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Fire Sales and Bank Runs in the Presence of a Saving Allocation by Depositors

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Highlights

- The liquidity of saving matters for fire sales and their welfare effects.
- The banking sector can be both too risky and too big.
- Liquidity ratios can increase incentives for depositors to invest into bank deposits.

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Abstract

In this paper, we introduce a new mechanism into a banking model featuring distressed sale of assets (fire sales). As in reality, depositors choose between the liquid deposits of banks and the illiquid assets of funds from which early withdrawals are not possible. Our model reflects that dynamics, showing that two inefficiencies arise due to a pecuniary externality. The first inefficiency is well-known: banks do not keep enough liquidity buffers. The second inefficiency is that depositors do not invest the optimal amount into institutions that can be subject to runs (banks) relative to institutions that are preserved from runs (such as pension funds). To investigate whether there is too much deposits in banks or in pension funds, the direction of the inefficiency is studied numerically. Simulations show that the banking sector can be too big relative to pension funds, and that liquidity ratios -aimed at making banks less risky- can decrease welfare by increasing incentives to deposit into banks.

Keywords

Fire Sales, Liquidity ratios, Bank Run, Saving Allocation.

JEL

E44, G01, G18, G21.

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1 Introduction

During the 2008 crisis, banks and shadow banks suffered a run on their funding (Gorton and Metrick 2012): investors sought to withdraw their short-term deposits at the same time. More recently, Silicon Valley Bank endured massive withdrawals of uninsured deposits, with uninsured deposits funding over 78% of its assets (Jiang et al. 2023). Bank runs can arise because banks and shadow banks operate maturity transformation: they transfer funds from depositors in surplus demanding short-term deposits to agents in deficit with long-term financing needs.[1] When faced with a funding liquidity shock, financial institutions operating maturity transformation,[2] react by reducing lending, by hoarding liquidity and by engaging in fire sales (de Haan and End 2013), defined as "forced sale at a dislocated price".[3] After the run on its deposits, SVB had to sell assets (MBS, US bonds) at a loss.[4]

While the literature has already identified benefits of bank deposits and similar instruments (Gorton and Pennacchi 1990, Calomiris and Kahn 1991, Kashyap et al. 2002), the 2008 crisis spurred a renewed interest about excessive maturity transformation, i.e. worries that banks and shadow banks might be taking on too much liquidity risk (see for instance Drechsler et al. 2021).[5] With the attempt of mitigating the risk of fire sales, the Basel III regulatory framework introduced a liquidity coverage ratio aimed at ensuring that regulated banks hold enough liquid assets to sustain a liquidity shock. This regulation focuses on the *supply* side of the asset market, making sure that banks and shadow banks do not need to *sell* their illiquid assets to repay depositors in times of distress. Indeed, if financial institutions have to sell their illiquid assets at the same time, to pay out depositors, prices collapse, reinforcing the liquidity issue.

Yet another fundamental and complementary dimension of fire sales that policy-makers need to tackle is the *demand* side of the market for assets, which is the focus of this paper. Indeed, some institutions are able to *buy* the assets sold by banks because they do not need to pay out depositors: they can act as liquidity providers in times of distress because they do not operate maturity transformation. For example, Han et al. (2018) show that pension funds in Italy, Chile and Poland played the "*role of liquidity provider to the market in a fire sale*" by acquiring more aggregated risky assets during the 2008-2009 crisis. From a macroeconomic perspective, the allocation, by depositors, of savings between the financial institutions subject to runs and those which are not, determines, in an incomplete market world, the respective size of financial institutions on the sell side (institutions subject to

[1] See the liquidity preference theory developed in Hicks (1946).
[2] See section 2 and Adrian et al. (2013) for more details.
[3] Shleifer and Vishny 1992.
[4] See https://www.ft.com/content/84c4446a-d7aa-4f70-a286-adeb4fc4988c.
[5] See Segura and Suarez (2017) for a quantification of gains from regulation.

runs such as banks or shadow banks) or on the buy side (institutions preserved from runs such as pension funds or insurance companies) of the market of assets during a fire sale episode.

This paper therefore contributes to the literature by introducing a saving allocation into a banking model *à la* Diamond and Dybvig (1983) featuring fire sales in the spirit of Allen and Gale (2005): depositors choose between the liquid deposits of banks and the illiquid assets of funds from which early withdrawals are not possible. To the best of my knowledge, such a saving allocation has not been explored in the context of fire sales.[6] Due to this mechanism, the model features a new type of inefficiency and implies policy recommendations regarding liquidity ratios.

This setting allows to bring a macroeconomic perspective into the analysis of fire sales: our results indicate that financial institutions performing maturity transformation and subject to runs on their deposits (banks and shadow banks) can be too large compared to the institutions performing no maturity transformation, which invest locked long-term savings and are not subject to runs (pension funds, insurance companies). In addition, liquidity ratios -aimed at making banks less risky- can decrease welfare by increasing incentives to deposit into banks. This paper therefore draws attention to the need of considering both sides of the fire sale market when designing a policy. The message is not that liquidity ratios should not be implemented but rather that they should be complemented by a subsidy of long-term illiquid saving in order to rechannel savings adequately.

To formalize these ideas, we build a stylized banking model, in which we show analytically the existence of a pecuniary externality, while the direction of the inefficiency at general equilibrium is studied through numerical simulations. The inefficiency identified in this model is twofold: not only do banks operates too much maturity transformation, but the size of the banking sector can be too large compared to the size of financial institutions operating no maturity transformation. Banks can be mapped in the real world both to traditional banks and shadow banks, while funds can be best interpreted as pension funds or any financial institution whose funding is not fully liquid.

Imagine an economy in which depositors can choose between the liquid contract of a bank and the illiquid contract of a fund. Long-term illiquid saving instruments do not offer early withdrawal possibilities but have a higher return. An aggregate liquidity shock hits a random proportion of depositors who then only care about present consumption: they are impatient. After the liquidity shock, if banks do not hold enough reserves to pay impatient depositors, banks have to sell assets. Funds have liquidity available to buy assets as depositors cannot withdraw early from their contracts. No deadweight loss are incurred:

[6] Most papers in the banking literature feature mixed equilibrium (Carletti and Leonello (2018) or Allen and Gale (2004) for example), in which depositors invest in *ex ante* identical banks: depositors have no choice between financial institutions providing saving instruments with different liquidity.

funds get the same return when they buy the bank assets.[7] If the shock is high enough - i.e. the number of impatient depositors is too high -, a fire sales episode occurs.

In a frictionless world, fire sales only have innocuous redistributive effects between sellers and buyers: they do not imply any welfare loss. However, Greenwald and Stiglitz (1986) show that in the presence of microeconomic imperfections fire sales can imply a social cost. A pecuniary externality also arises in my model because markets are incomplete. The pecuniary externality is of the first type described in Dávila and Korinek (2018): a distributive externality, i.e. a zero-sum transfer between agents at a given date and state, and more specifically between patient and impatient depositors.

Due to market incompleteness, fire sales imply a pecuniary externality because the supply of liquidity available to buy assets is fixed: it is determined exactly by the amount of cash funds have at their disposal. During a fire sales episode, the price of assets falls below the fundamental value to the cash-in-the-market value, as in Allen and Gale (2005). The fact that agents do not internalize the price effect of fire sales - depositors, when they allocate their savings and banks, when they choose the level of liquid reserves - explains why inefficiencies arise. Importantly, the pecuniary externality in this setting does not arise because the price of assets appears in a collateral constraint, as is common in the literature, which has important policy implications: unlike in Stein (2012), *ex post* policies such as open-market operations cannot restore the second best because even if fire sales do not happen, the redistribution between patient and impatient is not optimal.

Imposing liquidity ratios on banks is not sufficient to restore constrained efficiency, as the inefficiency lies both in the banks' choice between assets and reserves and in the depositors' saving allocation. Liquidity ratios implemented alone can even worsen welfare in some cases as they increases incentives for depositors to over-invest into banks. Liquidity ratios should be complemented by a subsidy directed to households favoring the channeling of savings towards the long-term, illiquid saving instruments. The main prediction of the model is that incentivizing households to invest into financial institutions performing no liquidity transformation should reduce the risk and cost of fire sales.

The theoretical framework is stylized but captures relevant features of the real world. Financial institutions performing no maturity transformation, such as pension funds, allow to reduce stress on the liquidity market. Their funding is more stable as early withdrawals are strongly regulated and penalized in most countries.[8] During the 2008 crisis, no substantial increase in early withdrawal was identified (Argento et al. 2015), suggesting that pension funds are indeed largely preserved from liquidity issues. As a result, pension funds

[7]Some papers instead assume that the deadweight loss associated with asset sales arise from the fact that natural buyers - i.e. efficient users of the asset who are the only agents that can get its full return (See Shleifer and Vishny (2011).) - are liquidity constrained, as in Acharya and Yorulmazer (2008).

[8]See section 2 for a discussion of regulation restricting pension funds early withdrawals.

can limit stress on the liquidity markets. In addition to Han et al. (2018), some papers bring to light an active role of pension funds in increasing the depth of the market for assets. Thomas et al. (2014) show that during 2000-2010, pension funds have dampened stock market volatility. Koijen and Yogo (2019) show that the price impact of the average of institutional investors has decreased from 1980 to 2017; during a period characterized by a rise of pension funds, whose share in GDP went from 67% in 1996 to 144% in 2017 in the US. Coval and Stafford (2007) show that investors providing liquidity to distressed funds earn significant abnormal returns for several month, which can be interpreted as a possible social role for institutions providing liquidity in times of distress.

