

# Secondary Market Liquidity and the Optimal Capital Structure\*

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January 12, 2016

## Abstract

We present a model where endogenous liquidity generates a feedback loop between secondary market liquidity and firms' financing decisions in primary markets. Endogenous liquidity determines the liquidity premium, which affects issuance in the primary market, and feeds back into secondary market liquidity by changing investors' portfolio composition. We show that private allocations are inefficient because investors and firms fail to internalize how they affect secondary market liquidity. These inefficiencies are established analytically through a set of wedge expressions for key efficiency margins. Our analysis provides a rationale for the effect of quantitative easing on capital markets and the real economy.

**Keywords:** Market liquidity, secondary markets, capital structure, quantitative easing.

**JEL classification:** E44, G18, G30.

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\*We are grateful to Regis Breton, Francesca Carapella, Giovanni Favara, Zhiguo He (discussant), Nobu Kiyotaki, Michal Kowalik (discussant), Cecilia Parlatore, Lasse H. Pedersen, Skander Van den Heuvel, Chris Waller, and seminar participants at Econometric Society World Economic Congress, SED, Cowles General Equilibrium Conference, EEA, Day Ahead Conference, LACEA, IMF, Society for Advancement of Economic Theory, Federal Reserve Board, Federal Reserve System Conference Financial Structure and Regulation, St Louis Fed, Banque de France, and University of Chile for comments. All errors herein are ours. The views expressed in this paper are those of the authors and do not necessarily represent those of Federal Reserve Board of Governors or anyone in the Federal Reserve System.  
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# 1 Introduction

Secondary market liquidity is an important consideration for investors buying long-term assets. At the same time, the issuance of long-term debt in primary markets affects market liquidity by altering the maturity composition of investors' portfolios. The interaction between primary debt markets and secondary market liquidity is important for understanding the real effects of financial market imperfections. For example, how does debt issuance in primary markets affect liquidity in secondary markets? How does the compensation for bearing liquidity risk affect the firm's incentive to issue debt in the primary market? Does the interaction between these two channels lead to an efficient capital structure of the firm? How does quantitative easing affect the real economy through intervention in either the primary or secondary market?

This paper presents a model to formalize the interaction between primary and secondary capital markets in order to shed light on these questions. In particular, we are interested in imperfect secondary trading that gives rise to liquidity risk, as investors' liquidity needs cannot be met by selling assets frictionlessly in secondary markets.

A key contribution of our paper is to present an alternative theory of secondary market liquidity determination, where trade frictions interact with *limited* liquid assets available to financial market investors.<sup>1</sup> In our environment, investors have an incentive to hold the liquid asset in order to self-insure against liquidity shocks, but doing so comes at the cost of foregoing a higher return in illiquid long-term bonds. This tradeoff determines the investors' optimal portfolio allocation. Once the portfolio is allocated, there is a fixed amount of liquid assets available to support frictional trade of illiquid assets in the secondary market. Thus, our notion of secondary market liquidity is one defined by market thickness, as in the search literature, but where market thickness is determined endogenously by investors and firms decisions in the primary market.

Interacting this notion of secondary market liquidity with the optimal capital structure of the firm gives rise to three main results. First, we uncover a novel feedback loop, illustrated in Figure 1, between secondary market liquidity and the firm's financing decision in primary capital markets. This feedback loop allows for liquidity risk associated with trade in the secondary market to influence firms' financing decisions through funding costs. This direct channel has received considerable attention in the literature as it is closely related to the idea of transaction or information costs impeding trading, as well to the lending channel of monetary policy. Our framework differs, however, in that we cap-

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<sup>1</sup> To be explicit, we are drawing a distinction between a liquid asset and market liquidity. The former refers to an asset that can be easily and costlessly be transformed into consumption. The later refers to the ease with which one can trade in the market.

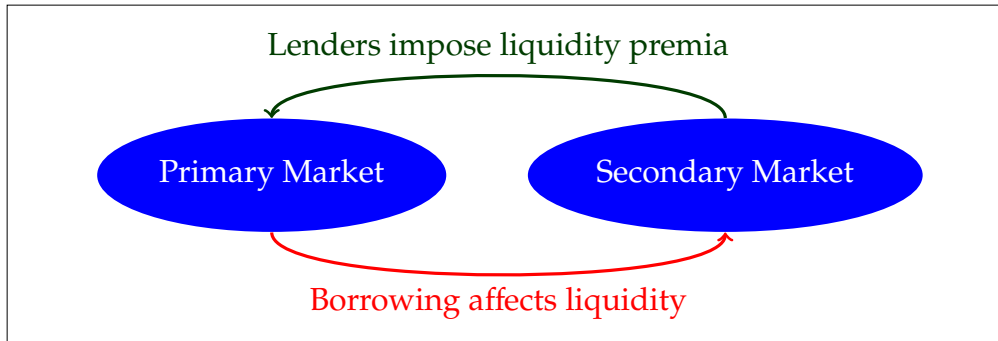


Figure 1: Feedback loop between primary and secondary market for corporate debt

ture an additional channel whereby the firm’s financing decisions in the primary market feed back into the determination of liquidity in the secondary market. This happens both directly through the supply of long-term assets and indirectly by altering the composition of investor portfolios. This link between primary issuance and secondary market liquidity is key to understanding how the liability structure of firms matters for the optimal intermediation of liquidity risk and the real economy. We prove the existence and uniqueness of an equilibrium featuring this feedback loop and characterize it in closed form.

Second, we show that this feedback loop distorts capital markets. The interaction between the primary and secondary markets generically leads to two distortions: one in the capital structure of the firm and another in the allocation of investor portfolios. These distortions arise from the fact that neither firms nor investors internalize how their behavior affects liquidity in the secondary market. In equilibrium, market liquidity can be suboptimally low (high) implying the firm is over-leveraged (under-leveraged), hence there is an under-supply (over-supply) of liquid assets for investors trading on the secondary market. A social planner would like to implement the optimal level of liquidity in the secondary market by altering the financing decision of firms and the portfolio allocation of investors. Such an outcome leads to higher firm profits while investors are no worse off. We derive a set of analytic wedge expressions that highlight two distorted margins and show how an appropriately designed tax system can decentralize the efficient equilibrium.

Finally, we provide a theoretical characterization for the effects of quantitative easing (QE) policies, like the ones observed following the Great Recession. Through the lens of our model, policies such as quantitative easing that directly alter the composition of investors’ portfolios shift liquidity risk from investors to the central bank, reducing liquidity premia. This, in turn, influences savings and investment decisions in the real

economy (see Stein, 2014, for a general discussion). Our analysis also highlights the benefits and limitations of such interventions. On the one hand, QE can improve the intermediation capacity of the economy by expanding its productive frontier. On the other hand, these policies may be limited by their redistributive effects, the limited expertise of central banks in bond market participation, and the prospect for financial losses.

The model has three periods, and it is populated by firms that need external financing to invest in long-term projects and investors who want to transfer funds over time to consume in all periods. In the initial period, ex ante identical investors supply funds to firms in primary capital markets, while firms issue claims against their long-term revenues that materialize only in the final period. The contracting problem between the firm and investors in the primary debt market is subject to agency frictions, which we model using the costly state verification (CSV) framework (Townsend, 1979; Gale and Hellwig, 1985; Bernanke and Gertler, 1989). The choice of the CSV framework is guided by the fact that it offers a convenient and well understood rationale for the firm's use of debt financing, which is central to our model. In addition, the CSV framework allows us to jointly study the effect of liquidity premia on the composition (leverage) and the riskiness of the capital structure of the firm. That said, the specific nature of the agency frictions in the primary market is not detrimental for the generality of our results.<sup>2</sup>

After the financial contract between the firm and investors is written and investment decisions are made, a subset of investors receive idiosyncratic (liquidity) shocks that make them want to consume before the firm's investments mature and proceeds are distributed. These shocks are private information and, thus, contingent contracts among patient and impatient investors cannot be written ex ante. Alternatively, investors can self-insure by investing part of their endowment in a storage technology or by holding corporate bonds and re-trading them in a secondary market once the type has been revealed. Corporate bonds thus not only are a claim on real revenues, but also have a role in facilitating exchange (see also Rocheteau and Wright, 2013).

In absence of frictions, the ability to trade long-term bonds in the secondary market would perfectly satisfy impatient investors' demand for liquidity. Indeed, in this special case we show that our model collapses to the benchmark CSV model of Bernanke and Gertler (1989) where liquidity concerns play no role. In practice, however, trading frictions may impinge on the ability of impatient investors to sell long-term assets. For corporate bonds, which are traded in over-the-counter (OTC) markets, empirical evidence by Ed-

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<sup>2</sup>The reason is that we are able to disentangle the channel through which market liquidity affects liquidity premia in long-term assets from the choice of the optimal contract/capital structure of the firm. Hence, any other financial friction in the primary market such that leverage is decreasing in borrowing costs will yield similar results.

wards et al. (2007) and Bao et al. (2011) suggests that search frictions are an important driver of liquidity premia. Bond financing has become one of the most important sources of external financing for U.S. corporations. Figure 3 shows that bond financing is the dominant source of credit liabilities for non-financial corporate firms (Financial Accounts of the United States data). This paper focuses on bond financing abstracting from the fact that firms enter into bank loans or other types of borrowing at the same time (see deFiore and Uhlig, 2011, Aoki and Nikolov, 2014, for models where bank and bond financing coexist).<sup>3</sup>

We follow the literature modeling OTC markets with search frictions (Duffie et al., 2005, Lagos and Rocheteau, 2009, He and Milbradt, 2014, and others). This literature captures a price-based notion of liquidity through the bid-ask spread and treats matching probabilities between buyers and sellers as exogenous. Price effects are important in our framework, but our focus is broader in the sense that we are interested in how primary markets for corporate assets interact with secondary market liquidity. A key aspect of this interaction involves the endogenous nature by which trading probabilities in the secondary market are determined. Our framework considers a notion of liquidity determined by market thickness as in Shi (2015), Bruche and Segura (2014), and Cui and Radde (2015).<sup>4</sup> In contrast with these papers, however, market liquidity in our setup is not determined through the free entry of buyers and sellers, but instead through the endogeneous decisions of investors and firms in the primary market. Introducing a costly entry decision for buyers in the secondary market would not be difficult, but would add an extra margin for the determination of liquidity that is beyond the scope of this paper.

*Related Literature.* In a seminal paper, Holmström and Tirole (1998) study a similar question to ours, but focus on the liquidity needs of firms to cover operational costs before their investment matures. In contrast, we focus on the liquidity demand of lenders. To this extent, we model the demand for liquidity as in the seminal paper of Diamond and Dybvig (1983), but bring re-trading of long-term assets, aggregate liquidity and the capital structure to the center of our analysis. Holmström and Tirole (1998) also advocate that there is a role for the public sector to create liquid assets, in particular government debt,

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<sup>3</sup>In principle, bank intermediation would be optimal to insure against idiosyncratic liquidity risk in the spirit of Diamond and Dybvig (1983) when bank runs are not very likely (see Cooper and Ross, 1998, and Goldstein and Puzner, 2005) or bank credit is not sufficiently more expensive than bond financing as in deFiore and Uhlig (2011). However, Jacklin (1987) shows that the efficiency gains of bank intermediation for investors vanish when secondary capital markets are available and function frictionlessly. This should continue to be true when the associated frictions in secondary markets are not too severe, while bank intermediation would dominate when markets are more imperfect (Diamond, 1997).

<sup>4</sup>In the language of Brunnermeier and Pedersen (2009), this is a concept of market liquidity (the ease with which illiquid assets can be sold), as opposed to funding liquidity (how much firms can raise by pledging assets as collateral).

which can be used by firms to insure against liquidity shocks. While similar in spirit, the mechanism through which public liquidity has real effects is different from ours. In our framework, investors have access to a storage technology in perfectly elastic supply, so there is no scope for the public sector to create a store of value, which is central in Holmström and Tirole. Reserves are a substitute for storage, but through quantitative easing liquidity risk is shifted from the private to the public sector, increasing the liquidity risk tolerance of investors.

A related literature has studied the role of endogenous liquidity for financial intermediation and the macroeconomy, considering adverse selection arising from asymmetrically informed agents participating in the secondary market. This literature differs from the search microfoundations of illiquidity because the difficulty of finding a buyer depends primarily on the extent of private information rather than the availability of trading opportunities. In a seminal paper in this literature, Gorton and Pennacchi (1990) show how the information sensitivity of financial contracts affects their liquidity in secondary markets and study the capital structure of the firm and efficient intermediation. Gorton and Pennacchi show that uninformed investors respond by demanding informationally insensitive assets, notably riskless debt. Hence, their approach is important for understanding how investors' decisions to participate in these markets (the extensive margin of investors' portfolio choice) affects the firm's capital structure. In contrast, our approach of introducing search frictions to limit trade in secondary markets allows us to examine how—given full participation in both asset markets—the intensive margin of investors' portfolio choice affects the firm's financing decision and how the firm's financing decision, in turn, affects investors' portfolios.

