\right) \quad \equiv \quad n_1 \tag{41}$$

Similarly, the liquidation threshold n_0 is given by the proportion of withdrawing late households that induces positive liquidation:

$$d_1[\lambda + n_0(1-y)] \quad = \quad y \qquad \Leftrightarrow \tag{42}$$

$$\frac{1}{1-\lambda}\left(\frac{y}{d_1} - \lambda\right) \quad \equiv \quad n_0 = \frac{y - \lambda d_1}{(1-\lambda)d_1} \tag{43}$$

Note that $n_0 = 0$ if there is no excess liquidity.

Proposition 5 *If the success probability is linear in the fundamental, $p(\theta) = \theta$, then*

$$\frac{\partial \mathbb{E}[u(c_2(n, \widetilde{\gamma}_k))]}{\partial n} \leq 0$$

.

There are three relevant cases: n may be below n_0, between n_0 and n_1 and above n_1. For $n \in [0, n_0]$, the bank accomodates the liquidity demand from the few withdrawing late households with excess liquidity $y - \lambda d_1$.

Case 1: $n \geq n_1$ The claim is trivially satisfied for this range. The bank always liquidates its portfolio in full such that no funds will be received tomorrow: $c_2 = 0$.

Case 2: $n \in [n_0, n_1]$ Let the liquidated share in case of partial liquidation be denoted by $\alpha \in [0, 1]$. Equating $d_1[\lambda + n(1-\lambda)]$ and $y + \alpha(1-y)\beta$ yields:

$$\alpha = \frac{d_1[\lambda + n(1-\lambda)] - y}{\beta(1-y)} \tag{44}$$

Note that more liqudity implies a lower liquidation share ($\partial\alpha/\partial y < 0$). Consider the resources available in $t = 2$. Late households expect to obtain $(1-\alpha)(1-y)\widetilde{\gamma}_k$ which has to be divided by $(1-n)(1-\lambda)$ late consumers, where $(1-\alpha) = \frac{d_\beta - d_1[\lambda+n(1-\lambda)]}{\beta(1-y)}$. This leads to:

$$(1-n)(1-\lambda)\widetilde{c}_2 = \frac{d_\beta - d_1[\lambda + n(1-\lambda)]}{\beta}\widetilde{\gamma}_k \quad \Leftrightarrow \tag{45}$$

$$\widetilde{c}_2(n, \widetilde{\gamma}_k) = \underbrace{\frac{d_\beta - d_1[\lambda + n(1-\lambda)]}{\beta(1-n)(1-\lambda)}}_{\kappa}\widetilde{\gamma}_k \tag{46}$$

Direct differentiation reveals that the coefficient κ is strictly decreasing in n for $n \in [n_0, n_1]$. Thus, the expectation $\mathbb{E}[u(c_2(n, \widetilde{\gamma}_k)]$ is strictly decreasing in n for $n \in [n_0, n_1]$.

Case 3: $n \in [0, n_0]$ There is excess liquidity in this case. Then, $\alpha = 0$ and $d_1[\lambda + (1-\lambda)n] \leq y$ at the interim date. Thus, funds worth $(1-y)\widetilde{\gamma}_k + y - d_1[\lambda + (1-\lambda)n]$ are available at the final date, where $\widetilde{\gamma}_k$ is the posterior distribution of the bivariate investment return given the receipt of the signal. This leads to patient household's consumption level of

$$\widetilde{c}_2(n, \widetilde{\gamma}_k) = \frac{(1-y)\widetilde{\gamma}_k + (y - d_1[\lambda + n(1-\lambda)])}{(1-n)(1-\lambda)} \tag{47}$$

There are two effects from a deline in n: more excess liquidity, but also more people to share with, which implies that the overall effect is ambiguous in general. The derivative is given by:

$$\frac{\partial\widetilde{c}_2(n, \widetilde{\gamma}_k)}{\partial n} = \frac{y + (1-y)\widetilde{\gamma}_k - d_1}{(1-\lambda)(1-n)^2} \tag{48}$$

and the expectation by:

$$\frac{\partial \mathbb{E}_{\widetilde{\gamma}_k}[\cdot]}{\partial n} = \mathbb{E}\left[u'(c_2)\frac{y - d_1 + (1-y)\widetilde{\gamma}_k}{(1-\lambda)(1-n)^2}\right] \tag{49}$$