In the model, the two saving instruments (liquid deposits of banks and illiquid contracts of funds) are taken as given, because they are useful simplifications of the two major types of financial institutions (subject to runs on their funding, or not). However, both assets are in zero net supply and depositors can freely chose not to deposit anything if the *ex ante* return is negative. In particular, the fact that illiquid contract offered by pension fund does not offer early withdrawals can be rationalized by the fact that the government seeks to insure that long-term savings are protected from excessive early access threatening the whole pension system, and that it might be too costly to offer deposit insurance on those savings. Investors could decide to withdraw early if he or she has non-standard present-biased preferences (Laibson 1997, Harris and Laibson 2013). In this case, restricting the liquidity of contracts can even have the effect of increasing long-term savings as present-biased agents prefer illiquid commitment (Beshears et al. 2015a).

In this paper, we focus on fundamental bank runs i.e. runs triggered by fundamentals and not by a panic (Allen and Gale 1998). We therefore abstract from coordination failure or sunspot bank runs, which have been modeled in the context of the 2008 crisis in Liu 2016 using global games techniques,[9], or in Egan et al. 2017.

This paper builds on two strands of the literature: in the banking literature, on the seminal work of Diamond and Dybvig (1983), Jacklin (1987), Bhattacharya and Gale (1987), Allen and Gale's series of papers (Allen and Gale 1998, Allen and Gale 2004, Allen and Gale 2005); in the fire sales literature, on the seminal papers of Dávila and Korinek (2018), Gromb and Vayanos (2002), Lorenzoni (2008). Dávila and Korinek (2018) in particular develop a general framework to analyze fire sales in the presence of financial constraint, which allows to distinguish between distributive and collateral externalities and to provide general results on the direction of the inefficiencies.

This paper is also closely linked to the literature on the instability of financial intermediairies (for example Gorton and Pennacchi 1990, Calomiris and Kahn 1991, Kashyap et al. 2002, Drechsler et al. 2021, Gu et al. 2023, Segura and Suarez 2017). On the empirics

[9]See Rochet and Vives 2004, Morris and Shin 1998 Goldstein and Pauzner 2005.

side, Falato et al. (2021) establishes the price impact of fire sales, Hau and Lai (2017) analyses the contagion of the 2007-2008 crisis across different stock classes through equity funds linkages, Choi et al. (2020) consider the role of mutual funds in the 2008 crisis, and Chernenko and Sunderam (2020) show that mutual funds do not fully internalize the price impact of their trading.

The saving choice studied in this paper is complementary to, but different from the choice between traditional and shadow banks studied in the literature (Egan et al. 2017, Matvos and Seru 2022, Corbae and D'Erasmo 2021, Xiao 2019). This literature is concerned with a choice about the type of financial institutions where liquid deposits should be made, not by a choice between saving instruments with different liquidity profiles.

The paper proceeds as follows. Section 2 discusses empirical evidence which motivates the stylized theoretical framework of the model. Section 3 describes the model. Section 4 derives the equilibrium in the decentralized economy and in the constrained efficient economy. Section 5 investigates analytically partial equilibrium mechanism of the externality, and examines the effect of liquidity ratios on welfare. Section 6 provides several numerical examples in order to study the direction of the inefficiency at general equilibrium and section 7 concludes.

2 Stylized facts

Stylized facts outlined in this section motivates the modeling choices, in particular why this paper studies fire sales in a framework in which depositors choose between the liquid contract of banks or shadow banks, and the illiquid contract of pension funds from which they cannot withdraw early.

Pension funds are a major actor on financial markets. At the end of 2019, before the Covid crisis, pension funds held a total of USD 32.3 trillion in OECD countries, among which USD 18.8 trillion were hold by pension funds from the United state.[10] This figure can be compared to the total value of stock traded in the United states of USD 23 trillion in 2019 13 to assess how important pension funds can turn out to be during a liquidity crisis. Pension fund also represent a stable share of 35% of American households' total assets.

As outlined by OECD reports[11], most pension funds have very small liquidity needs in relation to their total assets under management. This means that they do not have to sell assets at low prices during a liquidity crisis to meet benefit payments and other expenditures. Indeed, they can instead rely on the regular flow of contributions and investment

[10] OECD (2020a).
[11] OECD (2010).

income, even if the latter is reduced. And more importantly, they are not subject to sudden withdrawals as early withdrawal are carefully regulated.

Pension funds are not designed to operate maturity transformation but to ensure a sufficient return in the long-run for workers to retire. The objective of a sound pension system is indeed to reduce poverty in old age. Therefore withdrawals before retirement are limited in most developed by policy makers, although to different degrees. The need to restrict early withdrawals is even stated by the OECD as an important policy guideline: "early access to retirement savings should be a measure of last resort" (OECD (2020b)). In some countries, such as Germany, Singapore, or the United Kingdom, early withdrawals are banned (Beshears et al. (2020)). In Canada and Australia, balances can be accessed in case of a sufficiently large adverse labor income shocks. In the US, early withdrawals are not banned but are strongly discouraged through taxation. Instead of being exempted, withdrawals from pension plans must be included in taxable income and taxed at individual's marginal rate of income tax. In addition the individual must pay an additional 10% early withdrawal tax if the withdrawal occurs before he turns 59.5 year-old (OECD (2019)).

From a theoretical point of view, how can those regulations be rationalized i.e. why would the government decide to restrict or to simply ban early withdrawals as is common across all developed countries? When depositors' liquidity needs are private information, pension funds cannot distinguish between an investor who has a true liquidity needs and an investors who does not. A patient investor can indeed misrepresent his type and withdraw for instance in the case of coordination failure or sunspot bank run, or if he has non-standard present-biased preferences.

In both cases, restricting early withdrawals can be welfare-enhancing. In the case of sunspot bank run, it is likely that the government does not have the cash needed (or is not ready to commit to taking on the necessary amount of debt) to guarantee an insurance system that would be covering the entirety of long-term savings. The government can therefore recur to restricting early withdrawal as a second-best tool. Even though such a policy of restricting early withdrawals ex ante must be distinguished from the ex post suspension of convertibility in the Diamond and Dybvig framework with sequential serving constraint, it is interesting to note that suspension of convertibility is welfare-enhancing in Diamond and Dybvig framework, including when withdrawals are stochastic - even though it does not allow to reach the first best. In the second case of investors with self-control problems, restricting early withdrawals can increase the long-term savings of present-biased agents, who prefer illiquid commitment (Beshears et al. (2020)), and avoids that they withdraw when it is not in their long-term interest.

During the 2007-2008 crisis, early withdrawals from pension funds barely increased in the US. as shown in figure 1, which is constructed from the data provided in Argento et al.

(2015). Figure 1 displays the share of tax payers younger than 55 with evidence of pension coverage or retirement account balances who experienced a penalized distribution, i.e. who withdrew early and were subject to a tax penalty. We see that this share indeed increased steadily over the period, but very modestly. Thus, even in the US where early withdrawals are relatively more liquid than in other major advanced countries (see Beshears et al. (2015b) for an international comparison of pension funds' liquidity), early withdrawals during the 2007-2008 crisis remained very limited.

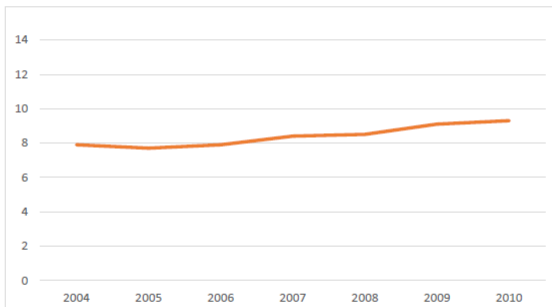
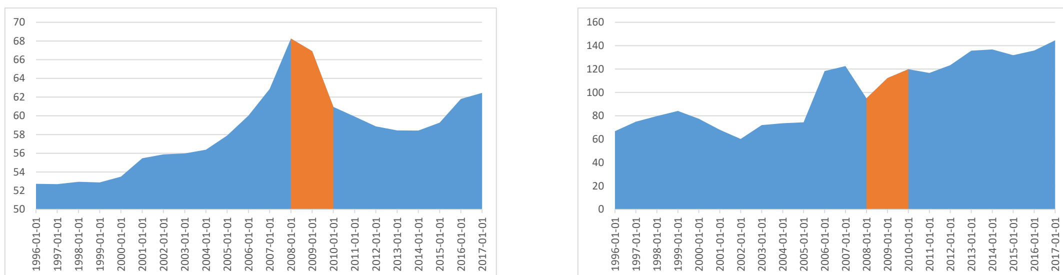


Figure (1) **Percent of tax units with penalized distributions for individuals below 55 with pension coverage**

Therefore, early withdrawals are sufficiently low to allow pension funds to be in a position not to sell any assets and in a position to buy assets during a liquidity crisis. Pension funds are thus likely to reduce stress on liquidity markets during a liquidity crisis such as the 2007-2008 one. A raw comparison of the evolution of banks' and pension funds' total assets to GDP during the 2007-2008 crisis -even though biased by the composition of assets of the types of institutions- provides intuition about the relative liquidity position of banks an pension funds during a crisis (figure 2). Banks share significantly decreases while the share of pension funds increased. There are many factors involved of course, but this stylized fact offers some suggestive evidence of the relatively higher stability of pension funds, which is likely to be rooted on their different funding structure.

Contrary to the stability of pension funds funding, the 2007-2008 crisis had a dramatic impact on the short-term funding of both traditional and shadow banks, which has largely been documented in the literature. Traditional banks suffered a freeze of interbanks markets while shadow banks were heavily affected by the run on repurchase agreements. Acharya and Merrouche (2012) show, focusing on the UK, that the liquidity demand of large banks increased by 30% in the period immediately following August 9 2007, when BNP Paribas froze three of its hedge funds. Gorton and Metrick (2012) show that the 2007-2008 liquidity crisis was the most severe for shadow banks as all short-term debt markets became vulnerable during the crisis. Shadow banks endured an increased in the haircut on repurchased agreement: the haircut index constructed by Gorton and Metrick (2012) rose from zero at the beginning of 2007 to almost 50% at the peak of the crisis in late 2008. There was also acute stress on asset-backed commercial paper programs, short-term commercial paper and structured investment vehicles, threatening the funding of shadow banks.