Recent contributions to this literature have explored similar questions to ours. Guerrieri and Shimer (2014) examine how adverse selection about the quality of assets affects their liquidity premia, and suggest that unconventional policy interventions, such as asset purchases, can enhance the liquidity of assets not included in the purchase programs. Nevertheless, they do not study how illiquidity and policy interventions affect the equilibrium supply of assets, i.e., they abstract from corporate finance issues. Malherbe (2014), who builds on an adverse selection model of liquidity by Eisfeldt (2004), shows that, in contrast, excess cash-holdings impose a negative externality on others because they reduce the quality of assets put for sale in the secondary market. Kurlat (2013) and Bigio (2015) study the interaction of business cycle dynamics and illiquidity induced by adverse selection in asset markets. Gorton and Ordoñez (2014) present a dynamic model where costly information production can generate financial fragility and financial crises.

Our paper is also related to the literature that considers financial intermediation fric-

tions arising from aggregate liquidity risk and incomplete markets. When investors face aggregate liquidity risk which cannot be hedged due to market incompleteness, liquidity provision in the form of aggregate savings/reserves may be suboptimally low (Bhattacharya and Gale, 1987; Allen and Gale, 2004).<sup>5</sup> In our paper, inefficient liquidity stems from trading frictions rather than aggregate shocks, which yields important implications for the liquidity premia of corporate bonds during periods that aggregate liquidity shocks are expected to occur rather infrequently. Consequently, our mechanism could potentially explain the fluctuations in liquidity and default risk premia, as well as firms' leverage even when aggregate liquidity shortages are unlikely or excluded due to the presence of unconventional policies, such as quantitative easing.

The rest of the paper proceeds as follows. Section 2 presents the model and derives the equilibrium conditions. Section 3 shows how secondary market liquidity interacts with the optimal financing decisions of the firm. Section 4 present the social planner's problem, describes the externality operating through secondary market liquidity, and analytically describes the set of policy instruments that can implement the constrained efficient outcome. Section 5 analyses the effect of quantitative easing on secondary market liquidity and financing decisions. Finally, section 6 concludes. All proofs are relegated to the Appendix.

## 2 Model

### 2.1 Physical Environment

There are three time periods  $t = 0, 1, 2$ , a single consumption good, and two type of agents: entrepreneurs and investors. Entrepreneurs have long-term investment projects and may fund these projects with internal funds or with loans from investors. Ex ante identical investors lend funds to entrepreneurs, but once that lending has taken place and while production is underway, investors are subject to a preference (liquidity) shock which reveals whether they are impatient, and hence prefer to consume earlier rather than later, or patient. These two types of investors trade their assets in secondary asset markets with search frictions (see Figure 2).

There is a mass one of ex ante identical entrepreneurs, who are endowed with  $n_0$  units of capital at  $t = 0$ . Entrepreneurs invest to maximize the return on their equity, i.e., to

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<sup>5</sup>Liquidity under-provision may also stems from hidden trades undoing the efficient sharing of liquidity risk across impatient and patient agents as in Farhi et al. (2009) or fire-sales externalities (Lorenzoni, 2008; Korinek, 2011; Acharya, Shin and Yorulmazer, 2011), which we abstract from in our paper.

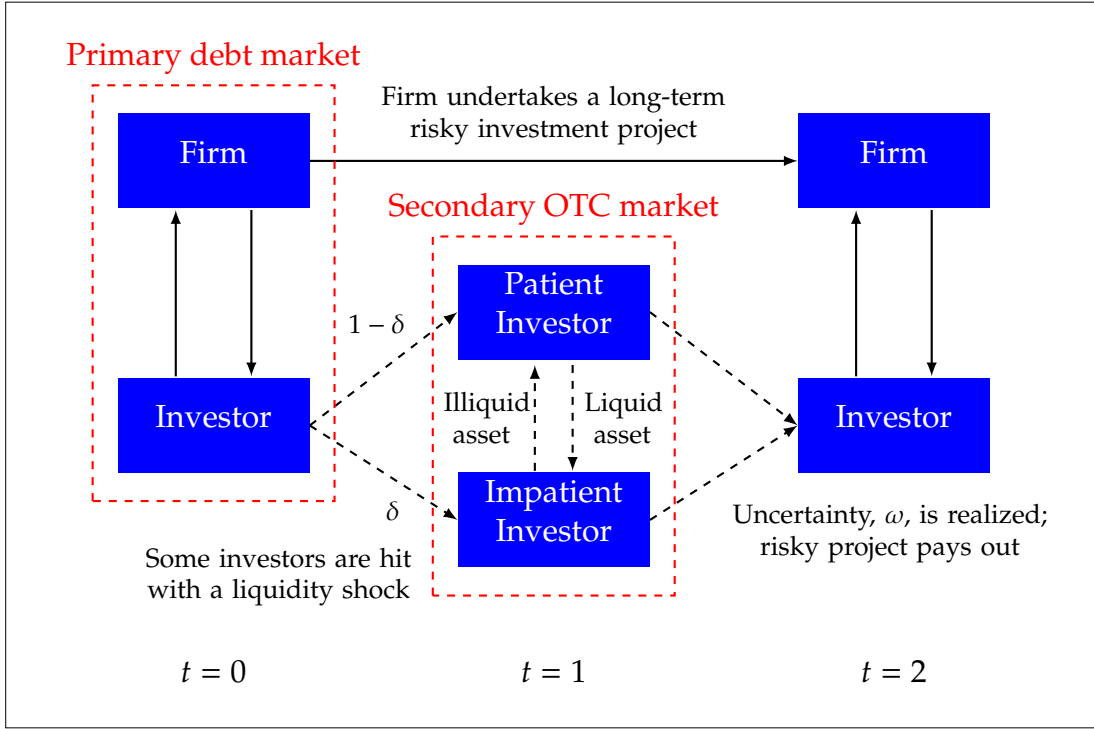


Figure 2: Timeline.

maximize profits per unit of endowment. The technology is linear and delivers  $R^k \omega$  at  $t = 2$ , per unit invested at  $t = 0$ . The random variable  $\omega$  is an idiosyncratic productivity shock that hits after the project starts, and is distributed according to the cumulative distribution function  $F$ , with unit mean. It is privately observed by the entrepreneur, but investors can learn about it when they seize entrepreneurs' assets and pay a monitoring costs  $\mu$  as a fraction of assets. The (expected) gross return  $R^k$  is assumed to be known at  $t = 0$ , as there is no aggregate uncertainty in the model. In order to produce, the firm must finance investment, denoted  $k_0$ , either through its own funds or by issuing financial contracts to investors. So profits equal total revenue in period 2,  $R^k \omega k_0$ , minus payment obligations from financial contracts. Entrepreneurs represent the corporate sector in our model, so we will talk about entrepreneurs' projects and firms interchangeably.

There is a mass one of ex ante identical investors, who are endowed with  $e_0$  units of capital at  $t = 0$ . Investors have unknown preferences at  $t = 0$ , and learn their preferences at  $t = 1$ . At  $t = 1$  investors realize if they are *patient* or *impatient consumers*, a fraction  $1 - \delta$  will turn out to be patient and a fraction  $\delta$  impatient. Patient consumers have preferences only for consumption in  $t = 2$ ,  $u^P(c_1, c_2) = c_2$ , whereas impatient consumers



have preferences for both consumption in  $t = 1$  and 2, but discount period 2 consumption at rate  $\beta$ ,  $u^I(c_1, c_2) = c_1 + \beta c_2$ .

Investors in both period 0 and 1 have access to a storage technology with yield  $r > 0$ , i.e., every unit stored yields  $1 + r$  units of consumption in the next period. The amount stored in period  $t$  is denoted  $s_t$ . In addition, at  $t = 0$ , they can invest in financial contracts issued by entrepreneurs in primary markets; and, at  $t = 1$ , they can buy and sell assets in secondary markets with search frictions (see Figure 2). When engaging in trade in the secondary market patient investors realize a return  $\Delta$ . Both the primary and secondary markets are described in detail below.<sup>6</sup>

In what follows we make the following assumptions.

**Assumption 1 (Relative Returns)** *The long-term return of the productive technology is larger than the cumulative two-period storage return and the return on storage plus the return on secondary markets, i.e.,  $(1 + r)^2 < R^k$  and  $(1 + r)\Delta < R^k$ . In addition, monitoring costs are such that  $R^k(1 - \mu) < (1 + r)^2$ .*

**Assumption 2 (Productivity Distribution)** *Let  $h(\omega) = dF(\omega)/(1 - F(\omega))$  denote the hazard rate of the productivity distribution. It is assumed that  $\omega h(\omega)$  is increasing.*

**Assumption 3 (Impatience)** *The rate of preference of impatient investors is such that  $\beta \leq 1/(1 + r)$ .*

**Assumption 4 (Investors Deep Pockets)** *It is assumed that investors' (total) endowment  $e_0$  is significantly higher than entrepreneurs' (total) endowment  $n_0$ , i.e.,  $e_0 \gg n_0$ .*

Assumption 1 is necessary for there to be a role for the entrepreneurial sector,  $R^k > (1 + r)^2$ , and,  $R^k > (1 + r)\Delta$ , when the prospective return on secondary market is taken into account. Furthermore, this assumption rules out equilibria where entrepreneurs are always monitored,  $(1 + r)^2 > R^k(1 - \mu)$ . Assumption 2 ensures that there is no credit rationing in equilibrium, and together with Assumption 1 will ensure the existence and uniqueness of equilibrium, as we discuss below. Assumption 3 makes impatient investors have a (weak) preference for current versus future consumption when the interest rate is  $r$ . Finally, Assumption 4 ensures that investors can meet the credit demand of entrepreneurs.

## 2.2 The Financial Contract

Entrepreneurs finance their investments using either internal funds,  $n_0$ , or by selling long-term financial contracts to investors in the primary corporate debt market. These

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<sup>6</sup>Note that since  $r > 0$  and since investors preferences have been assumed time separable and risk neutral, there was no loss of generality in abstracting away from consumption at  $t = 0$  for investors, and consumption at  $t = 1$  for patient investors.

contracts specify an amount,  $b_0$ , borrowed from investors at  $t = 0$  and a *promised* gross interest rate,  $Z$ , made upon completion of the project at  $t = 2$ . If entrepreneurs cannot make the promised interest payments, investors can take all firm's proceeds paying a monitoring cost, equal to a fraction  $\mu$  of the value of assets.<sup>7</sup>

The  $t = 0$  budget constraint for the entrepreneur is given by

$$k_0 \leq n_0 + b_0 . \quad (1)$$

For what follows it will be useful to define the entrepreneur's leverage,  $l_0$ , as the ratio of assets to (internal) equity  $k_0/n_0$ .

The entrepreneur is protected by limited liability, so its profits are always non-negative. Thus, the entrepreneur's expected profit in period  $t = 2$  is given by

$$\mathbb{E}_0 \max \{0, R^k \omega k_0 - Z b_0\} .$$

Limited liability implies that the entrepreneur will default on the contract if the realization of  $\omega$  is sufficiently low such that the payoff of the long-term project falls below the promised payout; that is, when  $R^k \omega k_0 < Z b_0$ . This condition defines a threshold productivity level,  $\bar{\omega}$ , such that the entrepreneur defaults when

$$\omega < \bar{\omega} = \frac{Z l_0 - 1}{R^k l_0} . \quad (2)$$

The productivity threshold measures the credit risk of the financial contract; and is increasing in the spread between the promised return and the expected return on the entrepreneur investment, and increasing in firm's leverage.

For notational convenience, we define  $G(\bar{\omega}) \equiv \int_0^{\bar{\omega}} \omega dF(\omega)$  and  $\Gamma(\bar{\omega}) \equiv \bar{\omega}(1 - F(\bar{\omega})) + G(\bar{\omega})$ . The function  $G(\bar{\omega})$  equals the truncated expectation of entrepreneurs' productivity given default. The function  $\Gamma(\bar{\omega})$  equals the expected value of a random variable equal to  $\omega$  if there is default ( $\omega < \bar{\omega}$ ) and equal to  $\bar{\omega}$  when there is not ( $\omega \geq \bar{\omega}$ ). It follows that  $R^k k_0 \Gamma(\bar{\omega})$  corresponds to the expected transfers from entrepreneurs to investors.

Then, firms' objective, expected profits per unit of endowment, or return on equity,

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<sup>7</sup>We consider deterministic monitoring rather than stochastic monitoring, which results in debt being the optimal contract. Krasa and Villamil (2000) derive the conditions under which deterministic monitoring occurs in equilibrium in costly enforcement models. In addition, our model features perfect, but costly, ex-post enforcement. See Krasa et al. (2008) for a more elaborate enforcement process and its implications for firms' finance.

can be expressed using the previous notation as <sup>8</sup>

$$\frac{1}{n_0} \mathbb{E}_0 \max \{0, R^k \omega k_0 - Z b_0\} = [1 - \Gamma(\bar{\omega})] R^k l_0 . \quad (3)$$

Similarly, the *total* expected payoff of bond contracts can be expressed as

$$\int_{\bar{\omega}}^{\infty} Z b_0 dF(\omega) + (1 - \mu) \int_0^{\bar{\omega}} R^k \omega k_0 dF(\omega) = k_0 R^k [\Gamma(\bar{\omega}) - \mu G(\bar{\omega})] .$$

Therefore, the expected gross return of holding a *single* bond to maturity  $R^b$  is given by

$$R^b = \frac{l_0}{l_0 - 1} R^k [\Gamma(\bar{\omega}) - \mu G(\bar{\omega})] , \quad (4)$$

which is a function of only leverage and the productivity threshold.