Using $\mathbb{E}[XY] = \mathbb{E}[X]\mathbb{E}[Y] + cov(X,Y)$, one obtains:

$$\mathbb{E}[u'(c_2)]\underbrace{\mathbb{E}\left[\frac{y - d_1 + (1-y)\widetilde{\gamma}_k}{(1-\lambda)(1-n)^2}\right]}_{B} + \underbrace{cov\left(u'(c_2), \frac{y - d_1 + (1-y)\widetilde{\gamma}_k}{(1-\lambda)(1-n)^2}\right)}_{A} \tag{50}$$

The sign of the derivative of the expectation is determined by two terms. The covariance term A is negative: $\gamma_k \uparrow$ implies $c_2 \uparrow$, from which follows $u'(c_2) \downarrow$, as $u''(\cdot) < 0$. Hence, $B \leq 0$ is a sufficient condition for $\partial \mathbb{E}[\cdot]/\partial n < 0$. We show that this will always be satisfied for a linear success probability.

$$\mathbb{E}[y - d_1 + (1-y)\widetilde{\gamma}_k] \leq 0 \quad \Leftrightarrow \quad \theta_k \leq p^{-1}\left(\frac{d_1 - y}{R(1-y)}\right) \tag{51}$$

Note that the resource constraint $d_1 \leq y + (1-y)R$ implies that the above constraint is always satisfied for a linear success probability.

A.2 Calculations

A.2.1 Interbank contagion

There is interbank contagion in the sense that the more likely the bank in H defaults, the more likely the bank in L defaults as well:

$$\frac{\partial \overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}}}{\partial \overline{\theta}_{3,\mathrm{H}}} = \frac{[1 - p(\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}})](u(c^{BN}_{3L}) - u(c^{BD}_{3L})) + p(\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}})(u(c^{GN}_{3L}) - u(c^{GD}_{3L}))}{p'(\overline{\theta}^{\mathrm{u}}_{3,\mathrm{L}})\left(\overline{\theta}_{3,\mathrm{H}}[u(c^{GD}_{3L}) - u(c^{BD}_{3L})] + (1 - \overline{\theta}_{3,\mathrm{H}})[u(c^{GN}_{3L}) - u(c^{BN}_{3L})]\right)} > 0 \tag{52}$$

as $c^{G,N}_{3L} > c^{G,D}_{3L}$ and $c^{B,N}_{3L} > c^{B,D}_{3L}$.

A.2.2 Interbank contagion and fire sales

If both fire sales and interbank contagion are pressent, the effect of higher default probability in region H on region L is ambiguous:

$$\frac{\partial\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}}}{\partial\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}} = \frac{\overbrace{[1-p(\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}})](u(c^{BN}_{3L})-u(c^{BD}_{3L}))+p(\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}})(u(c^{GN}_{3L})-u(c^{GD}_{3L}))}^{\text{interbank contagion: }+}+\overbrace{u(\underline{d}_{\beta}-b)-u(\overline{d}_{\beta}-b(1-\beta\phi))}^{\text{fire sales: -}}}{p'(\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}})\left(\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}}[u(c^{GD}_{3L})-u(c^{BD}_{3L})]+(1-\overline{\theta}^{\mathrm{u}}_{4,\mathrm{H}})[u(c^{GN}_{3L})-u(c^{BN}_{3L})]\right)} \tag{53}$$

Hence, the partial derivative is positive (negative) if interbank contagion (fire sales) is the dominant force. Thus, interbank contagion dominates if and only if:

$$A \equiv [u(c^{BN}_{3L})-u(c^{BD}_{3L})]-[u(\overline{d}_{\beta}-b(1-\beta\phi))-u(\underline{d}_{\beta}-b)] \tag{54}$$

$$A > p(\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}})\left([u(c^{GD}_{3L})-u(c^{BD}_{3L})]-[u(c^{GN}_{3L})-u(c^{BN}_{3L})]\right)>0 \tag{55}$$

where the right-hand side is positive by concavity of the utility function.

We turn to the existence and uniqueness of uninformed-case equilibrium and sketch the proof here. Consider the linear case $p(\theta)=\theta$. Then, the set of equation simplify to a quadratic equation in $\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}}$. As this equation has has exactly one positive root, there exists a unique set of thresholds in the uninformed case.