Banks **Pension funds**

Figure (2) **Assets to GDP in %, US, Annual. Source: World Bank, Saint Louis Fed**

Finally, there is some evidence of an active role of pension funds in increasing the depth of the market for assets. Thomas et al. (2014) show that during 2000-2010, pension funds have dampened stock market volatility. Han et al. (2018) find that pension funds in Italy, Chile and Poland played the "*role of liquidity provider to the market in a fire sale*" by acquiring more aggregated risky assets during the 2008-2009 crisis.

3 Model

In a banking model *à la* Diamond and Dybvig (1983), an asset market and a saving choice by depositors between two types of institutions are introduced. An aggregate liquidity shock hits depositors preferences in period 1 making a proportion of depositors impatient and wanting to withdraw.

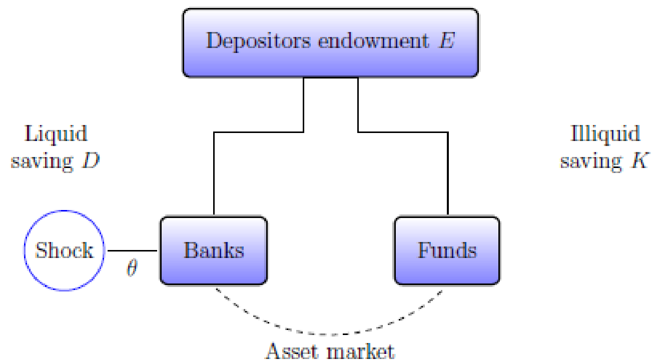


Figure (3) **Structure of the model**

The three-date (0, 1 and 2) model has two type of institutions, banks and funds. A bank offers demand-deposit-like contracts (liquid contracts) while a fund offers longterm illiquid contracts, from which depositors cannot withdraw early. The two types of institutions can trade in an asset market at the intermediate date, when a large enough aggregate shock hits at the intermediate date (i.e., a lot of bank depositors turn out to be impatient ones who need to withdraw early at the intermediate date). Thus, banks who do not have enough liquidity to satisfy the early withdrawals can sell their illiquid assets in the asset market to fetch liquidity from the funds (as asset buyers). Figure 3 illustrates the model.

The model analyzes the equilibrium at the intermediate date ($t = 1$) and the equilibrium at the initial date ($t = 0$). The equilibrium at $t = 1$ consists of the asset market equilibrium, i.e., how the two types of institutions trade in the asset market given the realization of the aggregate shock. The equilibrium at the initial date ($t = 0$) concerns the portfolio choices of the two types of institutions as well as the depositors saving allocation between banks and funds.

At $t = 0$, a depositor splits his money E by choosing the portfolio (D, K). After getting D, a bank makes its portfolio choice $\left(L^B, S^B\right)$. After getting K, a fund makes its portfolio choice $\left(L^F, S^F\right)$. At $t = 1$, when the shock θ is realized, the two types of institutions, banks and funds, trade and the equilibrium asset price is $P(\theta)$.

3.1 Technology

There are three different technologies in the economy: early assets, late assets and storage. Storage provides 1 unit next period for 1 unit stored. It is available to depositors, banks and funds.[12] Early assets are undertaken in period 0 by banks and funds and mature in

[12]Nevertheless, between period 0 and period 1 , depositors will never store but rather deposit in banks which are maximizing their depositors' utility. Therefore, there is no loss in generality in assuming that

period 2 and yield R^E at maturity for each unit invested. There are no change of ownership costs: return is the same whether assets are sold to funds or kept by banks until maturity. Late assets are undertaken in period 1 by banks and funds and yield R^L in period 2. We assume that:

Assumption 1.

$$1 \leq R^L \leq R^E.$$

3.2 Liquidity shock

There is a mass 1 of ex ante identical depositors on the unit interval $[0,1]$. In period 1, a liquidity shock hits a fraction θ of them. As in Diamond and Dybvig (1983), any consumer i can be hit by the idiosyncratic shock χ_i :

$$\chi_i = \begin{cases} 1 & \text{if depositors } i \text{ is impatient} \\ 0 & \text{if depositors } i \text{ is patient} \end{cases}$$

where χ_i follows a binomial $\mathcal{B}(1,\theta)$ with parameter θ.

Consumers who are hit are called impatient and only care about period 1 consumption. Consumption in period 2 provide them no utility. Consumers that are not hit are called patient consumers. They only care about period 2 consumption. The size of the shock, i.e. the fraction θ of consumers being hit, is stochastic - introducing aggregate uncertainty. The shock distribution is drawn from a law that has

The utility function is twice continuously differentiable, increasing, strictly concave and satisfies Inada conditions $u'(0) = \infty$ and $u'(\infty) = 0$. The ex ante expected consumption of a given household is:

$$U(c_1, c_2; \theta) = \begin{cases} u(c_1) & \text{if } \chi = 1 \\ u(C_2) & \text{if } \chi = 0 \end{cases}$$

where c_1 is consumption by impatient depositors and C_2 consumption by patient depositors.[13]

depositors are not storing but rather depositing in a bank that will store if optimal between period 0 and period 1 . a continuous probability distribution function, known by all agents. It is assumed to be uniform over the interval $[0,1] : \theta \hookrightarrow \mathcal{U}([0,1])$.

[13] Lower case c_1 is used for period 1 consumption as it only includes return from the liquid contracts of banks, and upper case C_2 for period 2 as it includes both the return from the liquid contracts of banks and the illiquid contract of funds (funds profits are realized in period 2 when assets have matured).

The threshold $\underline{\theta}$ is the threshold below which the bank does not need to sell any early assets. The second threshold $\bar{\theta}$, is the threshold above which the bank defaults, which will be defined below (see equation 2).

3.3 Depositor choice of saving instrument liquidity

Depositors are endowed in period 0 with E units of savings. They allocate those savings between two instruments of different liquidity: the liquid deposits of banks, in which they invest D, and the illiquid contracts of funds, in which they invest K. The budget constraint in period 0 writes:

$$D + K = E$$

Depositors can withdraw early from liquid bank deposits, i.e. before asset maturation in period 2. Illiquid contracts offered by funds do not offer this possibility of early withdrawal. The government forbids early withdrawals for reasons not modeled, but which can be rationalized when the government seeks to insure that long-term savings are protected from excessive early access threatening the whole pension system.[14] In addition, depositors are not able to trade claims on the funds, once the liquidity shock is realized. This assumptions is motivated by the fact that the the objective of the paper is to study regulated long-term investment vehicles such as pension funds, whose shares are indeed not tradable and can be accessed only at a cost.[15]

In the spirit of Diamond and Dybvig (1983), in period 2, when fund profits are realized, impatient depositors no longer care about consumption. In such a world, money invested into an illiquid contract is completely lost to them. In addition, it is assumed that patient receive the entirety of the funds' profits, instead of receiving only a share of those profits, which serves as a simplification: assuming that patient agents would receive only a share of profits does not change the qualitative mechanism and could even reinforce its quantitative

[14]See section 2 for more on this argument.

[15]Considering to relax this constraint is reminiscent of the Jacklin critique (Jacklin (1987)) who pointed out that the optimality of the banking contract with deposit insurance in a Diamond and Dybvig framework implicitly hinges on the assumption that agents cannot engage in ex post trades (after the liquidity shock is realized). In this model, the question is whether such a possibility would restablish constrained efficient, i.e. if the pecuniary externality identified would disappear. Let us imagine that in this framework, depositors are now allowed to trade claims on funds after the liquidity shock is realized. As a result, patient agents would buy shares of the patient agents, providing them with liquidity, thereby actually making the funds contract liquid. With such a financial market, there would be no asymmetry of information problems -i.e. patient agent misrepresenting their type as being impatient- and only impatient agents should try to sell their shares. A formal proof is difficult to offer but the framework seems indeed to be subject to the Jacklin critique.

message.[16]

c_1 is the per capita payment by banks to impatient. c_2 is the per capita payment by banks to patient. C_2 is the total payment to patient consumers, including both the payment by banks and their share of funds' profits, $\pi(\theta)$:

$$C_2 = c_2 + \frac{\pi(\theta)}{1-\theta}$$

The incompleteness of the set of contracts available to depositors captures in a simple way the saving allocation between bank deposits and contractual saving offered by pension funds and insurance companies from which members are not allowed to withdraw before the occurrence of the event defined in the contract (retirement, death, disease). Markets are also incomplete: there are no Arrow securities to ensure against the aggregate liquidity shock; funds cannot raise funds, short sell or borrow in period.[17] As a consequence, the liquidity available to buy assets is fixed after the shock hits.

When the liquidity shock is too high, banks sell assets to pay out impatient depositors. Funds instead are in a position to buy assets as they offer an illiquid contract. Therefore, the financial structure studied here allows understanding the supply and the demand of liquidity and the possible inefficiency in their ex ante level as chosen by depositors.