Clearly  $R^b$  is decreasing in  $l_0$  as leverage dilutes lenders claim on the firm's assets. Moreover, in equilibrium it will be increasing in risk,  $\bar{\omega}$ , as detailed below. Finally, note that the expected return is known in period 0 and 1, since there is no aggregate uncertainty or new information arriving after investors and the firm have agreed on the terms of lending. This means that idiosyncratic liquidity shocks in period 1 do not affect  $R^b$  and investors would trade bonds in a secondary market promising this expected payout.

### 2.3 The Secondary OTC Market

The ex post heterogeneity introduced by the preference shock generates potential gains from trading corporate debt in a secondary market. Impatient investors want to exchange long-term, imperfectly liquid, bonds for consumption, as they would rather consume at the end of period 1 than hold the bond to maturity until period 2 (Assumption 3). Patient investors are willing to exchange lower yielding storage for corporate debt with higher expected returns.

In order for such a trade to take place, buy and sell *orders* must be paired up according to a matching technology which aligns them. Impatient investors submit sell orders, one for each bond they are ready to sell at a given price  $q_1$ . Patient investors submit buy orders, one for each package of  $q_1$  units of storage they are ready to exchange for a bond. We model the OTC market such that matching is by order, as opposed to by investor.<sup>9</sup> Suppose, in aggregate, there are  $A$  sell (or ask) orders and  $B$  buy orders. The matching

<sup>8</sup>The objective of the firm in equation (3) is written in terms of return to equity rather than total profits. However, both formulations would yield the same equilibrium results as  $n_0$  is positive and given.

<sup>9</sup>This can be thought of as money chasing bonds, instead of investors chasing investors.

function is assumed to be constant returns to scale and is given by

$$m(A, B) = \nu A^\alpha B^{1-\alpha}, \quad (5)$$

with  $0 < \nu$  a scaling constant and  $0 < \alpha < 1$  the elasticity of the matching function with respect to sell orders. The number of matches is limited by the minimum of the number of buy and sell orders, so  $m(A, B) \leq \min\{A, B\}$ .

We define a concept of *market liquidity* through the ratio of buy orders to sell orders, or  $\theta = B/A$ . This notion of liquidity—defined by a concept of thickness in the OTC market—has different implications for traders on opposing sides of the market. For example, when  $\theta$  is large, a bond in the secondary market is relatively liquid, that is, it is relatively easy for sellers to trade. But, at the same time, it is relatively hard for buyers to trade. Note that our notion of liquidity is related to, but distinct from, the easiness to trade for *all* market participants, which is captured in our framework by the efficiency of the matching technology  $\nu$ . Increasing (decreasing)  $\nu$  makes it easier (harder) for participants on both sides of the market to trade in a symmetric fashion.

Using the matching function, the *probability that a sell order is executed* is expressed as

$$f(A, B) = \frac{m(A, B)}{A} \quad \text{or} \quad f(\theta) = m(1, \theta), \quad (6)$$

and the *probability that a buy order is executed* is expressed as

$$p(A, B) = \frac{m(A, B)}{B} \quad \text{or} \quad p(\theta) = m(\theta^{-1}, 1). \quad (7)$$

The fact that matches are bounded by the minimum number of orders, i.e.,  $m(A, B) \leq \min\{A, B\}$ , defines two liquidity threshold  $\underline{\theta}$  and  $\bar{\theta}$ . When liquidity is smaller than  $\underline{\theta} = \nu^{1/\alpha}$  then all buy orders are executed, i.e.,  $m(A, B) = B$ . In this case buyers trade with probability  $p(\theta) = 1$ , whereas sellers trade with probability  $f(\theta) = \theta$ . Alternatively, when liquidity is higher than  $\bar{\theta} = \nu^{-1/(1-\alpha)}$  then all sell orders are executed, i.e.,  $m(A, B) = A$ ; and thus the trade probabilities  $f(\theta) = 1$  and  $p(\theta) = \theta^{-1}$ . When liquidity is in  $[\underline{\theta}, \bar{\theta}]$  then matches are given by the matching function (5) and the trade probabilities by equations (6) and (7). Unless otherwise stated, we restrict attention to the case  $\nu < 1$ , which guaranties that  $\underline{\theta} < \bar{\theta}$ .

Once a buy order and a sell order are matched, the terms of trade are determined via a simple surplus sharing rule known by all agents. From the seller's perspective, a trading match yields additional liquid wealth from unloading the incremental bond sold at price  $q_1$ . If the seller walks away from the match she holds the bond, which matures in the final

period, delivering an expected payout of  $R^b$  in  $t = 2$ , which is discounted at rate  $\beta$ . Then, the surplus that accrues to an impatient investor is given by  $S^I(q_1) = q_1 - \beta R^b$ . Similarly, the value of a trading match to a buyer is the present value of the (expected) return on the bond, net of the price that needs to be paid for each bond in the secondary market,  $S^P(q_1) = R^b/(1+r) - q_1$ .

The price of the debt contract on the secondary market is determined by a sharing rule that maximizes the Nash product of the respective surpluses,

$$\max_{q_1} \left( S^I(q_1) \right)^\psi \left( S^P(q_1) \right)^{1-\psi} ,$$

where  $\psi \in [0, 1]$  is a parameter that determines the split of the surplus between patient and impatient investors.<sup>10</sup>

The solution of the surplus splitting problem yields the following bond price in the secondary market

$$q_1 = R^b \left( \frac{\psi}{1+r} + (1-\psi)\beta \right) . \quad (8)$$

Note that  $\psi = 1$  drives the price of the bond to the “ask” price, or the price that extracts full rent from the buyer,  $q_1 = \frac{R^b}{1+r}$ . By the same token,  $\psi = 0$  drives the price of the bond to the “bid” price, or the price that extracts full rent from the seller,  $q_1 = \beta R^b$ . From equation (8) it follows that the return that patient investors make in the secondary market, per executed buy order, depends only on exogenous parameters and is given by

$$\Delta = \frac{R^b}{q_1} = \left( \frac{\psi}{1+r} + (1-\psi)\beta \right)^{-1} \geq 1+r .$$

## 2.4 Investors

As described above, investors are ex ante identical and are endowed with  $e_0$  units of capital. At  $t = 0$  they can allocate their wealth across two assets: the storage technology and debt contracts. Thus, their budget constraint is given by<sup>11</sup>

$$s_0 + b_0 = e_0 , \quad (9)$$

where  $s_0, b_0 \geq 0$ , i.e., borrowing at the storage rate or short-selling corporate debt are not

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<sup>10</sup>Our sharing rule is very close to Nash bargaining over the surplus. Under Nash bargaining the parameter  $\psi$  can be interpreted as the bargaining power of sellers.

<sup>11</sup>Since the mass of both entrepreneurs and investors equals one, and we focus on the symmetric equilibrium, we abuse notation and denote the individual supply and demand of debt by  $b_0$ .

allowed.

The storage technology, denoted  $s_0$ , pays a fixed rate of return  $1 + r$  at  $t = 1$  in units of consumption. The proceeds of this investment, if not consumed, can be reinvested to earn an additional return of  $1 + r$  between period 1 and 2, again paid in units of consumption. In this sense, storage is a liquid asset, as at any point in time it can be costlessly transformed into consumption. Alternatively, the corporate bond has an expected payoff of  $R^b$ , but only at the beginning of  $t = 2$ . Moreover, for an investor to turn her bond into consumption at  $t = 1$ , she will have to post an order in a secondary market characterized by search frictions. So the bond is illiquid, as it does not allow investors to transform their investment costlessly into consumption in period 1.

The relative illiquidity of corporate debt comes into play because at the beginning of  $t = 1$ , a fraction  $\delta$  of investors receive a preference shock that makes them discount future consumption at rate  $\beta$ . Moreover, Assumption 3 implies that impatient investors prefer to consume in period 1 relative to period 2. In contrast, the remaining fraction  $1 - \delta$  are patient investors, who only enjoy consumption in  $t = 2$ .

Thus, impatient investors find themselves holding corporate debt contracts which cannot easily be transformed into period  $t = 1$  consumption. Ideally, they would like to sell this asset to patient investors who are willing to give up units of liquid storage in exchange for the higher yielding corporate debt. This trading activity takes place in an OTC secondary market. As described above, impatient investors looking to unload corporate debt contracts will only get their orders executed with endogenous probability  $f(\theta)$ . Similarly, patient investors looking to purchase corporate debt will only get their orders executed with endogenous probability  $p(\theta)$ . If a buy and a sell order are lucky enough to be matched in the OTC market a bilateral trade takes place and units of bonds are exchanged for units of storage at the agreed upon price  $q_1$ .

To describe the portfolio choice problem of investors, it is useful to first consider the optimal behavior of impatient and patient investors in  $t = 1$  when they arrive to that period with a generic portfolio of storage and bonds  $(s_0, b_0)$ .

### 2.4.1 Impatient Investors

By Assumption 3 at  $t = 1$  impatient investors want to consume in the current period. They can consume the payout from investing in storage,  $s_0(1 + r)$ , plus the additional proceeds from placing  $b_0$  sell orders in the OTC market. These orders are executed with probability  $f(\theta)$  and each executed order yields  $q_1$  units of consumption. Thus, the

expected consumption of impatient investors in period 1 is given by

$$c_1^I = s_0(1 + r) + f(\theta)q_1b_0 . \quad (10)$$

On the other hand, with probability  $1 - f(\theta)$  orders are not matched and impatient investors are forced to carry debt contracts into period 2. Therefore, expected consumption in the final period is given by

$$c_2^I = (1 - f(\theta))R^b b_0 , \quad (11)$$

and the utility derived from  $c_2^I$  is discounted by  $\beta$ .

### 2.4.2 Patient Investors

Patient investors only value consumption in the final period and will be willing to place buy orders in the OTC market if there is a surplus to be made, i.e., if  $q_1 \leq R^b/(1 + r)$ . The price determination in the OTC market guarantees that this is always the case ( $1 + r \leq \Delta$ ), thus patient investor would ideally like to exchange all of the lower yielding units of storage for corporate debt with a higher expected returns. But their buy orders will be executed only with probability  $p(\theta)$ .

Therefore, expected storage holdings at the end of  $t = 1$ ,  $s_1^P$ , are equal to a fraction  $1 - p(\theta)$  of the available liquid funds  $s_0(1 + r)$ , i.e.,

$$s_1^P = (1 - p(\theta))s_0(1 + r) .$$

On the other hand, patient investors place  $s_0(1 + r)/q_1$  buy orders, of which a fraction  $p(\theta)$  are executed on average. So patient investors expect to increase their bond holding by  $p(\theta)s_0(1 + r)/q_1$  units. It follows that expected consumption in the final period equals

$$c_2^P = (1 - p(\theta))s_0(1 + r)^2 + \left[ b_0 + p(\theta)\frac{s_0(1 + r)}{q_1} \right] R^b . \quad (12)$$

That is, the payout from units of storage that were not traded away in the secondary market plus the expected payout from corporate debt holdings.

### 2.4.3 Optimal Portfolio Allocation

In the initial period investors solve a portfolio allocation problem, choosing between storage and bonds to maximize their expected lifetime utility

$$\mathbb{U} = \delta(c_1^I + \beta c_2^I) + (1 - \delta)c_2^P ,$$

subject to the period 0 budget constraint (9), and the expressions for expected consumption of impatient and patient investors (10)-(12).

We can rewrite the expected lifetime utility as

$$\mathbb{U} = U_s s_0 + U_b b_0 ,$$

where  $U_s$  and  $U_b$  denote the expected utility from investing in storage and bonds in period 0, respectively, and are given by

$$U_s = \delta(1 + r) + (1 - \delta) \left[ (1 - p(\theta))(1 + r)^2 + p(\theta)(1 + r) \frac{R^b}{q_1} \right] , \quad (13)$$

$$\text{and} \quad U_b = \delta \left( f(\theta) q_1 + \beta(1 - f(\theta)) R^b \right) + (1 - \delta) R^b . \quad (14)$$

Note that both of these expressions depend on the characteristics of the financial contract,  $(l_0, \bar{\omega})$ , through the expected return on holding the bond to maturity  $R^b$ ; and on the characteristics of the secondary market,  $(q_1, \theta)$ , through the secondary market price  $q_1$  and matching probabilities  $f(\theta)$  and  $p(\theta)$ .

Using these definitions, we can express the asset demand correspondence that maximizes the investors portfolio problem as

$$\begin{cases} s_0 = 0, & b_0 = e_0 & \text{if } U_s < U_b \\ s_0 \in [0, e_0], & b_0 = e_0 - s_0 & \text{if } U_s = U_b \\ s_0 = e_0, & b_0 = 0 & \text{if } U_s > U_b \end{cases}$$

That is, when the expected benefit of holding storage in period 0 is dominated by the benefit of holding bonds, then investors will demand only bonds in period 0. On the contrary, if the expected benefit of holding storage is greater than then expected benefit of buying a bond in period 0, then investors will only hold storage in the initial period. Finally, if the expected benefits are equal, investors will be indifferent between investing in storage and bonds initially, and their demands will be an element of the set of feasible portfolio allocations:  $s_0, b_0 \in [0, e_0]$ , such that the total value of assets equal the initial endowment (9). Given our assumptions, in equilibrium the portfolio allocation will be interior (i.e.,  $U_s = U_b$  with  $s_0, b_0 > 0$ ), thus we focus our analysis on this case.