Finally, we derive a condition sufficient for the effects of interbank contagion on systemic risk to dominate the effects of fire sales on systemic risk. In particular, we consider the case in which fire sales are dominated by interbank contagion in region L such that the condition derived above holds ($A>0$). Note that greater transparency is associated with an increase in systemic risk if and only if the systemic risk in the informed case is larger than the systemic risk in the uninformed case, $SR^i_4 > SR^u_4$. Rewriting this condition under the linearity assumption $\partial(\theta)=\theta$ that we make once more and the assumption of weak concavity ($[u(c^{GD}_{3L})-u(c^{BD}_{3L})]-[u(c^{GN}_{3L})-u(c^{BN}_{3L})]\approx 0$), we obtain:

$$1 > \underbrace{\left(1+(1-\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}})\frac{u(\overline{d}_{\beta}+b)-u(\underline{d}_{\beta}+b)}{u(\underline{d}_{\beta}+b)-u(c^{B}_{3H})}\right)}_{>1}\underbrace{\left(1-(1-\overline{\theta}^{\mathrm{u}}_{4,\mathrm{L}})\frac{A}{u(\underline{d}_{\beta}-b)-u(c^{BD}_{3L})}\right)}_{<1} \tag{56}$$

As the cross term is negative, a sufficient condition for the inequality is:

$$\underbrace{\frac{u(c_{3L}^{BN}) - u(c_{3L}^{BD})}{u(\underline{d}_\beta - b) - u(c_{3L}^{BD})}}_{\text{interbank contagion effect in region L}} > \underbrace{\frac{u(\overline{d}_\beta + b) - u(\underline{d}_\beta + b)}{u(\underline{d}_\beta + b) - u(c_{3H}^{B})}}_{\text{fire sale effect in region H}} + \underbrace{\frac{u(\overline{d}_\beta - b(1-\beta\phi)) - u(\underline{d}_\beta - b)}{u(\underline{d}_\beta - b) - u(c_{3L}^{BD})}}_{\text{fire sale effect in region L}} \tag{57}$$

A.3 Comparative Statics

A.3.1 Baseline case

Consider the implicit definition of $\bar{\theta}_1$ in equation (7). The partial derivative of threshold with respect to the withdrawal at the interim date is thus:

$$\frac{\partial \bar{\theta}_1}{\partial d_1} = \frac{\lambda}{1-\lambda} \frac{[(1-p(\bar{\theta}_1))u'(c_1^B) + p(\bar{\theta}_1)u'(c_1^G)]}{p'(\bar{\theta}_1)[u(c_1^G) - u(c_1^B)]} > 0 \tag{58}$$

Likewise, the partial derivative of the threshold with respect to storage is:

$$p'(\bar{\theta}_1)[u(c_1^G) - u(c_1^B)]\frac{\partial \bar{\theta}_1}{\partial y} = \underbrace{(1-\beta)u'(d_\beta)}_{\text{effect } (i)} + \underbrace{\frac{R-1}{1-\lambda}p(\bar{\theta}_1)u'(c_1^G)}_{\text{effect } (ii)} \underbrace{-\frac{1-p(\bar{\theta}_1)}{1-\lambda}u'(c_1^B)}_{\text{effect } (iii)} \tag{59}$$

The partial derivative of the threshold with respect to the measure of early consumers is:

$$\frac{\partial \bar{\theta}_1}{\partial \lambda} = \frac{-[y + (R+1-2\lambda)]p(\bar{\theta}_1)u'(c_1^G) - [y + d_1(1-2\lambda)](1-p(\bar{\theta}_1))u'(c_1^B)}{p'(\bar{\theta}_1)[u(c_1^G) - u(c_1^B)](1-\lambda)^2} \tag{60}$$

A sufficient condition for $\frac{\partial \bar{\theta}_1}{\partial \lambda} < 0$ is $\lambda \leq \frac{1}{2}$.

A.3.2 Interbank contagion

The derivative of the withdrawal threshold in the high liquidity demand region $\bar{\theta}_{2H}$ with respect to the interbank loan b is:

$$\frac{\partial \bar{\theta}_{2H}}{\partial b} = \frac{u'(d_\beta + b) + \frac{\phi-1}{1-\lambda_H}\left[p(\bar{\theta}_{2H})u'(c_{2H}^G) + (1-p(\bar{\theta}_{2H}))u'(c_{2H}^B)\right]}{p'(\bar{\theta}_{2H})\left[u(c_{2H}^G) - u(c_{2H}^B)\right]} > 0 \ , \tag{61}$$

which is positive as $p'(\cdot) > 0$ and $c_{2H}^G > c_{2H}^B$.