3.4 Banks

Banks receive the deposits D in period 0 . As the banking sector is perfectly competitive, banks maximize the utility of their depositors. They invest S^B in early assets and keep L^B in reserves i.e. in storage, taking as given the deposits D received. The banking contract's terms stipulate that the bank has to promise a fixed payment $\bar{c}$ to any consumer

[16] This assumption could be relaxed, by assuming that patient depositors, instead of receiving the whole profits of the funds, $\frac{\pi}{1-\theta}$, only receive their share $\frac{\pi}{1} < \frac{\pi}{1-\theta}$, as there is a mass 1 of depositors. Hence, under this assumption, patient depositors would receive a lower payment from funds. Impatient depositors would then receive a payment from firms in periods 2 but that they value at a given discounting factor $\delta = 0$. In other words, we would maintain the assumptions that impatient depositors have extreme preference as in Diamond and Dybvig and that consumption at date 2 provides them zero utility. From a qualitative point of view, the assumption that patient depositors would receive only a share of funds' profits would not change the nature of the externality. Indeed, the qualitative mechanism of the model, the existence of the pecuniary externality, remains as the incentive compatibility constraint still defines a bankruptcy threshold which depends on the fire-sale price, itself depending on the choice variables of both households and banks. However from a quantitative point of view, the assumption could have a very interesting quantitative effect: it actually decreases even more the incentives of depositors to invest into the contracts of funds given that the payment they receive even in the lucky outcome of being impatient is lower.

[17] There are also trading restrictions that impede impatient depositors to sell to patient depositors *i*) their bank deposits and *ii*) their illiquid contracts. See Jacklin (1987) for a discussion on that assumption.

in period 1 that cannot be made contingent on the realization of the liquidity shock.[18] After the realization of the shock, either the bank holds enough reserves to be able to pay its depositors the promised rate, or it needs to sell an amount $X(\theta)$ of total early projects S^B to funds. The price of early assets depends on the realization of the liquidity shock θ and can fall below its fundamental value making early assets riskier than reserves.[19] The budget constraint of the bank in period 0 writes:

$$S^B + L^B = D$$

After the liquidity shock, in period 1 , if banks have any cash remaining after paying their depositors $\theta\bar{c}D$, they can invest it in late assets, returning R^L next period.

Each consumer knows if she is impatient or patient in period 1 but this is a private information. Therefore the contract must be incentive compatible. The bank is solvent if it is able to pay patient consumers at least the same amount in present value as the fixed rate $\bar{c}$ served to impatient consumers. Otherwise, patient consumers would withdraw early, forcing the bank to default.[20] The incentive compatibility constraint or solvency condition writes:[21]

$$\theta\bar{c}D + (1-\theta)\bar{c}D\frac{P(\theta)}{R^E} \leq L^B + X(\theta)P(\theta) \tag{1}$$

where $(\bar{c}D)$ is the minimum level of consumption the bank must be able to pay patient consumers for them not to withdraw early, $\frac{P(\theta)}{R^E}$ is the present value of one unit of good at date 2, and where the price $P(\theta)$ and the number of early assets $X(\theta)$ sold by the bank depend on the realization of the liquidity shock.

Default happens when equation 1 is not satisfied, above a certain threshold of the liquidity shock called $\bar{\theta}$. The default threshold is defined as the size of the liquidity shock for which equation 1 holds with equality. Let P^* be the price for which the bank defaults. It is the price of early assets when all early assets are sold $\left(X(\theta) = S^B\right)$.

[18] The paper does not aim at defining the optimal contract but rather takes the banking contract's terms as exogenous. The contract incompleteness alone arising from its non contingent terms is not per se a source of inefficiency because default allows restoring some contingency as shown in Allen and Gale (2004).

[19] The fundamental value is defined formally below: it is the ratio of returns from the two productive assets. See equation 3.

[20] We refer here to a fundamental bank run as defined in Allen and Gale (2007) and not to the sunspot bank run studied in Diamond and Dybvig (1983). In other words, we focus here on situations where it is individually rational for a depositor to withdraw, regardless of what the others do, i.e. independent of any strategic considerations.

[21] The formulation is similar to the one that can be found in Allen and Gale (2005).

$$\bar{\theta} = \frac{R^E L^B + R^E S^B P^* - \bar{c}P^* D}{\bar{c}D\left(R^E - P^*\right)} \tag{2}$$

When the bank does not default, it pays the promised rate on deposits $\bar{c}D$. In case of default, the bank sells all assets and divides the profits among all depositors[22]. Let c_B be the payment by banks in case of default. The liquidation value of the portfolio is equal to all liquid reserves put in storage plus early assets sold at price P^*. The payment in case of default is then:

$$c_B = L^B + S^B P^*$$

The analysis is restricted to fundamental bank runs, in line with Allen and Gale's series of papers (1998, 2004). This paper abstracts from sunspot bank runs, where banks runs are described as panics phenomenon in which, when deciding whether to run or not, consumers take their decision conditional on every other patient consumers running. We apply the following rule of equilibrium selection: whenever a no-run equilibrium exists, we select the no run equilibrium, meaning that we rule out sunspot bank run. The objective of this paper is indeed not to study such multiple equilibria situations. Alternatively, assuming that banks benefit from deposit insurance aimed at protecting bank from panics bank runs only - so that banks are still forced to design an incentive compatible contract ruling out fundamental runs- can also rule out sunspot bank runs.

3.5 Funds

In period 0, funds receive K from depositors. Given K, they choose how much to invest into early assets, S^F, and how much to invest into liquid reserves, L^F.

In period 1, funds invest $Y(\theta)$ in late assets which mature in period 2 yielding R^L. If banks sell early assets, funds buy back an amount $X(\theta)$ for a price $P(\theta)$. They benefit from the exact same gross return on these sold early assets, R_E, as originators (banks). This assumption rules out any technological externality.

4 Equilibrium

Two economies are studied: first, a constrained-efficient economy in which social planner chooses in the name of agents, internalizing the impact of choices on the price of assets, and

[22]We do not adopt a Diamond and Dybvig (1983) sequential service constraint rule. As a bankruptcy rule, we rather choose an equal division of the bank portfolio among all depositors, as Allen and Gale (1998, 2004).

second, a decentralized economy in which agents are price takers. In the two economies, the same technological and institutional constraints prevail. The two equilibria are formally defined in appendix A.2. In other words, the inefficiency that arises in the decentralized economy is identified with respect to a second-best economy. The model is solved backward.

4.1 Period 1

4.1.1 Fund program and fire sales

After the shock, funds choose the amount of late assets to undertake, $Y(\theta)$, and the amount of early assets to buy from banks, $X(\theta)$. Funds have an amount L^F of cash available, the liquid reserves they chose to keep in period 0 . They give back their profits to patient consumers in period 2 who are the only consumers left to still care about consumption at that time. After the shock, they maximize the period 2 profits:

$$\max_{X(\theta),Y(\theta)} R^L Y(\theta) + R^E X(\theta)$$

subject to the budget constraint:

$$L^F = Y(\theta) + P(\theta)X(\theta)$$

Funds never sell early assets as early withdrawals are not authorized from their illiquid contracts, and as $R^E \leq R^L$. The first order conditions gives the price of the early assets sold by banks when $X(\theta) \geq 0$ and $Y(\theta) \geq 0$, the fundamental value, or fundamental price, P^F :

$$P(\theta) = \frac{R^E}{R^L} \equiv P^F \tag{3}$$

For the secondary market of early assets to clear, it is necessary that there is sufficient funds available liquidity L^F to buy back all assets sold by the bank:

$$P(\theta)X(\theta) \leq L^F \tag{4}$$

When the liquid reserves of funds are not sufficient to pay all assets sold by banks at the fundamental price during fire sales, all early assets are sold $X(\theta) = S^B$, and the price falls to its fire-sales level P^* :

$$P^* = \frac{L^F}{S^B} \tag{5}$$

This is an example of cash-in-the-market pricing,[23] which is due to the fact the supply of liquidity is inelastic. The amount of liquidity available to buy back early assets is fixed, due to markets incompleteness.[24] It is equal to L^F, the amount of reserves kept by funds in period 1, whatever the size of the liquidity shock. θ^* is the liquidity shock threshold above which the price falls to the cash-in-the-market value.[25]

We focus on cases that are relevant to the analysis, cases in which a default by the bank necessarily triggers a fire sale episode, meaning that the default happens at the fire-sale price. Those are cases for which in equilibrium $L^F/S^B < P^F$. As L^F and S^B are endogenous variables, the following assumption can be made: a sufficient condition to ensure that the cash-in-the market pricing happens when the bank is defaulting, i.e. selling all early assets $X = S^B$, is to choose R^E sufficiently high compared to R^L, i.e. the return of early assets sufficiently higher than the return of late assets.

Relying on Shleifer and Vishny (1992) definition, fire sales are situations in which a bank is forced to sell an asset, because it needs to pay impatient consumers as stated by the solvency condition (equation 1), and has to do so at a dislocated price. In case of fire sales, the price is no longer determined by relative productivities but rather by the amount of cash available to buy assets, L^F, and by the total amount of assets sold S^B (equation 5).

Importantly, both the probability and the severity of fire sales depends on the fire sale price. The more reserves funds and banks keep, the higher is the fire sale price P^*, the less distressed the market.

4.1.2 Payments to depositors

When $\theta < \bar{\theta}$, the price is at its fundamental value and the bank is solvent. Early assets are sold at the fundamental price because the liquidity of funds is sufficient to buy back all assets sold at the fundamental price. Impatient consumers get the promised rate on their deposits.

$$\text{If } \theta < \bar{\theta}, \begin{cases} c_1 = \bar{c}D \equiv \overline{c_1} \\ C_2 = \frac{S^B R^E + \left(L^B - \theta\bar{c}D\right)R^L + S^F R^E + L^F R^L}{1-\theta} \end{cases}$$

When $\theta \geq \bar{\theta}$, the early asset price falls at the fire-sales price $P^* = L^F/S^B$ and the bank defaults because it cannot both pay the promised rate to impatient depositors in period

[23] See Allen and Gale (2005).