All told, in equilibrium it must be that the two assets in period 0 yield the same expected discounted utility, so the return to storage equals the return to lending to entrepreneurs,

$$U_s(l_0, \bar{\omega}, q_1, \theta) = U_b(l_0, \bar{\omega}, q_1, \theta) .$$

For future reference we label the previous equation the *investors' break-even condition*. Note that the expected utility from investing in storage,  $U_s$ , is not smaller than the expected utility in financial autarky:  $U_a = \delta(1+r) + (1-\delta)(1+r)^2$ , since the return of buying a bond in the secondary market  $\Delta \geq 1+r$ .

## 2.5 Equilibrium

The equilibrium of the model is defined as follows.

**Definition 1 (Competitive Equilibrium)** *We say that  $(l_0, \bar{\omega}, \theta, q_1)$  is a competitive equilibrium if and only if:*

1. *Given the outcome in the secondary market  $(\theta, q_1)$ , the debt contract is described by  $(l_0, \bar{\omega})$  that maximizes entrepreneurs' return on equity subject to investors' break-even condition.*
2. *Market liquidity corresponds to  $\theta = (1-\delta)(1+r)s_0/q_1/(\delta b_0)$ .*
3.  *$q_1$  is determined via the surplus sharing rule.*
4. *All agents have rational expectations about  $q_1$  and  $\theta$ .*

The equilibrium of the model is described by the entrepreneur's choice of leverage,  $l_0$ , and risk,  $\bar{\omega}$ , to maximize the payoff of the risky investment project. Entrepreneurs' profits are higher when  $l_0$  is higher and when the promised payout is lower, that is, when  $\bar{\omega}$  is lower. But entrepreneurs are constrained in their choices of  $l_0$  and  $\bar{\omega}$  as they need to offer terms that make financial contracts attractive to investors: the investors' break-even condition.

Entrepreneurs are aware that when selling in the secondary market, investors obtain a price that depends on the contract characteristics. In fact, the price is determined via the sharing rule (equation 8). Substituting the secondary market price in the expressions for the expected utilities of investing in storage and bonds (equations 13 and 14) we get

$$U_s(\theta) = \delta(1+r) + (1-\delta)(1+r) [(1-p(\theta))(1+r) + p(\theta)\Delta] ,$$

and

$$U_b(l_0, \bar{\omega}, \theta) = \left\{ \delta [f(\theta)\Delta^{-1} + (1-f(\theta))\beta] + (1-\delta) \right\} R^b(l_0, \bar{\omega}) .$$

It follows that the entrepreneur's problem can be written as

$$\max_{l_0, \bar{\omega}} [1 - \Gamma(\bar{\omega})]R^k l_0$$

subject to:

$$U_s(\theta) = U_b(l_0, \bar{\omega}, \theta). \quad (15)$$

Let  $\lambda$  be the multiplier on the break-even condition (15), then the entrepreneur's privately optimal choice of leverage is given by

$$[1 - \Gamma(\bar{\omega})]R^k = -\lambda \frac{\partial U_b(l_0, \bar{\omega}, \theta)}{\partial l_0}. \quad (16)$$

That is, the marginal increase in profits from higher leverage for entrepreneurs need to be proportional to the marginal reduction in expected utility of financial contracts for investors.

Similarly, the privately optimal choice for the risk profile of corporate debt is given by

$$\Gamma'(\bar{\omega})l_0 = \lambda \frac{\partial U_b(l_0, \bar{\omega}, \theta)}{\partial \bar{\omega}}. \quad (17)$$

That is, the marginal increase in profits from lower risk for entrepreneurs need to be proportional to the marginal increase in expected utility of financial contracts for investors.

Taking a ratio of the equations (16) and (17) gives

$$\frac{1 - \Gamma(\bar{\omega})}{\Gamma'(\bar{\omega})l_0} = -\frac{\partial U_b(l_0, \bar{\omega}, \theta)/\partial l_0}{\partial U_b(l_0, \bar{\omega}, \theta)/\partial \bar{\omega}}. \quad (18)$$

This equation, which describes the privately optimal debt contract, taken together with the investors' break-even condition, given by equation (15), and the expressions that characterize the secondary market  $(\theta, q_1)$  provide a complete description of the equilibrium of the model.

Finally, note that both the price in the secondary market  $q_1$  and secondary market liquidity  $\theta$  can be expressed as a function of the characteristics of the optimal financial contract  $(l_0, \bar{\omega})$ . In fact, the price is a function of the expected return on holding the bond to maturity,  $R^b$ , which depends on  $(l_0, \bar{\omega})$ ; so we can write market liquidity as

$$\theta = \frac{(1 - \delta)s_0(1 + r)}{\delta b_0 q_1} = \frac{(1 - \delta)(1 + r)\Delta(e_0 - n_0(l_0 - 1))}{\delta n_0(l_0 - 1)R^b(l_0, \bar{\omega})}. \quad (19)$$

The following theorem establishes the existence and uniqueness of equilibrium in our

model.

**Theorem 1 (Existence and Uniqueness of Competitive Equilibrium)** *Under the maintained assumptions there exists a unique competitive equilibrium of the model. Furthermore, in the unique equilibrium credit is not rationed, i.e.,  $\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega}) > 0$ .*

*That is,  $\exists!(l_0, \bar{\omega}, \theta, q_1)$  where the optimal contract in the primary market is described by (18), the investors' break-even condition (15) is satisfied, and both secondary market bond pricing and liquidity are consistent with the decisions in primary markets, i.e., they are given by equations (8) and (19), respectively.*

As is the case in the canonical CSV model (e.g. Bernanke et al. 1999), the result on existence follows from our assumptions. That is, we have assumed that the return on the entrepreneurs' technology is better than the return on financial assets, including the possibility of secondary market retrading, so entrepreneurs will always be able to offer contractual terms that are attractive to investors. In contrast, while uniqueness is relatively straightforward to establish in the CSV model, our framework is complicated by the endogeneity of liquidity. Nevertheless, we are able to establish that even in our setup with feedback effects between outcomes in primary and secondary markets, multiple equilibria do not obtain, which owes to the constant return to scale assumed in the matching function.

### 3 Frictions and the (Ir)relevance of OTC Trade

It is useful to define a benchmark interest rate that is the return on a two-period bond that could be traded in a perfectly liquid secondary market. Naturally, such a contract needs to deliver the same return in expectation as a strategy of investing only in storage both in the initial and interim periods.<sup>12</sup> This gives rise to the following definition.

**Definition 2 (Liquid Two-period Rate)** *The liquid two-period rate is defined as the gross interest rate on a perfectly liquid two-period bond.*

$$R^\ell \equiv (1 + r)^2 .$$

The benchmark rate allows us to decompose the total gross return on the financial contract written by the firm into a default and a liquidity premium. In order to do this,

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<sup>12</sup>No arbitrage under perfectly liquid markets implies that trading a two-period bond should yield the same expected return for investors to rolling over one period safe investments, i.e.  $\delta \cdot R^\ell / (1 + r) + (1 - \delta) \cdot R^\ell = \delta \cdot (1 + r) + (1 - \delta) \cdot (1 + r)^2$ .

express the total corporate bond premium as the gross return of the firm's contract relative to the benchmark rate,  $Z/R^\ell$ . Then, this total premium is decomposed into a component owing to default risk,  $Z/R^b$ , and a component owing to liquidity risk,  $R^b/R^\ell$ . With this decomposition, we have the following definitions for the default and liquidity premia, respectively.

**Definition 3 (Default and Liquidity Premia)** *The default premium  $\Phi^d$  and the liquidity premium  $\Phi^\ell$  on the firm's debt contract are given by*

$$\Phi^d \equiv \frac{Z}{R^b} \quad \text{and} \quad \Phi^\ell \equiv \frac{R^b}{R^\ell}.$$

Consequently, the total corporate premium is given by  $\Phi^t \equiv Z/R^\ell = \Phi^d \Phi^\ell$ . These definitions provide sharp characterizations of both the default and liquidity premia, which are convenient to help trace out the underlying economic mechanisms in our model. The relationship between the liquidity premium and the investors' break-even condition, in equilibrium, is described in the next remark.

**Remark 1 (Investors Break-even Condition and Liquidity Premium)** *If investors correctly expect the period 1 bond price to be determined via the sharing rule, then the investors' break-even condition (15) can be expressed as*

$$(1+r)^2 \Phi^\ell = R^b, \quad (20)$$

*with the liquidity premium being only a function of secondary market liquidity given by*

$$\Phi^\ell(\theta) = \frac{1}{1+r} \frac{\delta + (1-\delta)[(1-p(\theta))(1+r) + p(\theta)\Delta]}{\delta[f(\theta)\Delta^{-1} + (1-f(\theta))\beta] + (1-\delta)}. \quad (21)$$

Equation (21) provides an analytical characterization for the liquidity premium in terms of only the secondary market liquidity. We defer the discussion of this relationship after establishing Lemma 1 below.

On the other hand, the next proposition shows that the default premium, in equilibrium, is an increasing function of *only* the risk of the financial contract  $\bar{\omega}$ .

**Proposition 1 (Default Premium and Risk)** *Under the maintained assumptions, the default premium,  $\Phi^d$ , depends only on the risk of the financial contract,  $\bar{\omega}$ , and it is strictly increasing in  $\bar{\omega}$ .*

Intuitively, investors demand a higher default premium for financial contracts that are more likely to default (i.e., contracts that are more risky, or specify a higher productivity

threshold  $\bar{\omega}$  for paying out the full promised value). The more subtle part of the argument is that leverage does not affect the default premium. This is due to the fact that, for a fixed threshold level,  $\bar{\omega}$ , leverage affects both the face value of the contract,  $Z$ , and the hold-to-maturity return for investors,  $R^b$ , in the same way. So leverage is irrelevant for the default premium, as is the case in the benchmark CSV model, though leverage and risk are jointly determined in equilibrium.

We now turn to our main results.

### 3.1 A Frictionless Benchmark

Our first result, stated in Proposition 2, establishes the conditions under which trade in the secondary market is irrelevant, so that secondary OTC market liquidity has no bearing on the firm's optimal capital structure.

**Proposition 2 (Irrelevance of OTC Trade)** *Under the following conditions, there is no liquidity premium, i.e.,  $\Phi^\ell = 1$ , implying that the model collapses to the benchmark costly state verification model:*

1. *All investors are patient, so that  $\delta = 0$ ;*
2. *Impatient investors discount at rate  $\beta = 1/(1 + r)$ ;*
3. *Impatient investors extract their full value from all their sell orders in the secondary market, which is true for  $\psi = 1$  and  $\{e_0 \geq \bar{e}_0 : f(\theta) = 1\}$ ; or*
4. *OTC trade is frictionless, which is true in the limit as  $v \rightarrow \infty$  and patient investors have deep pockets, i.e.,  $n_0 \ll e_0(1 - \delta)$ .*

The case in which  $\delta = 0$  is straightforward. When all investors are patient, there is no need to trade in secondary markets; investors only care about the hold-to-maturity return. Liquidity is not priced in financial contracts and the model collapses to the standard costly state verification (CSV) setup presented in, for example, Townsend (1979) and Bernanke and Gertler (1989).

The same result obtains for the second case, though for different reasons. When impatient investors discount future consumption at exactly the rate of return that comes from holding a unit of storage, so that  $\beta = 1/(1 + r)$ , they will be indifferent between consuming in the final or interim period. This indifference implies that there are no gains from OTC trade. In this case, the liquidity preference shock is immaterial and investors

only consider the hold-to-maturity return when buying financial contracts in primary markets.

The third case considers the situation in which impatient investors can fully satisfy their liquidity needs in secondary markets. That is, the terms of trade are set such that impatient investors extract the entire surplus, i.e.,  $\psi = 1$ , and all their sell orders will be executed, given that  $f(\theta) = 1$ . In this case, as before, liquidity considerations will not factor in the lending decision of investors in primary markets. In turn,  $f(\theta) = 1$ , requires that there is enough storage at  $t = 1$  that all sell orders can be satisfied, which requires that investors' endowment is sufficiently large. We derive this threshold for investors endowment in the proof of Proposition 2 in the Appendix.

The final case considers the situation when trade in the secondary market is not subject to trade frictions. In this case, investors are able to trade all their holdings. Since in equilibrium investors need to be indifferent between bonds and storage ex-ante, it must be that  $\Delta = R^b/(1+r)$ . Moreover, given that patient investors have deep pockets, it must also be that they are indifferent between holding storage and trading bonds at  $t = 1$ , implying that  $\Delta = 1+r$ . Together, these imply that there is no liquidity premium,  $\Phi^\ell = 1$ , and the model collapses to the benchmark CSV.<sup>13</sup>

### 3.2 OTC Trade in the Secondary Market

We now characterize the effects of frictional OTC trade. For the remainder of the paper, we consider only the cases in which trading frictions in the secondary market result in a non-negligible liquidity premium. That is, assume that (i) the probability of being an early consumer is positive,  $\delta > 0$ ; (ii) impatient investors discount future consumption strictly more than is implied by the storage rate, i.e.,  $\beta < 1/(1+r)$ ; (iii) impatient investors cannot fully satisfy their liquidity needs in secondary markets,  $\psi < 1$  or  $f(\theta) < 1$ ; and (iv) OTC trade is frictional, and we restrict attention to the case where  $\nu < 1$ .<sup>14</sup>

Under these assumptions we begin by establishing the link between imperfect liquidity in the secondary market and the associated liquidity premium.