A.4 Figures

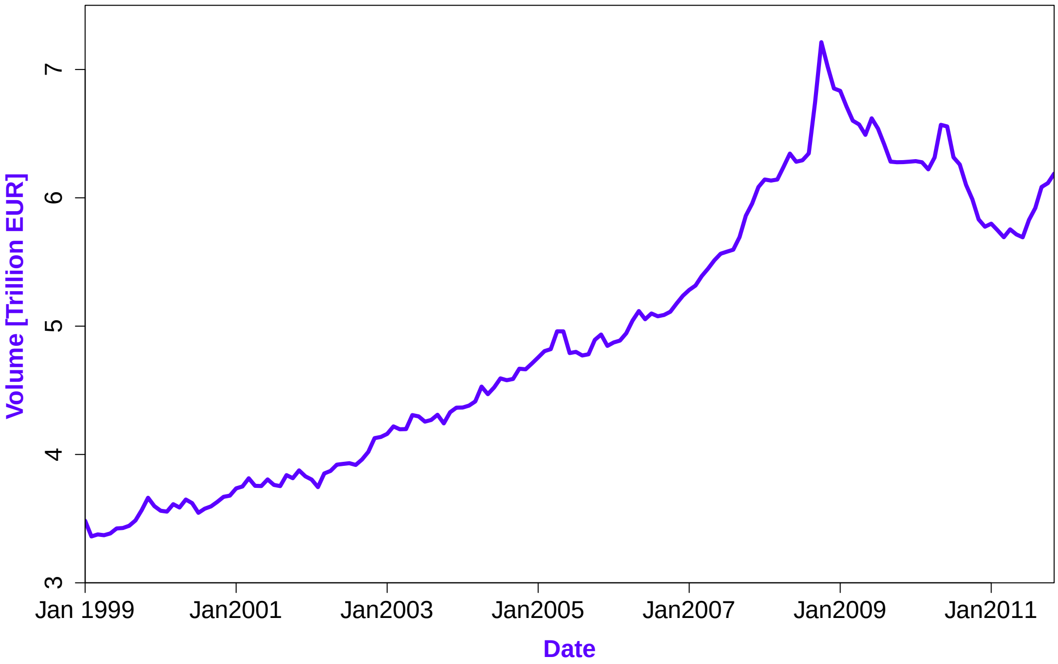

Figure 1: Deposit liabilities of euro area MFIs vs. other euro area MFIs, outstanding amounts at the end of the period, neither seasonally nor working day adjusted. Source: ECB Statistical Data Warehouse.

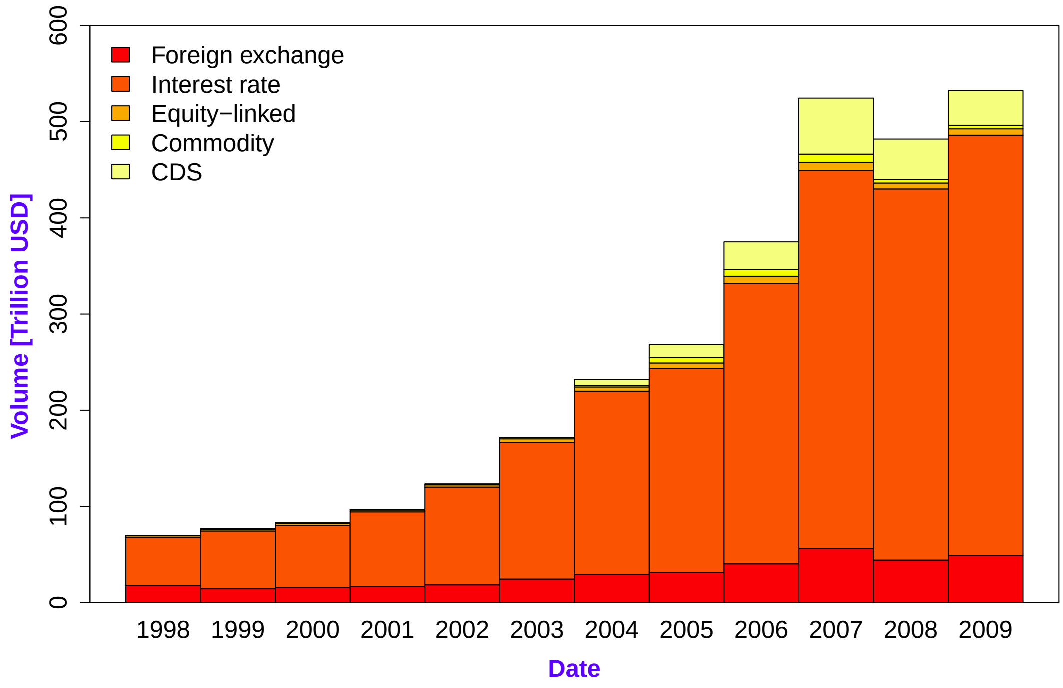

Figure 2: Global Over-the-Counter Derivatives Markets. Notional amounts of contracts outstanding. Source: IMF.