[24] We assume short selling away: $Y(\theta) \geq 0$. Funds cannot take on debt either.

[25] It is easily shown that $\theta^* \geq \bar{\theta}$ is satisfied. In other words, it cannot happen that a cash-in-the-market situation arises while the bank is still solvent as governed by the solvency equation, forcing the bank to sell its whole portfolio $\left(X = S^B\right)$ whereas it is solvent.

1 and make at least the same payment to patient depositors in period 0 : the solvency condition 1 is no longer satisfied. Both patient and impatient consumers receive their equal share of the liquidation value in period 1. On top of the bank's payment, patient consumers get their share of funds' profits in period 2.

4.2 Period 0

4.2.1 Fund problem

In period 0, funds choose early assets S^F and reserves L^F to maximize their profits. Their profits are redistributed to patient depositors in period 2. The problem writes:

$$\max_{L^F,S^F} \Bigg(\underline{\theta} \left[R^E S^F + R^L L^F \right] + \int_{\underline{\theta}}^{\bar{\theta}} \left[R^E S^F + Y(\theta) R^L + X(\theta) R^L \right] d\theta$$
$$+ (1-\bar{\theta}) \left[R^E \left(S^F + S^B \right) \right] \Bigg)$$

subject to the budget constraints at period 0 and period 1 :

$$L^F + S^F = K$$

Combining the two first order conditions yields:

$$\bar{c}D = L^B \frac{R^E - R^L}{R^L} \tag{6}$$

4.2.2 Bank problem

The banking sector is perfectly competitive. Given the deposits D received, the bank chooses how much to keep in reserves, L^B, how much to invest in productive early assets S^B, and how much to promise impatient depositors, $\bar{c}$, to maximize its depositors' utility. The problem writes:

$$\max_{\bar{c},L^B,S^B} \left\{ E_\theta \left\{ u \left[\theta c_1(\theta) + (1-\theta) C_2(\theta) \right] \right\} \right\}$$

subject to the budget constraint, whose Lagrange multiplier is μ_1 :

$$D = L^B + S^B$$

The contract needs to be incentive compatible: when the bank can no longer satisfy the solvency condition stated in equation 1, it defaults. The first order conditions of the program (equations 8, 9 and 10 for the decentralised economy and equations 7, 9 and 10 for the constrained efficient economy) are implicit equations in $\bar{c}, L^B$ and S^B. Combined, they ensure that the expected marginal utility of an impatient consumer equals the expected marginal utility of a patient consumer, taking into account the marginal returns of assets.

Crucially, the fire-sales price P^* enters this decision rule through the default threshold $\bar{\theta}$ and through the level of the payments in case of default. In other words, the fire sale price matters both for the probability and for the severity of fire sales and ultimately determines the level of insurance against the idiosyncratic liquidity risk. As explained below, it is the reason why in the decentralized economy, a pecuniary externality arises when price-taking agents do not consider the impact of their decision on this price, therefore achieving an inefficient level of insurance.

Due to market incompleteness, the overall amount of S^B chosen will have an impact on the fire-sales price $P^* = L^F/S^B$. In the decentralized economy, the failure of the price-taking bank to take into account the impact of its choice of S^B on P^* explains the inefficient choice.

4.2.3 Depositor problem

A given depositor i chooses deposits D to invest into liquid contract and the contribution K to invest into funds illiquid contract. In period 0, depositors do not know whether they will become impatient or patient consumer in period 1. This is a sequential problem, with the depositors maximizing over D and K the utility that is maximized by banks over the bank choice variables on a second step. Then, the depositors choose before the banks, anticipating that the banks will optimally choose $S^B, L^B, \bar{c}$ after that. They know the optimal function decisions of the depositors: $S^{B*} = S^{B*}(D, K), \bar{c}^* = \bar{c}^*(D, K)$ and $L^{B*} = L^{B*}(D, K)$. The problem writes:

$$\max_{D,K} \left\{ \max_{\bar{c},L^B,S^B} \{ E_\theta \left[\theta u \left[c_1(\theta) \right] + (1-\theta) u \left[C_2(\theta) \right] \right] \} \right\}$$

subject to the budget constraint $E = D + K$. The optimality condition with respect to D (equation 15 in appendix A.6 for the decentralized economy and equation 13 in appendix A.5 for the constrained efficient economy) ensures that the marginal return of investing into deposits expressed in utility terms equals the marginal cost. Similarly, the optimality condition with respect to K (equation 16 in appendix A.6 for the decentralized economy and equation 14 in appendix A.5 for the constrained efficient economy) ensures that the marginal return of investing into the illiquid contract of funds expressed in utility terms equals the marginal cost.

5 Externality and Policy

In this section, it is shown analytically that there are two types of inefficiencies in the decentralized economy compared to the constrained-efficient one. Therefore, the decentralized economy cannot reach the second best. The direction of the inefficiency is studied numerically in section 6.

The inefficiency arises from the failure of the price-taking banks and the pricetaking depositors to internalize the impact of their choice on the fire-sale price and therefore on the probability and the severity of fire sales. As a result, an inefficient level of insurance against the idiosyncratic liquidity risk is achieved.

5.1 Externality

5.1.1 Inefficient choice by the bank

As shown in appendix A.4, by comparing the expression of the derivative of Lagrangian with respect to the choice variables of the bank, the externality only lies in the choice of S^B. The expression of the first order conditions with respect to $\bar{c}$ and L^B are identical in the constrained efficient and in the centralized economy.[26] Compared to the decentralized economy (see equation 8), the first order condition in the constrained efficient economy has two differences (highlighted in bold below):

$$\begin{aligned}&\int_0^{\bar{\theta}} R^E u'\left(C_2\right) d\theta + \int_{\bar{\theta}}^1 \boldsymbol{R^E} u'\left(C_2^B\right) d\theta \\ &+ \frac{R^E P^*}{\bar{c}D\left(R^E - P^*\right)} \frac{\bar{c}\boldsymbol{D} - \boldsymbol{K} - \boldsymbol{L}^B}{\boldsymbol{R}^E \boldsymbol{S}^B - \boldsymbol{K}} \left[E\left(U_{ND}\right) - E\left(U_D\right)\right] = \mu_1\end{aligned} \tag{7}$$

At the equilibrium, the fact that the choice of S^B is distorted implies an inefficient equilibrium level of $\bar{c}$. The redistribution of wealth between patient and impatient depositors is not efficient even when fire sales do not arise because the bank does not choose the efficient level of $\bar{c}$. Fire sales imply welfare costs even when they do not actually occur.

This happens because the decentalized bank does not consider the impact of its choice of assets on the fire-sale price. Yet, the fire-sale price matters for the probability and the severity of fire sales. As a result, the bank does not achieve the efficient transfer of wealth between patient and impatient and then the efficient level of insurance against risk of being impatient.

[26] Evaluated at the equilibrium, due to the inefficiency in S^B, they will of course differ but for given S^B, K and D, they are identical.

5.1.2 Inefficient choice by depositors

The depositors' portfolio allocation between the liquid contracts of banks and the illiquid contracts of funds is inefficient in the decentralized economy: the optimality conditions in the centralized economy (equations 13 and 14 in appendix A.5) and in the decentralized economy (equations 15 and 16 in appendix A.5) differ.

Therefore, in this setting which includes a choice by depositors of the liquidity of their saving, the pecuniary externality does not materialize only in banks' choice: it also appears in depositors' choice. Consequently, depositors over or under invest in the illiquid contracts of funds, compared to constrained efficiency. As a result, the relative size of banks and funds is not optimal - and is not even reaching the constrained efficient level. It means that the size of financial institutions performing maturity transformation is not optimal. It will be shown numerically in section 6 that banks and shadow banks are actually very often too big. The intuition for the existence of an externality in the saving decision of depositors is that depositors do not take into account the impact of their chosen degree of savings' liquidity on the fire-sale price and therefore on the probability of fire sales. Therefore, their saving allocation will result in an efficient insurance against the idiosyncratic liquidity risk.

5.2 Policy

5.2.1 Liquidity ratios

First, liquidity ratios, that constitute an ex ante policy, are investigated. The aim of the paper is not to design the optimal policy but rather to study the effect of the Basel III Liquidity Coverage Ratio, and offer some insight on how they could be complemented given their unintended effect.

Ex post policies could be contemplated, such as a lender of last resort policy. However, beyond moral hazard issue, in this setting, ex post policies implemented only in cases of fire sales could not help alleviating the fact that the fixed payment $\bar{c}$ has not been chosen optimally by the bank due to a non optimal choice of S^B. Therefore, even when fire sales do not occur, the bank operates an inefficient redistribution between patient and impatient. Thus, implementing a policy only when fire sales occur is not sufficient.

Liquidity ratios suggested in the Basel III framework aim at forcing banks to hold more liquid assets. In the model, the proposed liquidity coverage ratio would be equivalent to forcing bank to hold more reserves L^B and to invest less in early assets S^B. This makes sense in the model in which the bank invests too much in S^B in the decentralized economy with respect to the constrained efficient economy.

Formulation. Formally, the bank problem with liquidity ratios is similar to the decentralized economy problem with an additional constraint:

$$\max_{\bar{c},L^B,S^B} \{E_\theta u [\theta c_1(\theta) + (1-\theta)C_2(\theta)]\}$$

subject to the same former budget constraint whose Lagrange multiplier is μ_1 :

$$D = L^B + S^B$$

and to the liquidity ratio constraint whose Lagrange multiplier is μ_2 :

$$S^B \leq \alpha D \text{ with } \alpha \leq 1$$

Partial equilibrium effect: bank choice. A partial equilibrium analysis is conducted in this section to show how liquidity ratios can create the wrong incentives for depositors.