**Lemma 1 (Secondary Market Liquidity and the Liquidity Premium)** *The liquidity premium,  $\Phi^\ell$ , or equivalently, the hold-to-maturity return,  $R^b$ , is a decreasing function of secondary*

<sup>13</sup>In the limiting case where  $\nu \rightarrow \infty$ , should we drop the assumption of patient investors' deep pockets there might not be excess liquidity at  $t = 1$  and the bond price could be lower than  $R^b/(1+r)$ , as in cash-in-the-market pricing models (e.g., Shleifer and Vishny, 1992). However, in our model without aggregate uncertainty, we show the price will always reflect the valuation (indifference condition) of either patient or impatient investors at  $t = 1$ . As a result, without the deep pockets assumption firm leverage initially will be rationed by the available resources of investors.

<sup>14</sup> $\nu < 1$  guarantees that  $p(\theta), f(\theta) < 1$  for any  $\theta$ .

market liquidity,  $\theta$ . Moreover, the elasticity of the liquidity premium,  $\Phi^\ell$ , with respect to secondary market liquidity,  $\theta$ , is lower than 1 in absolute value.

Lemma 1 formalizes the intuition that the price of liquidity risk (i.e., the liquidity premium) is inversely proportional to the amount of liquidity in secondary OTC markets. When secondary market liquidity,  $\theta$ , is lower, investors require a higher liquidity premium,  $\Phi^\ell$ , or equivalently, a higher hold-to-maturity return,  $R^b$ . This relationship forms the basis for the direct link between primary and secondary markets shown by the upper arrow in Figure 1. In our model, market liquidity determines the likelihood that investors' orders will be executed in an OTC trade. In particular, as the market becomes less liquid sell orders will be more difficult to execute ( $f(\theta)$  decreases), and impatient investors will have a harder time fulfilling their liquidity needs in secondary markets. By the same token, as liquidity declines buy orders are more likely to be executed ( $p(\theta)$  increases) which provides an incentive for investors to shift their portfolios out of illiquid bonds and into storage. Both of these channels lead to a reduction in the demand for illiquid bonds in the primary market and an increase in the price of liquidity.

In equilibrium, the firm naturally responds to higher funding costs by altering the contract that it issues. A key contribution of this paper is to show that this, in turn, has knock-on effects for liquidity in the secondary market (the lower arrow in Figure 1). This transmission mechanism is summarized by the following remark.

**Remark 2 (The Optimal Contract and Secondary Market Liquidity)** *Secondary market liquidity,  $\theta$ , is decreasing in leverage,  $l_0$ , and the riskiness of the contract offered in the primary market,  $\bar{\omega}$ .*

Taken together with Lemma 1 this remark completes the feedback loop at the heart of this paper. Intuitively, when investors require additional compensation to bear liquidity risk, the firm has an incentive to alter the characteristics of the contract it offers in primary markets, reducing leverage and risk. By doing this, the firm's actions indirectly enhance liquidity in the secondary market, attenuating the initial increase in the liquidity premium. Similarly, an exogenous shock in the primary market will ripple through secondary market liquidity, affecting the liquidity premium, and thus, feeding back into the decisions in the primary market.

Now we describe the effect of the parameters that determine demand and supply in the primary market in the equilibrium of the model. We begin by describing the effect on the demand for bonds.

**Proposition 3 (Investors' Bond Demand)** *Investors require a higher a higher liquidity pre-*

mium,  $\Phi^\ell$ , and hence a higher hold-to-maturity return on the bond,  $R^b$ , when

1. (Liquidity shock) The probability of becoming impatient is higher, i.e.,  $\delta$  is higher;
2. (Impatience) Impatient investors discount the future more heavily, i.e.,  $\beta$  is lower; and
3. (Endowments) Investors have less to invest in storage, i.e.,  $e_0$  is lower.

The proposition describes how the parameters that describe investors' preferences ( $\delta$  and  $\beta$ ) and endowments ( $e_0$ ) affect demand in the primary market when the characteristics of the financial contract (leverage and risk) are held constant. As investors' preferences are more sensitive to liquidity risk ( $\delta$  is higher or  $\beta$  is lower), the associated liquidity premium drives up the hold-to-maturity return that investors require to hold corporate debt. On the other hand, when investors are poorer ( $e_0$  is smaller) they reduce their savings through storage one-for-one conditional on buying the same number of financial contracts. Less liquid savings reduces liquidity in secondary markets, and thus also drives up the required hold-to-maturity return through an increase in the liquidity premium (Lemma 1).

The equilibrium implications for the optimal capital structure, considering the feedback loop with secondary market liquidity, are summarized in the following proposition.

**Proposition 4 (Equilibrium Comparative Statics)** *In equilibrium, the firm's leverage,  $l_0$ , and risk of the contracts it offers in the primary market,  $\bar{\omega}$ , both decrease when*

1. (Liquidity shock) The probability of becoming impatient is higher, i.e.,  $\delta$  is higher;
2. (Impatience) Impatient investors discount the future more heavily, i.e.,  $\beta$  is lower;
3. (Investors' Endowments) Investors have less to invest in storage, i.e.,  $e_0$  is lower; and
4. (Firms' Endowments) Firms have more equity (i.e.,  $n_0$  is higher).

This proposition presents the comparative statics in *equilibrium* for the parameters that describe preferences and endowments for investors and firms. For the first three cases, Proposition 3 establishes that an increase in  $\delta$  or a decrease in  $\beta$  or  $e_0$  will push up the firm's cost of funding through the liquidity premium. According to Proposition 4, entrepreneurs adjust to this increase in the cost of funding along two margins (recall that the debt contract is two-dimensional). They offer fewer contracts in the primary market and the contracts that are offered are less risky relative to an equilibrium in which the firm's debt is traded with a lower liquidity premium. A reduction in the number of bonds issued in the primary market lowers the number of possible sell orders in the secondary market, which attenuates the increase in the liquidity premium. That is, the adjustment



of the firms' optimal capital structure mitigates the effect of trading frictions on the price of liquidity.

The fourth case of Proposition 4 deserves special attention. In the benchmark CSV model, altering the firm's endowment of equity has no impact on the characteristics of the optimal contract. The reason is because, given an increase in equity, the firm expands its size proportionally so that the optimal amount of leverage,  $l_0 = k_0/n_0$ , remains unchanged. This result does not carry through in our framework with endogenous secondary market liquidity. As in the benchmark model—indeed, for exactly the same reason—there is no *direct effect* of an increase in equity on the optimal contract. But our framework is different in that an increase in equity raises the number of debt contracts issued in the primary market. To see this consider the firm's budget constraint expressed in terms of leverage;  $b_0 = n_0(l_0 - 1)$ . In order for  $l_0$  to remain unchanged, the firm must increase primary issuance in proportion to the size of the equity injection. But, this alters liquidity because higher primary debt issuance raises the number of possible sell orders in the secondary market and changing investors' portfolio composition reduces the number of potential buy orders. This leads investors to reprice the liquidity premium. Thus, in our framework, the size of the corporate sector relative to the financial sector influences the capital structure of the firm *indirectly* by altering secondary market liquidity. It is worth noting that the model is homogeneous of degree zero in  $(n_0, e_0)$ : increasing the size of the corporate sector  $n_0$  and the financial sector  $e_0$  in the same proportions have no effect on secondary market liquidity or the characteristics of the optimal contract.

Finally, we note that the link between the liquidity premium and the optimal capital structure of the firm has the following corollary.

**Corollary 1 (Default Premium Comparative Statics)** *In equilibrium, the default premium  $\Phi^d$  decreases when*

1. *(Liquidity shock) The probability of becoming impatient is higher, i.e.,  $\delta$  is higher;*
2. *(Impatience) Impatient investors discount the future more heavily, i.e.,  $\beta$  is lower;*
3. *(Investors' Endowments) Investors have less to invest in storage, i.e.,  $e_0$  is lower; and*
4. *(Firms' Endowments) Firms have more equity, i.e.,  $n_0$  is higher.*

This corollary is a direct consequence of Propositions 1 and 4.

### 3.3 A Numerical Illustration

We present a simple numerical illustration using the following parameter values. We set the initial endowment of entrepreneurs at  $n_0 = 0.2$  and the endowment of investors at  $e_0 = 1$ . Investors' preferences are described by a discount factor for impatient investors  $\beta = 0.85$ , while  $\delta$  will take different values in  $[0, 1]$  to illustrate the results established above. Entrepreneurs' expected return is given by  $R^k = 1.2$ , whereas the return on storage is assumed to be  $r = 0.01$ . The parameters of the matching function in the OTC market are the scaling constant  $\nu = 0.2$  and the elasticity of the matching function with respect to sell orders is  $\alpha = 0.5$ . The surplus that accrues to impatient investors in the sharing rule is  $\psi = 1$ . Idiosyncratic productivity shocks  $\omega$  are distributed according to a log-normal distribution with mean equal 1 and variance equal to 0.25. Finally, monitoring costs are a share  $\mu = 0.2$  of firms' revenue.

We begin with the frictionless benchmark, taking  $\delta = 0$ .<sup>15</sup> The equilibrium of the model is described by entrepreneurs' choice of leverage,  $l_0$ , and risk,  $\bar{\omega}$ , subject to the constraint imposed by investors' break-even condition and the consistency requirements for liquidity,  $\theta$ , and price,  $q_1$ , in the secondary market. The characteristics of the optimal contract  $(l_0, \bar{\omega})$  determine the hold-to-maturity return,  $R^b$ , and thus the secondary market price  $q_1$ . (Recall that the return on executed orders in secondary markets is pinned down by  $\psi$ ,  $r$ , and  $\beta$ .) The optimal contract will determine the portfolio allocation of investors and thus secondary market liquidity  $\theta$  (equation 19). Thus, we use the  $(l_0, \bar{\omega})$ -space to describe the optimal contract and the equilibrium of the model. Figure 4 depicts the firm's isoprofit curves in green.<sup>16</sup> Investors' break-even condition is shown by the red line. Firm's profits increase with leverage and decrease with risk, so isoprofit curves represent higher profits moving south-east in the figure. The private equilibrium in the frictionless benchmark economy is given by the tangency between the break-even condition and the isoprofit line shown by the solid black dot in Figure 4.

Figure 5 illustrates the case of an increase in the liquidity shock,  $\delta$ , (i.e., the case 1 of Propositions 3 and 4). As the probability of becoming impatient increases, investors require a higher liquidity premium to compensate for liquidity risk (Proposition 3). In contrast, the firm's isoprofit lines for a given contract specified by  $(l_0, \bar{\omega})$  are invariant to  $\delta$ . Nevertheless, the firm adjusts the terms of the contract it offers in the primary market owing to the increase in the liquidity premium. In particular, the firm reduces its supply

<sup>15</sup>From Proposition 2 the frictionless benchmark is obtained if alternatively we set  $\beta = 1/1.01$ , or if  $\psi = 1$  (as in our example) and  $e_0$  is sufficiently high so  $f(\theta) = 1$ .

<sup>16</sup>Note that the shape of the isoprofit curves (increasing and concave) holds in general, as follows from the properties of the  $\Gamma(\bar{\omega})$  function, and does not depend on the particular values used in our example.

of primary debt, which partially compensates investors for the reduction in secondary market liquidity. The resulting equilibrium has a lower level of leverage and a less risky debt contract, as shown in Figure 5 (Proposition 4).

Finally, Figure 6 presents a decomposition of the total corporate premium  $\Phi^t$  paid on the primary debt contract in terms of the default premium  $\Phi^d$  and the liquidity premium  $\Phi^\ell$ . The figure shows that lower levels of leverage and risk due to increased liquidity demand result in lower total corporate bond premia. Naturally, the liquidity premium goes up, but the default premium decreases since the firm is offering a lower  $\bar{\omega}$  (Corollary 1), and the latter effect dominates in this case.

## 4 The Efficient Structure of Corporate Debt

We analyze the efficient structure of corporate debt by considering a social planner constrained by the presence of matching frictions and the structure of trade in the secondary market. Hence, our concept of efficiency is one of constrained efficiency, or second best.<sup>17</sup>

The planner chooses the optimal contract to maximize the profits of the firm while internalizing the effect of the capital structure on secondary markets through liquidity and bond prices. To formalize the planner's problem let  $(l_0, \bar{\omega}, \theta, q_1)$  be allocations that describe the socially efficient outcome and let  $(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}, q_1^{ce})$  be the allocations in the competitive equilibrium described in section 3. Then, the planner's problem can be written as

$$\max_{\bar{\omega}, l_0, \theta, q_1} [1 - \Gamma(\bar{\omega})] R^k l_0 \quad (22)$$

subject to:

$$\mathbb{U}(l_0, \bar{\omega}, \theta, q_1) \geq \mathbb{U}(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}, q_1^{ce}) \quad (23)$$

and equations (8) and (19).