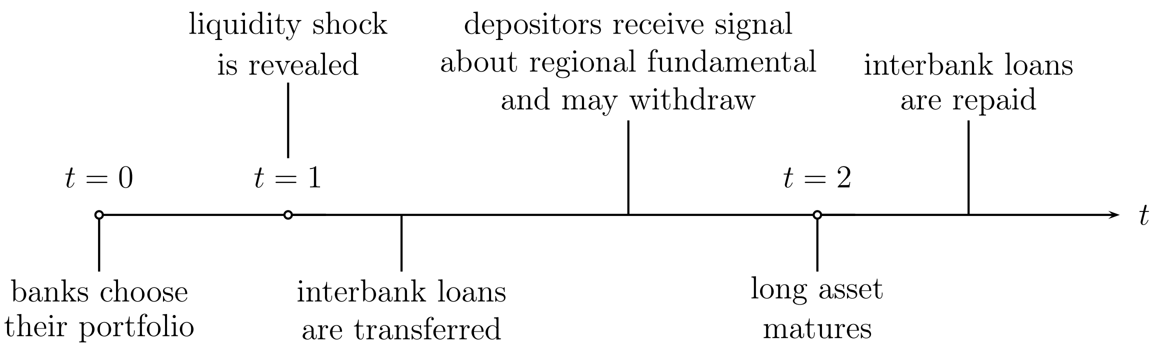

Figure 3: Timeline of the model

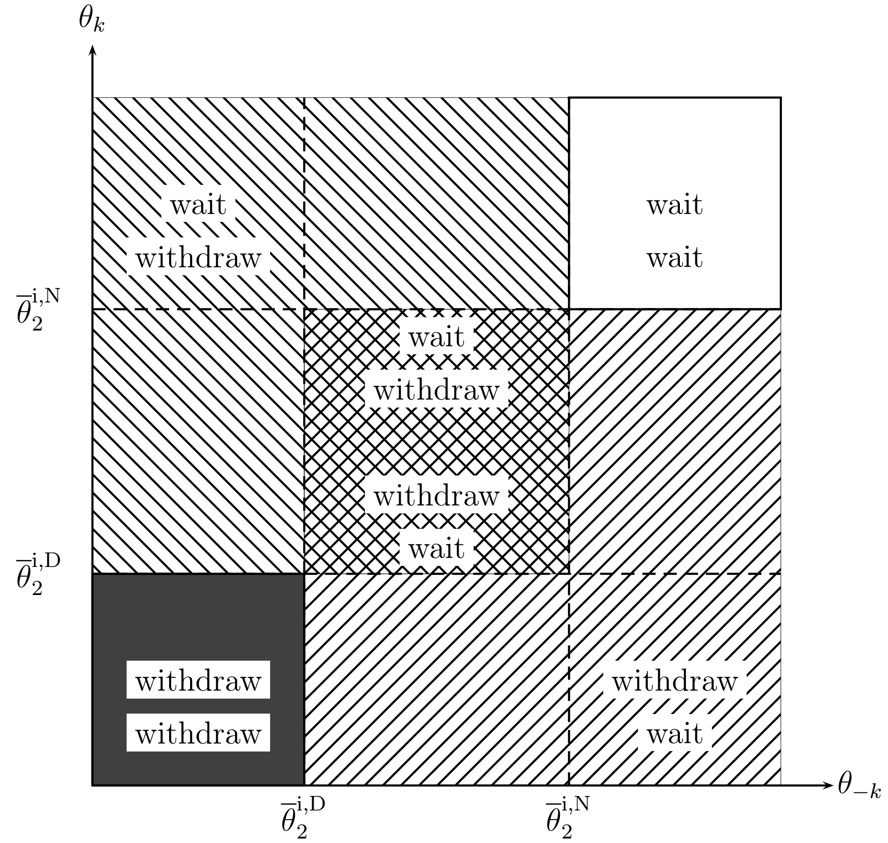

Figure 4: Equilibrium behaviour in the pure fire sale case. The above (below) action refers to the late households in region k ($-k$). Signal regions with a unique equilibrium in which late households in only one region withdraw are hatched. Signal regions with multiple equilibria are cross-hatched.

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