To study how constraining the choice of S^B can help alleviating the inefficiency in the bank choice, the decentralized economy with ratio is compared to a fictitious economy having efficient banks and inefficient depositors, $E_{eB,iH}$. It allows to shut down the bank's choice inefficiency to focus only on the impact of liquidity ratios on the inefficient saving allocation by depositors.

Proposition 1. *Imposing binding liquidity ratios allows to get the decentralized allocation closer to the economy $E_{eB,iH}$ - i.e. not considering the depositor choice.*

See proof in appendix A.7.

Partial equilibrium effect: depositor choice. As explained, there are two inefficiencies in the model so that one instrument is not sufficient to restore the constrained efficient allocation. But in the model, liquidity ratios can also worsen the inefficiency lying in the depositors choice in some cases. It is an unintended effect of liquidity ratios.

The Lagrange multiplier μ_2 associated to the liquidity ratio constraint appears also in the program of the depositors. For a given allocation, imposing liquidity ratios can increase the value of depositing into banks as increasing deposits relaxes the constraint of the bank, allowing it to invest more into early assets S^B.

Proposition 2. *For a given allocation, when $\mu_2 > 0$, $\frac{\partial \mathcal{L}_{ratios}}{\partial D} \geq \frac{\partial \mathcal{L}_{decentralized}}{\partial D}$*

See proof in appendix A.8.

Therefore, liquidity ratios are not putting in place the right incentives for depositors.

5.2.2 Subsidy of long-term illiquid savings

Since: *i*) in general, one instrument is not sufficient to solve for two inefficiencies and *ii*) in this particular model, liquidity ratio can worsen the inefficiency in depositors' choice, another policy than liquidity ratios should be contemplated. The objective of this policy would be to reallocate depositors savings by subsidising illiquid savings. It should aim at creating an incentive for depositors to invest in long-term investments by subsidising such saving instruments.

The government could finance the subsidy by imposing a non contingent tax t on depositors withdrawing in period 1 that would then be paid to patient depositors remaining in period 2. This policy is equivalent to a redistribution between depositors types (impatient and patient). As the inefficiency in the model takes the form of a failure of insurance between types, such a tax seems well-fitted to restore efficiency. Note that such a policy does not require to observe the type, only to observe which depositor is withdrawing.

A positive tax t should lower the level of D and increase the level of K chosen by depositors, bringing it closer to the efficiency. The tax allows to rebalance the incentives of depositors that fail to make the efficient choice because they take the price as given, by modifying the expected payments of both assets (deposits or funds shares of profits).

See the appendix A.9 for a discussion of this policy.

6 Insight into general equilibrium: simulations

To conduct a general equilibrium analysis of the model, this section analyses numerically the inefficiency.[27] In particular, simulations are used to study the direction of the inefficient choice made by depositors when deciding on the liquidity of their saving; in other words simulations will help investigate when depositors invest too much into liquid deposits of banks and not enough into the illiquid contracts of funds. The impact of liquidity ratios is also studied.

6.1 Direction of the inefficiency

There are two key parameters in the model: the risk aversion γ and the ratio of the return of the two productive assets $\left(R^E/R^L\right)$. Parameters of each of the three simulations are shown in figure 4. For each of them, the risk aversion is set to take a large range of values.

[27] Those simulations are programmed in Julia, see Bezanson et al. (2014) for more details.

Simulation	1	2	3
Risk aversion γ	$2-30$	$2-10$	$2-10$
R^E	1.6	1.1	1.15
R^L	1.2	1.2	1.2
HH endowment E	5	5	5

Figure (4) **Parameter values**

The chosen utility function is the constant relative risk aversion one (CRRA): $u(c) = c^{1-\gamma}$. In all simulations, the curvature parameter γ varies. The objective is to investigate numerically the impact of the risk aversion in determining the sign of the externality lying in the inefficient decision by the households on the degree of liquidity of their savings.

Estimates of risk aversion are closer to values between 2 and 3 for traditional macroeconomics models, but values up to 10 and 30 are showed here for an illustrative purpose, suited to investigate the behavior of a highly stylized framework.

Furthermore, the CRRA functional form is not suited to capture risk aversion across long-term periods such as the ones under consideration in the model which are longer than the shorter periods usually considered in macroeconomic models.[28] Indeed the stylized model considered here corresponds to period of several decades, not quarters.

Figure 5 shows that, compared to the second best, households over invest in deposits in the three simulations considered and across most values of the risk aversion parameters.[29] Consequently, they under-invest in the illiquid contract of pension funds.

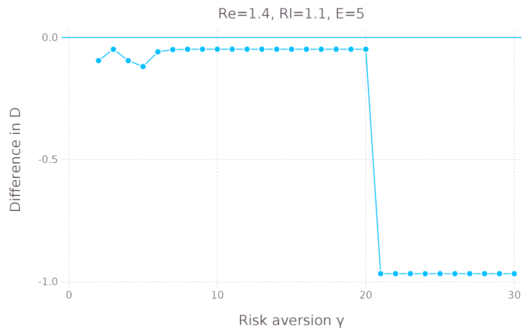
This result brings an interesting macroeconomic perspective into the analysis of fire sales. It means that in the decentralized economy the financial institutions performing maturity transformation are too large compared to the institutions who perform no maturity transformation but instead invest locked long-term savings. Mapping the model with the real world, this result implies that in countries where the government is restricting early withdrawals in order to protect long-term saving (from coordination failure bank run, or in the presence of some present-biased agents), the size of the financial sector operating maturity transformation -which includes banks and shadow banks- is excessive, while pension funds are relatively too small.

6.2 Liquidity ratios

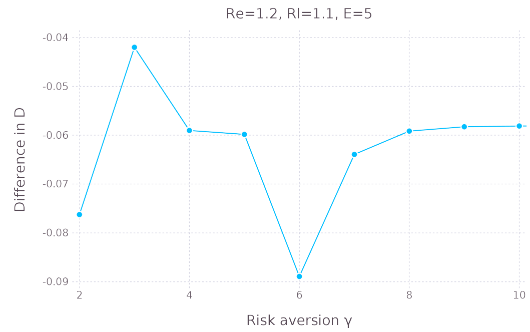
The effects of liquidity ratios are now investigated, taking as given risk aversion, as presented in figure 7.

[28]See for instance Gonzalo and Olmo (2019) which show that long-term risk aversion is higher than short-term risk aversion and that it increases with the investment horizon.

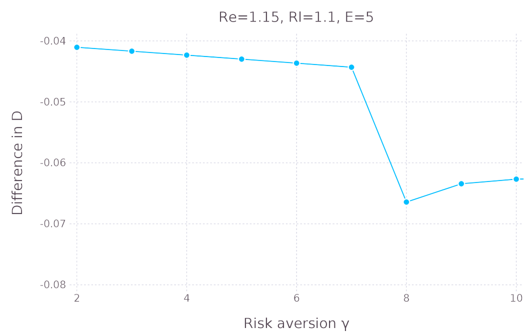
[29]The size of the inefficiency varies with risk aversion in a non-monotonic manner across the three simulations.



(a) **Simulation 1**



(b) **Simulation 2**



(c) **Simulation 3**

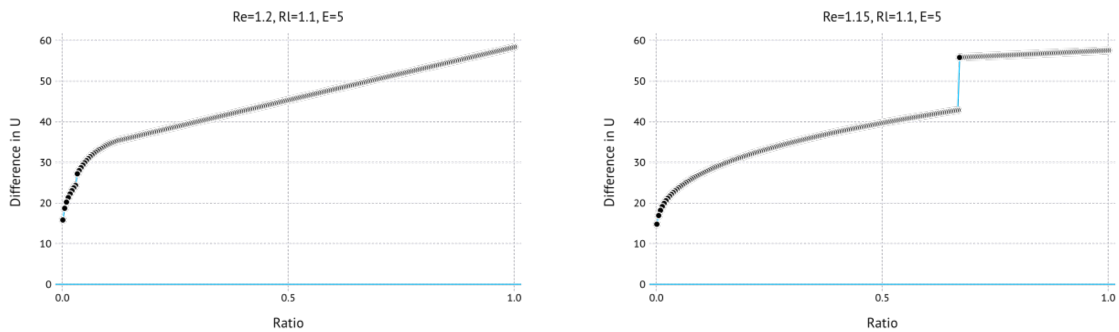
Figure (5) **Depositors can over-invest in liquid savings**

Figure 6 shows that liquidity ratios can decrease welfare, in the presence of an inefficiency in the choice of liquidity of depositors' saving.

The fact that liquidity ratios do not allow to reach the utility attained in the second best (i.e. constrained efficient economy) is easily explained by the fact that ratios cannot solve for two inefficiencies at once. But the fact that, in some cases, it can decrease welfare is more surprising. The reason is that by increasing the value of the banks, liquidity ratios can increase incentives for households to over invest in deposits, and overall decrease welfare.

7 Conclusion

This paper introduces an allocation of savings by depositors between instruments of different liquidity, offered by distinct financial intermediaries and investigates how the liquidity



(a) **Simulation 2** (b) **Simulation 3**

Figure (6) **Liquidity ratios can decrease welfare**

Simulation	2	3
Risk aversion γ	2	2
R^E	1.1	1.15
R^L	1.2	1.2
HH endowment E	5	5

Figure (7) **Parameter values**

of savings decision interacts with fire sales and their related welfare costs. A welfare loss arises because of an inefficient insurance between patient and impatient households. This inefficient insurance is due to the transfer of wealth implied by fire sales between the two *ex post* types of households that are not internalized by agents.

Price-taking banks fail to internalize the impact of their choice on the transfer operated during fire sales. The decentralized bank can choose too much assets and not enough liquid reserves, even compared to the constrained efficient allocation. Then, the bank fails as a provider of insurance against the idiosyncratic risk of being impatient.