Condition (23) says that the planner cannot choose equilibrium allocations that result in lower welfare for investors compared to the competitive equilibrium, whereas equations (8) and (19) force the planner to respect the determination of prices and liquidity, respectively, in secondary markets.<sup>18</sup> The social planning problem differs from the competitive

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<sup>17</sup>In the interest of space the analysis in sections 4 and 5 restricts attention to the more interesting case where  $\theta \in (\underline{\theta}, \bar{\theta})$ , so trading probabilities depend on the matching function (5) and are not pinned down by the minimum number of buy or sell orders.

<sup>18</sup>We also considered a more general problem, as an alternative but not reported, where the planner can additionally determine the terms of trade in the secondary market and assigns Pareto weights on the two agents to maximize a social welfare function.

equilibrium in two respects: (1) the planner need not respect the investor's break-even condition (15), but may want to influence it to satisfy (23); and (2) the planner internalizes how period 0 choices affect liquidity in the secondary market by explicitly considering (19) as a constraint, which, in contrast, is an equilibrium condition in the competitive economy.<sup>19</sup>

We substitute equations (8) and (19) in the planner's problem, and let  $\lambda$  be the multiplier on constraint (23), to obtain that the socially optimal choice of leverage is given by

$$[1 - \Gamma(\bar{\omega})]R^k = -\lambda \left[ n_0(U_b - U_s) + b_0 \frac{\partial U_b}{\partial l_0} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial l_0} \right]. \quad (24)$$

That is, the marginal increase in the firm's profits from additional leverage needs to be proportional to the marginal reduction in total expected utility for investors. The latter has three components: (i) the portfolio composition effect: as leverage increases investors need to re-allocate  $n_0$  units from storage to bonds; (ii) the effect on the expected utility of bond holdings  $U_b$ ; and (iii) the effect through secondary market liquidity: as liquidity increases it becomes easier for impatient investors to sell their bonds, but it becomes more difficult for patient investors to buy bonds and earn the return  $\Delta$  in the secondary market.

Similarly, the socially optimal choice for the risk profile of corporate debt is given by

$$l_0 \Gamma'(\bar{\omega}) R^k = \lambda \left[ b_0 \frac{\partial U_b}{\partial \bar{\omega}} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{\omega}} \right]. \quad (25)$$

That is, the marginal increase in the firm's profits from reducing risk need to be proportional to the marginal reduction in total expected utility for investors, which has two components: the effect on the hold-to-maturity return  $R^b$  and the effect through secondary market liquidity.

Taking a ratio of equations (24) and (25) gives

$$\frac{1 - \Gamma(\bar{\omega})}{\Gamma'(\bar{\omega}) l_0} = - \frac{n_0(U_b - U_s) + b_0 \frac{\partial U_b}{\partial l_0} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial l_0}}{b_0 \frac{\partial U_b}{\partial \bar{\omega}} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{\omega}}}. \quad (26)$$

This equation, together with the constraint on investors total expected utility (23), describes the socially optimal debt contract.<sup>20</sup> We are ready to establish the generic ineffi-

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<sup>19</sup>Recall that investors, and thus firms, explicitly considered (8) in the competitive equilibrium as well, thus its explicit consideration does not modify the planner's problem relative to the competitive equilibrium, unless the planner can affect the terms of secondary trade.

<sup>20</sup>The constraint will always be binding since the planner cares only about the firm, but this need not be the case if the planner maximizes aggregate social welfare. In that case the planner may want to split the aggregate gains according to some set of Pareto weights.

ciency of the debt contract in competitive markets.<sup>21</sup>

**Proposition 5 (Generic Constrained Inefficiency of the Debt Contract)** *Consider a planner that designs an optimal debt contract, as described in (23), (26), (8) and (19). If the parameters  $(\alpha, \psi, r)$  belong to a generic set  $\mathcal{P}$ , the planner will set a level of secondary market liquidity that is different from the competitive equilibrium. That is, the competitive equilibrium is generically constrained inefficient.*

Given Proposition 5, we can identify two distorted margins that drive a set of wedges between the private and socially efficient outcomes. Comparing the equilibrium conditions (15) and (18) to the social planner's counterparts (23) and (26), the first distortion is evident from the  $\partial\mathbb{U}/\partial\theta$  terms in equation (26) that does not appear in equation (18). This term captures the liquidity externality. It arises because neither the firm nor investors internalize the effect that their decisions in the primary market have on liquidity in the secondary market. This generates a pecuniary externality as firms and investors decisions affect the liquidity premium, which affects firms cost of financing and investors ability to retrade illiquid assets.

To understand the role of  $\partial\mathbb{U}/\partial\theta$ , which measures the effect of market liquidity on investors ex ante welfare, consider the following reinterpretation of the conditions that determine the optimal contract. Let the negative of risk measure the safety of the financial contract. Then, firms profits are increasing in both leverage and safety, and the optimality conditions can be reinterpreted as equating the marginal benefit with the marginal cost, in terms of investors compensation, of increasing leverage or safety. Using this interpretation, the planner finds that a positive externality ( $\partial\mathbb{U}/\partial\theta > 0$ ) increases the compensation required to increase leverage and reduces the compensation required to increase safety. Consequently, a planner that internalizes this externality would reduce leverage and risk (increase safety), leading to higher secondary market liquidity and firm's profits.

The second distortion appears in the optimal portfolio composition of investors. It can be easily seen by comparing the weak Pareto improvement constraint (23) that the planner faces to the break-even condition (15) in the competitive equilibrium, i.e.,  $U_b = U_s$ . Since  $U_s = U_a + (1 - \delta)(1 + r)(\Delta - (1 + r))p(\theta)$ , we can rewrite equation (23) as  $n_0(l_0 - 1)(U_b - U_s) = e_0(1 - \delta)(1 + r)(\Delta - (1 + r))[p(\theta^{ce}) - p(\theta)]$ . Written this way, the equation tells us that as long as  $\partial\mathbb{U}/\partial\theta \neq 0$  the planner chooses a different level of market liquidity, so that  $\theta^{ce} \neq \theta$ , then  $U_b \neq U_s$ . In this case, the expected return on holding bonds will not be equated with the return to storage, as must be the case in the competitive equilibrium.

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<sup>21</sup>See also Geanakoplos and Polemarchakis (1986) for a general characterization of constrained inefficiency.

The following proposition summarizes the linkages between these two distortions.

**Proposition 6 (Constrained Efficient Equilibrium)** *The constrained efficient allocations can be characterized conditional on the model parameters  $(\alpha, r, \psi)$  as follows:*

- *If  $\psi(1 + \alpha r) > \alpha(1 + r)$  then secondary market liquidity generates a positive externality on investors ( $\partial \mathbb{U} / \partial \theta > 0$ ); the planner implements a higher level of secondary market liquidity ( $\theta > \theta^{ce}$ ); and the optimal capital structure of the firm is characterized by lower leverage,  $l_0 < l_0^{ce}$ , and less risk,  $\bar{\omega} < \bar{\omega}^{ce}$ .*
- *If  $\psi(1 + \alpha r) < \alpha(1 + r)$  then secondary market liquidity generates a negative externality on investors ( $\partial \mathbb{U} / \partial \theta < 0$ ); the planner implements a lower level of secondary market liquidity ( $\theta < \theta^{ce}$ ); and the optimal capital structure of the firm is characterized by higher leverage,  $l_0 > l_0^{ce}$ , and more risk,  $\bar{\omega} > \bar{\omega}^{ce}$ .*
- *If  $\psi(1 + \alpha r) = \alpha(1 + r)$  then there is no externality ( $\partial \mathbb{U} / \partial \theta = 0$ ) and equilibrium is constrained efficient, i.e.,  $(l_0, \bar{\omega}, \theta) = (l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce})$ .*

To understand the intuition behind the proposition, consider for example the effect of an increase in liquidity on investors' welfare. On the one hand, an increase in liquidity generates ex ante welfare gains for impatient investors simply because they will find it easier to sell unwanted corporate debt in secondary markets. On the other hand, patient investors suffer welfare losses as it becomes more difficult to earn a higher return by purchasing bonds at a discounted price in the secondary market. Whether, in equilibrium, investors are ex ante better off with higher liquidity depends on the parameters  $(\alpha, r, \psi)$ .

In particular, the gains to impatient investors outweigh the losses to patient investors, making ex ante investors better off, when the trade surplus that accrues to impatient investors is sufficiently large, such that  $\psi(1 + \alpha r) > \alpha(1 + r)$ . In this case, we say the liquidity externality is positive. Intuitively, the benefit of increased liquidity that accrues to impatient investors from earning a larger share of the surplus more than outweighs the cost of reduced trading opportunities for patient investors. Alternatively, and equivalently, the liquidity externality is positive when the private incentives to hold storage and provide liquidity are low, that is when  $r < (\psi - \alpha) / (\alpha - \alpha\psi)$ .

How can the planner implement a higher level of liquidity in a way that increases the profitability of firms? Recall from equation (19) that liquidity can be expressed as a function of the characteristics of the firm's debt contract,  $\theta(l_0, \bar{\omega})$ . Furthermore, we know  $\partial \theta / \partial l_0 < 0$  and  $\partial \theta / \partial \bar{\omega} < 0$ . So, from the firm's perspective, the planner can increase secondary market liquidity by directing the firm to take on less leverage,  $l_0 < l_0^{ce}$ , and

write debt contracts that are less risky,  $\bar{\omega} < \bar{\omega}^{ce}$ . Profitability increases because, despite the reduction in scope owing to lower leverage, the firm reduces its overall cost of funding; higher liquidity lowers the liquidity premium and the less risky nature of the debt contracts lowers the default premium.<sup>22</sup>

Increasing liquidity in this way has, by design, implications for the portfolio composition of investors. Specifically, it requires that investors shift out of corporate bonds and into storage. At the same time, increasing secondary market liquidity depresses the return to storage (given that  $\partial p(\theta)/\partial \theta < 0$ ) and increases the return on bond holdings (given that  $\partial f(\theta)/\partial \theta > 0$ ). So, investors are being asked to shift their portfolios out of higher return corporate bonds and into storage, which offers a lower return. The only way such an outcome can obtain is if the expected return for holding bonds in the more liquid portfolio dominates the expected return from holding storage, so that ( $U_b > U_s$ ). In other words, the only way to support allocations that deliver higher liquidity is to violate the breakeven condition. The opposite intuition holds when  $\psi(1 + \alpha r) < \alpha(1 + r)$ .

Finally, in the knife-edge case where  $\psi(1 + \alpha r) = \alpha(1 + r)$  private liquidity is efficient so that at the margin an increase in liquidity generates gains for impatient investors that are perfectly offset by losses to patient investors and the planner cannot exploit the externality to improve upon the competitive equilibrium. This special case highlights the relationship of our result with the well-known congestion externalities that arise due to the matching function.<sup>23</sup> But, the inefficiency of the private provision of liquidity in debt markets that we describe is related to, but importantly different from, this well known results. Here the key is the interaction between two externalities. On the investors' side, when they make their portfolio choice regarding primary debt they do not internalize the *congestion externality* imposed on all investors participating in the secondary debt market. The planner, in contrast, understands that by changing aggregate holdings of liquid assets and affecting secondary market liquidity it can make investors ex ante better off. On the firms' side, when they make their borrowing decisions in the primary debt market they do not internalize the *pecuniary externality* imposed on all firms through liquidity and default premia. The planner, on the contrary, realizes that altering the aggregate size and risk of debt issuance affects borrowing costs and increases firms' profitability. In sum, our planner generically wants to exploit the congestion externality to create surplus for investors ex

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<sup>22</sup> It is interesting to note that by implementing higher secondary *market* liquidity, the planner in essence increases *funding* liquidity in the primary market by implementing a reduction in the liquidity premium and thus in the total bond premium.

<sup>23</sup>The parameter restriction is analogous to the Hosios (1990) rule that determines the efficient surplus split in search and matching models of the labor market. Arseneau and Chugh (2012) study the implications of inefficient surplus sharing for optimal labor taxation in a dynamic general equilibrium economy.

ante, which the planner redistributes to firms redesigning the optimal debt contract in the primary market to account for the pecuniary externalities imposed through debt premia. Thus, our result is driven by the interaction between a congestion externality among investors (participants in the search-based OTC market) with a pecuniary externality among firms (who do not participate in the OTC market).

## 4.1 Decentralizing the Efficient Equilibrium

A complete set of tax instruments allows us to decentralize the efficient equilibrium. We introduce a marginal tax  $\tau^s$  on the return from storage  $U_s$  ( $\tau^s < 0$  corresponds to a subsidy) and a marginal tax  $\tau^l$  on leverage ( $\tau^l < 0$  corresponds to a subsidy). With these tax instruments, the objective of investors becomes  $\mathbb{U} = b_0 U_b + s_0 U_s (1 - \tau^s) + T^s$  and the objective of the firm changes to  $[1 - \Gamma(\bar{\omega})] R^k l_0 - \tau^l \lambda l_0 + T^l$ . The taxes are funded in a lump-sum fashion on the same agents, thus  $T^l = \tau^l \lambda l_0$  and  $T^s = \tau^s s_0 U_s$  in equilibrium. Also, in order to simplify the exposition note that we have normalized the tax on leverage by the Lagrange multiplier,  $\lambda > 0$ , on the constraint faced by firms in the competitive economy (i.e., the investor's break-even condition).