The saving allocation by depositors between the liquid contract i.e. bank deposits, and the long-term illiquid contract offered by financial institutions akin to pension funds or insurance companies is not optimal. Households can invest too much in deposits and too little in funds shares because they ignore the impact of their choice of deposits on the fire-sales price. Consequently, the banking sector can be too big compared to the non-banking sector (the funds).

Imposing liquidity ratios seeking to reduce the inefficiency in the bank's choice can worsen the inefficiency on the households liquidity of savings decision with an overall decrease in utility in some cases. This paper therefore draws attention to the need of considering both sides of the fire sale market when designing a policy and more specifically shows how the decision by households on the liquidity of their savings instrument matters. The message is not that liquidity ratios should not be implemented but rather that they should be complemented by a subsidy of long-term illiquid saving in order to rechannel depositors savings adequately.

A Appendix

A.1 Proofs

A.2 Equilibrium definitions

Definition 1. *An equilibrium is an allocation made period 0 choice variables* $(D, K, S^B, L^B, \bar{c}, S^F, L^F)$*, the solvency threshold* $\overline{\theta}$*, and for each state* θ *of period 1 choice variables* $(X(\theta), Y(\theta))$ *and of price of early assets* $P(\theta)$ *along with the equilibrium conditions:*

- *i. the solvency condition 1;*
- *ii. the two fund optimality conditions in period 0 combined in equation 6;*
- *iii. the two fund optimality conditions in period 1 combined in equation 3;*
- *iv. the three bank' optimality conditions in period 0 (equations 8, 9, 10 for the decentralised economy and equations 7 9, 10 for the constrained efficient economy)*[30]
- *v. the two depositors' optimality conditions in period 0 (equations 15 and 16 for the decentralised economy and equation 13 and 14 for the constrained efficient economy);*
- *vi. the market clearing equation of assets (equation 4 written with equality and for* $X(\theta) = S_b$*) giving the fire sale price;*

under the assumptions that:

1. *depositors' type (impatient / patient) is private information;*
2. *there is perfect competition in the banking sector, and exogenous non-contingent banking contract;*
3. *markets are incomplete.*

Definition 2. *In the constrained efficient economy, the equilibrium is defined as in definition 1 with an additional assumption: the social planner does not take price and aggregate quantity as given.*

Definition 3. *In the decentralized economy, the equilibrium is defined as in definition 1 with an additional assumption: banks, depositors and funds take price and aggregate quantity as given.*

A.3 Bank problem in the decentralized economy

As the payment function by the bank is not continuous in $\bar{\theta}$ due to default, it is useful to define $E[U_{ND}]$ the expected utility when θ tends to $\bar{\theta}$ from the left so that the bank remains solvent - where the subscript ND stands for 'non default':

[30] Only the first order condition with respect to S differ as explained above.

$$E\left[U_{ND}\right]=\bar{\theta}u\left(\overline{c_1}\right)+(1-\bar{\theta})u\left[\frac{R^E\left(S^B+S^F\right)}{1-\bar{\theta}}\right]$$

$E\left[U_D\right]$ is the expected utility when θ tends to $\bar{\theta}$ from the right so that the bank is defaulting - where the subscript $_D$ stands for 'default':

$$E\left[U_D\right]=\bar{\theta}u\left(L^B+L^F\right)+(1-\bar{\theta})u\left[L^B+L^F+\frac{R^E\left(S^B+S^F\right)}{1-\bar{\theta}}\right]$$

The Lagrangian of the problem writes:

$$\begin{aligned}\mathcal{L}_{bank}&=E_\theta\left[u\left(c_1\right)+(1-\theta)u\left(C_2\right)\right]+\mu_1\left[D-L^B-S^B\right]\\&=\int_0^{\underline{\theta}}\left[u\left(c_1\right)+(1-\theta)u\left(C_2\right)\right]d\theta\\&+\int_{\underline{\theta}}^{\bar{\theta}}\left[\theta u\left(c_1\right)+(1-\theta)u\left(C_2\right)\right]d\theta\\&+\int_{\bar{\theta}}^{1}\left[\theta u\left(L^B+S^BP^*\right)+(1-\theta)u\left(L^B+S^BP^*+\frac{\pi(\theta)}{1-\theta}\right)\right]d\theta+\mu_1\left[D-L^B-S^B\right]\end{aligned}$$

The first order condition with respect to S^B writes:

$$\begin{aligned}&\int_0^{\bar{\theta}}R^Eu'\left(C_2\right)d\theta+\int_{\bar{\theta}}^{1}\left[\theta P^*u'\left(C_1^B\right)+\left[(1-\theta)P^*+R^E\right]u'\left(C_2^B\right)\right]d\theta\\&+\frac{R^EP^*}{\bar{c}D\left(R^E-P^*\right)}\left[E\left(U_{ND}\right)-E\left(U_D\right)\right]=\mu_1\end{aligned}\tag{8}$$

The first order condition with respect to L^B writes:

$$\begin{aligned}&\int_0^{\underline{\theta}}u'\left(\overline{C_2}\right)d\theta+\int_{\underline{\theta}}^{\bar{\theta}}R^Lu'\left(C_2\right)d\theta+\int_{\bar{\theta}}^{1}\left[\theta u'\left(C_1^B\right)+(1-\theta)u'\left(C_2^B\right)\right]d\theta\\&+\frac{R^E}{\bar{c}D\left(R^E-P^*\right)}\left[E\left(U_{ND}\right)-E\left(U_D\right)\right]=\mu\end{aligned}\tag{9}$$

The first order condition with respect to $\bar{c}$ writes:

$$\begin{aligned}&\int_0^{\bar{\theta}} \theta D u'\left(\overline{c_1}\right) d\theta = \\ &\frac{R^E\left(L^B+S^B P^*\right)}{\bar{c} D\left(R^E-P^*\right)}\left[E\left(U_{ND}\right)-E\left(U_D\right)\right]+\int_0^{\underline{\theta}} \theta D u'\left(C_2\right) d\theta+\int_{\underline{\theta}}^{\bar{\theta}} R^L \theta D u'\left(C_2\right) d\theta\end{aligned} \tag{10}$$

The three first order conditions (with respect to S^B, L^B and $\bar{c}$) combined write:

$$\begin{aligned}&\frac{\bar{c}}{L^B+S^B P^*}\left(1-P^*\right) \int_0^{\bar{\theta}} \theta D u'\left(\overline{c_1}\right) d\theta+\int_{\bar{\theta}}^1 \theta\left[1-P^*\right] u'\left(c_1^B\right) d\theta= \\ &\int_0^{\underline{\theta}}\left[R^E-1+\frac{\theta D \bar{c}}{L^B+S^B P^*}\left(1-P^*\right)\right] u'\left(C_2\right) d\theta \\ &+\int_{\underline{\theta}}^{\bar{\theta}}\left[\left(R^E-R^L\right)+\frac{R^L \theta D \bar{c}}{L^B+S^B P^*}\left(1-P^*\right)\right] u'\left(C_2\right) d\theta \\ &+\int_{\bar{\theta}}^1\left[R^E-\left(1-P^*\right)(1-\theta)\right] u'\left(C_2^B\right) d\theta\end{aligned}$$

A.4 Bank problem in the constrained efficient economy

The first order condition with respect to L^B writes:

$$\begin{aligned}&\int_0^{\underline{\theta}} u'\left(\overline{C_2}\right) d\theta+\int_{\underline{\theta}}^{\bar{\theta}} R^L u'\left(C_2\right) d\theta+\int_{\bar{\theta}}^1\left[\theta u'\left(C_1^B\right)+(1-\theta) u'\left(C_2^B\right)\right] d\theta \\ &+\frac{S^B R^E}{\bar{c} D\left(R^E S^B-K\right)}\left[E\left(U_{ND}\right)-E\left(U_D\right)\right]=\mu\end{aligned} \tag{11}$$

Replacing P^* by its value L^F/S^B, the optimality condition obtained is exactly equal to the optimality condition in the decentralized economy (see equation 9). At the optimum, they will differ to the inefficient choice of S^B but everything else held equal, they are similar: the inefficiency does not arise from the choice of $\bar{c}$.

The first order condition with respect to $\bar{c}$ writes:

$$\begin{aligned}&\int_0^{\bar{\theta}} \theta D u'\left(\overline{c_1}\right) d\theta + \frac{S^B R^E\left(L^B+K\right)}{\bar{c}^2 D\left(R^E S^B - K\right)}\left[E\left(U_{ND}\right) - E\left(U_D\right)\right] \\ &= \int_0^{\underline{\theta}} \theta D u'\left(C_2\right) d\theta + \int_{\underline{\theta}}^{\bar{\theta}} R^L \theta D u'\left(C_2\right) d\theta\end{aligned} \tag{12}$$

A.5 Depositor problem in the constrained efficient economy

The first order condition with respect to D yields:

$$\begin{aligned}&\int_0^{\bar{\theta}} \theta \bar{c} u'\left(\overline{c_1}\right) d\theta + \mu_1 = \\ &\int_0^{\underline{\theta}} R^L \theta \bar{c} u'\left(C_2\right) d\theta + \int_{\underline{\theta}}^{\bar{\theta}} \theta \bar{c} R^L u'\left(C_2\right) d\theta + \lambda + \frac{S^B R^E\left(L^B+K\right)}{\bar{c} D^2\left(R^E S^B - K\right)}\left(E\left[U_{ND}\right] - E\left[U_D\right]\right)\end{aligned} \tag{13}$$

The first order condition with respect to K yields:

$$\begin{aligned}&\int_0^{\bar{\theta}} \left(R^L + R^E\right) u'\left(C_2\right) d\theta + \int_{\underline{\theta}}^{1} \theta u'\left(c_1^B\right) + \left[R^E + \frac{1}{1-\theta}\right] u'\left(C_2^B\right) d\theta \\ &+ \frac{S^B R^E\left(S^B R^E - \bar{c} D + L^B\right)}{\bar{c} D^2\left(R^E S^B - K\right)}\left(E\left[U_{ND}\right] - E\left[U_D\right]\right) = \lambda\end{aligned} \tag{14}$$

A.6 Depositor problem in the decentralized economy

In the decentralized economy, depositors choose individual quantities denoted by the subscript $i : D^i$ and K^i. If patient, each individual consumer gets in period 2 a share of banks and funds portfolio. The share of bank portfolio is equal to $\frac{D}{(1-\theta)D}$ and the share of funds portfolio to $\frac{K}{(1-\theta)K}$ as there are $(1-\theta)$ patient.

Using the envelop theorem, the first order condition with respect to D^i yields:

$$\begin{aligned}
&\int_0^{\bar{\theta}} \left[\theta\bar{c}u'\left(\overline{c_1}\right) + \frac{\left(L^B - \theta\bar{c}D\right)R^L + S^B R^E}{D}u'\left(C_2\right)\right]d\theta \\
&+ \int_{\underline{\theta}}^{\bar{\theta}} \left[\theta\bar{c}u'\left(\overline{c_1}\right) + \frac{\left(S^B - X\right)R^E}{D}u'\left(C_2\right)\right]d\theta \\
&+ \int_{\bar{\theta}}^{1} \left[\theta\frac{L^B + S^B P^*}{D}u'\left(c_1^B\right) + \frac{(1-\theta)\left(L^B + S^B\right)}{D}u'\left(C_2^B\right)\right]d\theta = \lambda^i
\end{aligned} \tag{15}$$

When the bank is solvent and there is no sales of assets, one unit of deposits yields $\bar{c}$ for impatient, so that this return is expressed in impatient utility terms, and $\frac{\left(L^B-\theta\bar{c}D\right)R^L+S^B R^E}{D}$ for patient by unit of deposits, so that this return is expressed in impatient utility terms. When the bank is solvent and there are some sales of assets, the payment to patient only changes. When the bank defaults, the payments to both types of depositors is the same $\frac{\left(L^B+S^B P^*\right)}{D}$. Notice that the Lagrange multiplier from the banks' problem μ_1 does not enter the decentralized households problem as they take the aggregate variable D as given.

The first order condition with respect to K^i yields:

$$\begin{aligned}
&\int_0^{\underline{\theta}} \frac{S^F R^E + L^F R^L}{K}u'\left(C_2\right)d\theta + \int_{\underline{\theta}}^{\bar{\theta}} \left[\frac{R^E X + Y R^L + S^F R^E}{K}\right]u'\left(C_2\right)d\theta \\
&+ \int_{\bar{\theta}}^{1} \frac{R^E\left(S^B + S^F\right)}{K}u'\left(C_2\right)d\theta = \lambda^i
\end{aligned} \tag{16}$$

Only patient consumers benefit from these returns so that returns from the illiquid contract offered by funds are expressed only in marginal utility of patient.

A.7 Proof of proposition 1

In order to focus on the bank inefficient choice, we compare the purely inefficient economy, i.e. the decentralized economy studied above, called E_{dec} thereafter, to a fictitious economy which includes efficient banks and inefficient depositors. It is a partially efficient economy called thereafter $E_{eB,iH}$.

In the decentralized economy with ratio, we have:

$$\frac{\partial\mathcal{L}_{dec}}{\partial S} = \frac{\partial U_{dec}}{\partial S} - \mu_1 - \mu_2$$

In the economy $E_{eB,iH}$, we have:

$$\frac{\partial \mathcal{L}_{E_{eB,iH}}}{\partial S} = \frac{\partial U_{soc}}{\partial S} - \mu_1$$

As we have shown that in the economy $E_{eB,iH}$, the value of the derivative of the Lagrangian with respect to S is too high for a given $\bar{c}, L, K$, and D, it follows that a positive μ_2 allows reducing the distortion arising from the inefficient choice of S.

We compare the purely inefficient economy (inefficient households and inefficient banks) to the fictitious efficient-banks-only economy (efficient banks, inefficient households). The households have the same behavior in both economies which makes the comparison straightforward. As demonstrated above, $\frac{\partial U_{\text{dec}}}{\partial S} > \frac{\partial U_{soc}}{\partial S}$ for a given D and a given K. Besides, the allocation is the same except for the derivative with respect to S. Indeed, we know that $\frac{\partial \mathcal{L}_{\text{soc}}}{\partial L} = \frac{\partial \mathcal{L}_{\text{dec}}}{\partial L} = \mu_1$ and $\frac{\partial \mathcal{L}_{\text{soc}}}{\partial \bar{c}} = \frac{\partial \mathcal{L}_{\text{dec}}}{\partial \bar{c}}$.

Overall, $L, \bar{c}, K$ and D are the same in both economies, decentralized and constrained efficient. Therefore, to have $\frac{\partial \mathcal{L}_{\text{dec}}}{\partial S}$ closer to $\frac{\partial \mathcal{L}_{\text{soc}}}{\partial S}$ for a given D and a given K, the Lagrange multiplier on the ratio constraint must be strictly positive: $\mu_2 > 0$.

A.8 Proof of proposition 2

Liquidity ratios change the expressions of the first order condition of depositors with respect to D only (of course ratios also change the first order condition with respect to K evaluated at the equilibrium, but not the expression itself).

$$\frac{\partial \mathcal{L}_{\text{ratio}}}{\partial D} \geq \frac{\partial U_{\text{dec}}}{\partial D} - \mu_2 \alpha$$

If liquidity ratio are binding, i.e. if $\alpha > 0$, then liquidity ratio increases the incentives for depositors to over invest in deposits.

A.9 Subsidy of long-term illiquid saving

The households withdrawing in period 1 now receive $c_1 = \bar{c}D(1-t)$ when the bank is solvent and the patient receive a subsidy equal to $\frac{\theta \bar{c} D t}{1-\theta}$. As above, we compare the purely inefficient economy to the fictitious efficient-households-only economy $E_{iB,eH}$ so that banks have the same behavior: we can focus on the inefficiency lying in households choice. We then obtain the following result by differentiating the modified Lagrangian including the new payments taking into account the tax:

Proposition 3. *For a given allocation,*

$$\frac{\frac{\partial \mathcal{L}_{dec}}{\partial K}}{\partial \tau} \geq 0 \ and \ \frac{\frac{\partial \mathcal{L}_{dec}}{\partial D}}{\partial \tau} \leq 0.$$

Recall that $\frac{\partial \mathcal{L}_{\text{dec}}}{\partial K} \leq \frac{\partial U_{soc}}{\partial K}$ so that households do not choose to invest enough into the illiquid contract offered by funds K. Therefore, a positive tax $\tau \geq 0$ can help with the distortion.

A tax policy modifies all the payments such that:

$$\text{When } \theta < \underline{\theta}, \begin{cases} c_1 = \bar{c}D(1-\tau) \\ C_2 = \frac{L-\theta\bar{c}D+SR^E+KR^L}{1-\theta} + \frac{\theta\bar{c}D\tau}{1-\theta} = \frac{L+SR^E+KR^L}{1-\theta} \end{cases}$$

$$\text{When } \underline{\theta} \leq \theta < \bar{\theta}, \begin{cases} c_1 = \bar{c}D(1-\tau) \\ C_2 = \frac{R^E S+R^L(K+L)+\theta\bar{c}D\tau}{1-\theta} \end{cases}$$

We consider the decentralized economy.

$$\frac{\partial \mathcal{L}_{dec}}{\partial D} = \int_0^{\bar{\theta}} \left[\theta\bar{c}(1-\tau)u'\left(\overline{c_1}\right)d\theta + \frac{L-\theta\bar{c}D\tau+SR^E}{D}u'\left(c_2\right)\right]d\theta$$
$$+\int_{\underline{\theta}}^{\bar{\theta}} \left[\theta\bar{c}(1-\tau)u'\left(\overline{c_1}\right) + \frac{(S-X)R^E}{D}\right]u'\left(c_2\right)d\theta +$$
$$\int_{\bar{\theta}}^{1} \left[\frac{\theta\left(L+SP^*\right)}{D}u'\left(c_1^B\right) + \frac{(1-\theta)\left(L+SP^*\right)}{D}u'\left(c_2^B\right)\right]d\theta$$

Therefore $\frac{\frac{\partial \mathcal{L}_{\text{dec}}}{\partial D}}{\partial \tau}$ is negative for a given allocation (we look at the impact of the tax on the first order conditions here).

$$\frac{\partial \mathcal{L}_{\text{dec}}}{\partial K} = \int_0^{\bar{\theta}} \frac{KR^L+\theta\bar{c}D\tau}{K}u'\left(c_2\right)d\theta + \int_{\underline{\theta}}^{\bar{\theta}} \frac{R^E X+\theta\bar{c}D\tau}{D}u'\left(c_2\right) + \int_{\bar{\theta}}^{1} \frac{\theta\left(R^E S\right)}{K}u'\left(c_2^B\right)d\theta$$

$$\frac{\frac{\partial \mathcal{L}_{\text{dec}}}{\partial K}}{\partial \tau} \geq 0$$

When $\frac{\partial \mathcal{L}_{\text{dec}}}{\partial K} \leq \frac{\partial U_{soc}}{\partial K}$ (so that households do not choose to invest enough into the illiquid contract offered by funds K), a positive tax $\tau \geq 0$ can help with the distortion.

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