Proposition 7 provides a general characterization of the optimal tax policy.

**Proposition 7 (Optimal Policy)** *The planner's solution can be decentralized by levying distortionary taxes on the portfolio allocation decision of investors and the capital financing decision of firms. The resulting optimal taxes on storage,  $\tau^s$ , and leverage,  $\tau^l$ , are given by:*

$$\tau^s = \frac{e_0}{b_0} \left( 1 - \frac{U_s(\theta^{ce})}{U_s(\theta)} \right), \quad (27)$$

$$\tau^l = \frac{n_0 U_s \frac{\partial U_b}{\partial \bar{\omega}} \tau^s + \left[ \frac{\partial U_b}{\partial l_0} \frac{\partial \theta}{\partial \bar{\omega}} - \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial l_0} \right] \frac{\partial \mathbb{U}}{\partial \theta}}{b_0 \frac{\partial U_b}{\partial \bar{\omega}} + \frac{\partial \theta}{\partial \bar{\omega}} \frac{\partial \mathbb{U}}{\partial \theta}} \quad (28)$$

where the term in square brackets and the denominator in (28) are strictly positive.

Combining the insights of Proposition 7 with Proposition 6 above, it is easy to characterize the optimal tax system more specifically. When  $\psi(1 + \alpha r) > \alpha(1 + r)$ , the liquidity externality is positive so that the planner wants to implement higher liquidity relative to the competitive equilibrium,  $\theta > \theta^{ce}$ . Accordingly, the optimal tax system needs to be designed in a way that results in investors holding a more liquid portfolio. This can be achieved through a storage subsidy, so that  $\tau^s < 0$ . Moreover, the optimal tax system needs to be designed in a way that results in firms issuing fewer debt contracts in the primary market, which can be achieved through a tax on leverage, so that  $\tau^l > 0$ . By the



same logic, when  $\psi(1 + \alpha r) < \alpha(1 + r)$ , the liquidity externality is negative and  $\theta < \theta^{ce}$ . The optimal tax system calls for a tax on storage,  $\tau^s > 0$ , and a leverage subsidy,  $\tau^l = 0$ . Only in the knife-edge case where  $\psi(1 + \alpha r) = \alpha(1 + r)$  we have that  $\tau^l = \tau^s = 0$ .

## 4.2 A Numerical Illustration

We continue the numerical example in section 3.3. Recall that in this illustration,  $\psi = 1$ . Moreover, because the planner has the same objective as the competitive firm, the isoprofits lines are the same in both problems. Figure 7 shows the planner's solution and the private equilibrium for two cases:  $\delta = 0$  and  $\delta = 0.1$ . In a frictionless environment ( $\delta = 0$ ), the planner's solution coincides with the private equilibrium (as we proved in Proposition 2). However, when there is a positive demand for liquidity,  $\delta > 0$  and  $\beta < (1 + r)^{-1}$ , and secondary market liquidity is not sufficiently high to guarantee  $f(\theta) = 1$ , the planner chooses lower leverage and a less risky capital structure, i.e., lower  $l_0$  and  $\bar{\omega}$ . The reason is because the planner internalizes the effect of the leverage decision on liquidity in the secondary market. This induces the planner to consider a steeper constraint compared to the breakeven condition considered by competitive firms (where market liquidity is taken as given). As a result, the planner understands how lower leverage and risk improves borrowing terms on the margin, when the total social costs are taken into account.

Table 1 shows the change in equilibrium allocations between the competitive and planner's solutions for  $\delta = 0.1$  as  $\psi$  moves from 1 to 0. Consistent with the analysis above, the planner's allocations can be replicated using appropriate tax instruments (subsidies if they are negative) on leverage and storage. For  $\psi = 1$ , the liquidity externality is positive implying that liquidity is suboptimally low in the competitive equilibrium. The planner would like to implement a tax on leverage to generate more liquidity in the secondary market (in this case all the surplus goes to sellers so the tax on storage is irrelevant). However, as the share of the gains from trade that accrues to impatient investors declines, the size of the liquidity externality shrinks. Hence, the planner is less aggressive in choosing the optimal combination of leverage tax and storage subsidy, i.e., both  $\tau^l$  and  $\tau^s$  shrink in absolute value. When the parameterization of  $\psi$  satisfies  $\psi(1 + \alpha r) = \alpha(1 + r)$ , the externality zeros out and the optimal tax system implies  $\tau^l = \tau^s = 0$ . For values of  $\psi$  below that point, the liquidity externality becomes negative, so that liquidity is over-provided in the competitive equilibrium. Accordingly, the sign of the optimal tax system flips so that leverage is subsidized,  $\tau^l < 0$ , and storage is taxed,  $\tau^s > 0$ .

## 5 Quantitative Easing as part of the Optimal Policy Mix

Many central banks following the Great Recession of 2007-09 have turned to unconventional monetary policies, such as quantitative easing (QE), to provide further monetary accomodation after they reduced standard policy rates to its minimum feasible levels. Ultimately, the goal of QE is for the central bank to influence the real economy through direct intervention in the markets for certain assets. Our model provides a stylized framework to analyze the effect of these policies.

### 5.1 Quantitative Easing Policy

We model QE through direct purchases by the central bank of long-term illiquid assets (the financial contracts issued by firms and which are retraded by investors in OTC markets, much like Treasuries and Mortgage Backed Securities).<sup>24</sup> These purchases are financed by the issuance of short-term liquid liabilities, referred to as reserves, that offer a return that is at least as large as that offered by the storage technology. This seems a reasonable approximation for the policies implemented by the Federal Reserve during the Great Recession, where lending facilities and asset purchases were financed primarily with redeemable liabilities in the form of reserves (see Carpenter et al. 2013).

In period  $t = 0$ , and before markets open, the central bank announces the quantity of bonds,  $\bar{b}_0$ , it will purchase in period 0 and will hold to maturity. These bond purchases are financed through the issuance of  $\bar{s}_0$  units of reserves that pay interest  $\bar{r} \geq r$ . Thus, the central bank budget constraint in period 0 is simply

$$\bar{b}_0 = \bar{s}_0 . \tag{29}$$

We assume the central bank finances itself in period 1 with reserves only. This assumption prevents the central bank from injecting additional resources into the economy in the interim period. In order to keep its bond holdings, the central bank needs to roll over its outstanding reserves and pay interest on them in period 1. The central bank will have to borrow an amount equal to  $(1 + \bar{r})\bar{s}_0$ .<sup>25</sup> Finally, in period 2 the central bank receives the debt payout from the financial contract and expends  $(1 + \bar{r})^2\bar{s}_0$  in interest and principal on outstanding reserves. It is assumed that the central bank allocates reserves evenly across

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<sup>24</sup>Note that in the model a pool of firms' contracts will have no aggregate risk.

<sup>25</sup>In practice, the long-term assets held by central banks pay interest in the interim period, and in an environment of low short-term interest rates these holdings will generate a positive net-interest income for the central bank. But for simplicity we abstract from these considerations. See, for instance, Carpenter et al. (2013) for estimates of net-interest income for the Federal Reserve.

investors who demand reserves in a given time period.

The central bank faces three constraints that, taken together, serve to limit the size of its QE program. First, we assume that the central bank is at a disadvantage relative to the private sector in monitoring investment projects. It thus needs to pay a higher monitoring cost relative to investors, denoted by  $\bar{\mu} > \mu$ .<sup>26</sup> This implies that in expectation the central bank anticipates receiving  $\bar{R}^b \bar{b}_0$  for its asset holdings, with  $\bar{R}^b$  the expected hold-to-maturity return on financial contracts for the central bank, given by

$$\bar{R}^b(l_0, \bar{\omega}) = \frac{l_0}{l_0 - 1} R^k [\Gamma(\bar{\omega}) - \bar{\mu} G(\bar{\omega})] = R^b(l_0, \bar{\omega}) - \frac{l_0}{l_0 - 1} R^k (\bar{\mu} - \mu) G(\bar{\omega}) .$$

Second, the central bank needs to fully finance its funding cost, i.e., the total interest on reserves, with its expected return on assets. That is,

$$\bar{R}^b \geq (1 + \bar{r})^2 . \quad (30)$$

Finally, we assume that investors cannot be made worse off by QE, as we describe in section 5.3.

## 5.2 Investors' Problem and Liquidity with QE

In period 0 investors allocate their wealth across three assets: the storage technology, debt contracts, and reserves. So the budget constraint at  $t = 0$  is given by

$$s_0 + \bar{s}_0 + b_0 = e_0 ,$$

with  $s_0, \bar{s}_0, b_0 \geq 0$ . Following the approach of Section 2, we consider the optimal behavior of impatient and patient investors in  $t = 1$  when they arrive with a generic portfolio of storage, reserves, and bonds  $(s_0, \bar{s}_0, b_0)$ .

**Impatient Investors.** By Assumption 3 impatient investors want to consume all their wealth at  $t = 1$ . They can consume the payouts of their liquid assets:  $(1 + r)s_0 + (1 + \bar{r})\bar{s}_0$ ; in addition, they can consume the proceeds from their sell orders in the OTC market:  $q_1$  units of consumption for each order executed. Thus, the expected consumption of impatient

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<sup>26</sup>Consequently, any positive effects of QE would not accrue from enhanced monitoring, as in the delegated monitoring models of Diamond (1984) and Krasa and Villamil (1992), but from its effect on liquidity premia.

investors in periods 1 and 2, respectively, is given by

$$c_1^I = (1 + r)s_0 + (1 + \bar{r})\bar{s}_0 + f(\theta)q_1b_0, \quad (31)$$

$$\text{and} \quad c_2^I = (1 - f(\theta))R^b b_0. \quad (32)$$

**Patient Investors.** Patient investors only value consumption in the final period and, as a result, are willing to place buy orders in the OTC market because the return from doing so,  $\Delta$ , is strictly greater than the return on storage,  $1 + r$ . Moreover, it is also the case that the return on reserves,  $1 + \bar{r}$ , is at least as large as that on storage, so patient investors are willing to allocate liquid wealth to reserves. Accordingly, liquidity provision in the secondary market will depend on the return on OTC trade,  $\Delta$ , relative to the return on reserves,  $1 + \bar{r}$ . Specifically, if  $1 + \bar{r} < \Delta$  patient investors will pledge *all* their liquid wealth to place buy orders in the OTC market. On the other hand, if  $1 + \bar{r} > \Delta$  patient investors will use their liquid wealth to buy higher yielding reserves first and then allocate the remainder of their liquid wealth to placing buy orders in the OTC market. For expositional purposes, we assume throughout the remainder of the paper that  $1 + \bar{r} < \Delta$  (although for the main results of this section—stated below in Propositions 8 and 9—we trace out the proofs over the entire parameter space of the model, where appropriate).

When the anticipated return to OTC trade exceeds the return on reserves, patient investors use  $(1 + r)s_0 + (1 + \bar{r})\bar{s}_0$  units of liquid wealth to place buy orders. A fraction  $p(\theta)$  are matched allowing patient investors to exchange liquid wealth for corporate debt, while the  $1 - p(\theta)$  unmatched portion needs to be reinvested in liquid assets in period  $t = 1$ . Because the central bank needs to finance itself in the interim period, it removes a total of  $(1 + \bar{r})\bar{s}_0$  reserves from a mass  $1 - \delta$  of patient investors. Individual reserve holdings in the interim period for patient investors,  $\bar{s}_1^P$ , totals  $(1 + \bar{r})\bar{s}_0/(1 - \delta)$ . All remaining liquid funds are placed into the lower yielding storage technology, so expected storage holdings at the end of  $t = 1$ ,  $s_1^P$ , equal

$$s_1^P = (1 - p(\theta))[(1 + r)s_0 + (1 + \bar{r})\bar{s}_0] - \frac{(1 + \bar{r})\bar{s}_0}{1 - \delta},$$

which is strictly positive from Assumption 4. It follows that expected consumption of patient investors equals

$$c_2^P = s_1^P(1 + r) + \frac{(1 + \bar{r})^2\bar{s}_0}{1 - \delta} + \left\{ b_0 + p(\theta)\frac{(1 + r)s_0 + (1 + \bar{r})\bar{s}_0}{q_1} \right\} R^b. \quad (33)$$

Using the optimal behavior of investors in period 1, summarized in equations (31)-(33), we can rewrite the expected lifetime utility as the portfolio weighted average of the utilities of the three assets available in the initial period:

$$\mathbb{U} = U_s s_0 + U_{\bar{s}} \bar{s}_0 + U_b b_0 .$$

As before, the expected utility of investing in storage and bonds,  $U_s$  and  $U_b$ , are given by equations (13) and (14), respectively. On the other hand, the expected utility of reserves is given by

$$U_{\bar{s}} = \delta(1 + \bar{r}) + (1 - \delta)(1 + \bar{r}) \left[ (1 - p(\theta))(1 + r) + \frac{\bar{r} - r}{1 - \delta} + p(\theta)\Delta \right] . \quad (34)$$

Reserves yield  $1 + \bar{r}$  for impatient investors. For patient investors, there is additional compensation that comes from the expected return from buy orders in the secondary market, plus the spread between reserves and storage,  $\bar{r} - r$ , for the additional reserves bought in period 1.<sup>27</sup>

We are now ready to establish the link between QE and secondary market liquidity.

**Proposition 8 (The Real Effects of Quantitative Easing)** *Quantitative easing, i.e., the size of the bond buying program,  $\bar{b}_0$ , increases secondary market liquidity  $\theta$  and, hence, has implications for the firm's optimal capital structure and investment.*

The intuition behind this result is straightforward, each bond bought by the central bank will be held to maturity, reducing the number of sell orders in the secondary market. At the same time, these bonds need to be financed with reserves, which patient investors can use to submit additional buy orders in the secondary market. So, a bond buying program affects secondary market liquidity *directly* through the purchase of bonds as well as *indirectly* through the liquidity created by issuing central bank reserves. Moreover, Remark 2 establishes an equilibrium link between liquidity and the optimal capital structure of the firm, which determines investment by the firm.

### 5.3 QE and Optimal Policy

To understand the role of QE in the optimal policy mix, we consider a planner who wants to maximize firm profits, but is restricted by the central bank budget constraint, equation (29), and the financing constraint, equation (30). In addition, as with the planner in Section 4, we assume the QE program cannot make investors worse off. To write this

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<sup>27</sup>If,  $1 + \bar{r} > \Delta$ , patient investors will use their liquid wealth first to buy reserves, and then will use their remaining liquid wealth to place buy orders in the OTC market. Proceeding as above we can derive for patient investors  $s_1^p$ ,  $c_2^p$ , and  $U_{\bar{s}}$ .

later constraint, let  $\mathbb{U}(l_0, \bar{\omega}, \theta, \bar{b}_0, \bar{r})$  be the expected lifetime utility of investors when the equilibrium is described by  $(l_0, \bar{\omega}, \theta)$ , with the secondary market price given by (8), and the QE program described by  $(\bar{b}_0, \bar{r})$ . Similarly, let  $\mathbb{U}(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce})$  be the expected lifetime utility of investors in the competitive equilibrium, when the secondary market price is given by (8). We refer to this planner that have access to QE policies as the central bank. Then, the central bank's problem can be written as

$$\max_{l_0, \bar{\omega}, \theta, \bar{b}_0, \bar{r}} [1 - \Gamma(\bar{\omega})] R^k l_0 \quad (35)$$

subject to:

$$\mathbb{U}(l_0, \bar{\omega}, \theta, \bar{b}_0, \bar{r}) \geq \mathbb{U}(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}) \quad (36)$$

and equations (19), (29) and (30).

The following proposition characterizes the role of QE as part of the optimal policy mix.

**Proposition 9 (Quantitative Easing as Part of the Optimal Policy Mix)** *The optimal design of QE conditional on the model parameters  $(\alpha, r, \psi)$  is described as follows:*

- *If  $\psi(1 + \alpha r) > \alpha(1 + r)$ , then QE improves upon the constrained efficient allocation; the optimal QE program consists of a positive bond buying program,  $\bar{b}_0 > 0$ , and paying interest on reserves that are strictly greater than the return on storage,  $\bar{r} > r$ .*
- *If  $\psi(1 + \alpha r) \leq \alpha(1 + r)$ , then QE does not improve upon the constrained efficient allocation; the optimal QE program is just  $\bar{b}_0 = 0$  and  $\bar{r} = r$ .*

As long as the liquidity externality is positive (liquidity is suboptimally low in the private equilibrium), a QE program can lead to a Pareto improvement over the constrained efficient allocations studied in Section 4. The reason this is possible is because the central bank can finance its purchases of long-term illiquid corporate debt by issuing liquid liabilities to investors subject to liquidity risk, much like a deposit contract offered by banks. The central bank has an advantage over a typical bank, however, in that it is not subject to runs by investors. In this sense, a central bank that is not subject to liquidity risk effectively enhances the intermediation technology of the economy. This technological improvement can only be realized when there are social gains from raising liquidity. When the liquidity externality is negative (liquidity is suboptimally high in the competitive equilibrium), QE is ineffective because the central bank cannot take a short position in the primary corporate debt market.

It is useful to point out that the proposition suggests QE is effective when the interest rate on storage is sufficiently low,  $r < \psi/(1 + \alpha - \alpha\psi)$ .<sup>28</sup> Although it is beyond the scope of this model, these conditions indicate that QE may be an effective policy response in a protracted low interest rate environment.

The other issue worth mentioning is that when QE is effective, the absence of constraints that limit the size of the program could lead to an extreme outcome in which the central bank disintermediates the bond market. That is, if there is nothing holding back the size of the program, as long as QE is effective, the optimal policy is for the central bank to buy all the bonds offered by the firm and offer the corresponding amount of reserves to investors, paying  $\bar{r} = r$ . Doing so allows the central bank to replicate the frictionless benchmark of section 3.1. However, as mentioned above, the size of the QE program is limited in our model by: (1) the higher monitoring cost that the central bank pays relative to investors; (2) the fact that the expected return on assets cannot be lower than the total cost of reserves; and (3) investors cannot be made worse off.

## 5.4 A Numerical Illustration

Table 2 extends our numerical example to study QE. The table shows the changes in allocations relative to the competitive equilibrium for three different economies. The first column shows the decentralization of the socially efficient outcomes without QE (through the leverage tax,  $\tau^l$ , and storage subsidy,  $\tau^s$ ). The second column shows the effects of QE by itself. Finally, the third column shows QE in conjunction with optimal tax policy. All cases assume the parameterization  $\alpha = 0.5$ ,  $\psi = 0.9$ , and  $r = 0.01$ . We choose this parameterization because it puts the model in a region of the parameter space where QE is effective, as per proposition 9. In addition, we assume that  $\bar{\mu} = 0.3$ , which is 50% higher than the baseline value of  $\mu = 0.2$ .

The first column (which, for reference, corresponds to a point half way between the results shown in the first and second columns of table 1) shows that in absence of QE, the efficient allocation is decentralized with a leverage tax,  $\tau^l = 0.21$ , and a modest subsidy for storage,  $\tau^s = -0.04$ . By raising liquidity in the secondary market, and hence depressing the liquidity premium, the resulting reduction in funding costs raises profits by 0.14% relative to the competitive equilibrium, leaving the utility of investors unchanged. The second column presents results where we shut down the tax system, but allow the planner access to a QE program. Even when we shut down the tax system, so that  $\tau^l = \tau^s = 0$ , the planner can use QE to achieve an even greater increase in firm profitability without

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<sup>28</sup>Alternatively,  $\psi > \alpha(1 + r)/(1 + \alpha r)$  or  $\alpha < \psi/(1 + r - r\psi)$ .

harming investors. The central bank is able to improve the intermediation technology in the economy by directly intermediating credit in the primary market, and financing its bond purchases through the issuance of reserves (upon which the central bank must pay investors a premium above the return on storage). With QE the planner can achieve a similar outcome in terms of liquidity, without tax instruments. Finally, the last column of the table shows that QE, by itself, is not a panacea. A planner can do even better by implementing QE in conjunction with tax policy. The way to interpret this last result is that although QE improves the intermediation technology in the economy, it does nothing to remove the underlying distortions, arising from the liquidity externality.

Figure 8 shows how the gains to the firm vary with  $\psi$  for different levels of the efficiency of the central bank monitoring technology. The thick lines show the case for  $\bar{\mu} = 0.3$  assuming QE in conjunction with the optimal tax system (the thick solid line) and, alternatively, assuming QE alone with no supporting tax system (the thick dashed line). The thin solid and dashed lines correspond to the same information when the monitoring cost is lower, so that  $\bar{\mu} = 0.2$ . Finally, the thin dotted line shows the gains to the firm from optimal tax policy alone in absence of QE. There are four things to take from the figure. First, QE is always more effective when combined with the optimal tax policy (the solid lines are always above the dashed line for the same monitoring cost assumption). Second, the effectiveness of QE is limited by the parameterization of  $\psi$  (the dashed lines are downward sloping), so that as the gains from trade that accrue to impatient investors decline, QE becomes less effective. Third, the effectiveness of QE depends importantly on the quality of the central bank's monitoring technology (the thick lines are below the thin ones, so the worse the technology, the less effective is QE). Finally, there are parts of the parameter space in which QE is ineffective to the point at which a planner would strictly prefer optimal taxation to QE (the regions in which the thick and thin dashed lines lie below the thin dotted line).

## 6 Conclusion

We present a model of secondary market liquidity determination, where trade frictions interact with limited liquid assets available in financial markets. Economic decisions in the primary market determine both the productive firms' capital structure and the available liquid assets that will support frictional trade in illiquid markets. This interaction creates a feedback loop between secondary market liquidity and firm's financing decisions in primary capital markets. We show that imperfect secondary market liquidity accruing from search frictions results in positive liquidity premia, lower levels of leverage—or



equivalently lower debt issuance—and less credit risk in primary markets.

Furthermore, this feedback loop creates externalities operating via secondary market liquidity, as private agents do not internalize how their borrowing and liquidity provision decisions affect secondary market liquidity. This externality changes the trade-off between risk and leverage and *generically* makes the competitive equilibrium constrained inefficient. We show how efficiency can be restored by correcting two distorted margins: one on firms and one on investors. We consider distortionary taxes to correct these distorted margins, but other instruments such as leverage or portfolio restrictions could also be considered (see also Perotti and Suarez, 2011, who propose Pigouvian taxation to address externalities from the under-provision of liquidity).

In our model liquidity holdings by investors can be either too low or too high relative to the efficient level, with borrowing by firms being too high or too low, respectively. This inefficiency arises as both type of agents fail to internalize how they affect secondary market liquidity. The result is similar to other results in the literature of over-borrowing and liquidity under-supply. However, our result has different policy prescriptions as two policy tools are needed to restore efficiency. This contrasts with previous results, which have just focused on one of these inefficiencies (Fostel and Geanakoplos, 2008; Farhi, Golosov and Tsyvinski, 2009); or where borrowers are also liquidity providers and one policy instrument is enough to restore efficiency (Holmström and Tirole, 1998; Caballero and Krishnamurthy, 2001; Lorenzoni, 2008; Jeanne and Korinek, 2010; Bianchi, 2011). Our result also highlights the possibility of liquidity over-provision as emphasized by Hart and Zingales (2015) considering a different mechanism.

Finally, we show how unconventional policies like quantitative easing are expected to affect both secondary market liquidity and debt issuance in primary capital markets. By substituting illiquid assets for liquid short-term securities, these policies increase the intermediation capacity of the economy, and under some circumstances may lead to an improvement on the productive capacity of the economy. Our analysis suggests that these type of policies ought to be implemented in conjunction with policies to limit corporate borrowing.

Our model suggest a set of testable predictions for the relationship between the availability of short-term liquid assets and liquidity premia. In our model there is only one set of investors who participate in OTC markets, but in practice there are many, potentially segmented OTC markets. In this context, the intuition of our model will predict that liquidity premia for a given asset, should be inversely related to the liquidity of the portfolio of the participants in the OTC market for that asset. Along these lines, our model predicts that quantitative easing financed with bank reserves should have an effect on the liquidity

premia of *all* the securities traded in OTC markets where banks are relevant participants, not only affecting the liquidity premia of illiquid assets purchased by central banks.

This paper leaves open questions that we are taking on future work. First, we would like to explore the quantitative relevance of the mechanisms described herein. For that we have deliberately stayed very close to the quantitative model of Bernanke et al. (1999), and we are planning to explore the quantitative prescriptions of our model. Second, in practice many different assets are traded in OTC markets, a dimension that we have abstracted from in our analysis but seems important in practice. Future work should explore the relationship between market segmentation in OTC trade and secondary market liquidity (Vayanos and Wang, 2007; Vayanos and Weill, 2008). Two important considerations that we abstracted from will have to be accounted for in this work: what are the strategic incentives in such an environment?, and, how is liquidity allocated across these markets?

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# Appendix

## A Proofs

**Proof of Theorem 1:** We need to show that there is a unique equilibrium, and that in this equilibrium credit is not rationed. For that, first, we rule out credit rationing equilibria (Part 1). Then, we establish existence of a non-rationed equilibria (Parts 2-3). Finally, we establish the uniqueness (Part 4).

*Part 1. Rule out credit rationing equilibrium.*

First of all, note that from Assumption 2,  $\bar{\omega}dF(\bar{\omega})/(1 - F(\bar{\omega}))$ , is increasing so

$$1 = \mu \frac{\bar{\omega}dF(\bar{\omega})}{1 - F(\bar{\omega})}$$

has only one root, which is strictly positive and is denoted by  $\bar{\omega} > 0$ .

Note that from the definition of  $\Gamma(\omega)$  and  $G(\omega)$  it follows that for  $\bar{\omega} > 0$

$$\begin{aligned} \Gamma(\bar{\omega}) &> 0, & 1 - \Gamma(\bar{\omega}) &= \mathbb{P}(\omega \geq \bar{\omega})\mathbb{E}[\omega - \bar{\omega} | \omega \geq \bar{\omega}] > 0 \\ 1 &> \Gamma'(\bar{\omega}) &= 1 - F(\bar{\omega}) > 0, & \Gamma''(\bar{\omega}) &= -dF(\bar{\omega}) < 0 \\ 0 &< G(\bar{\omega}) < 1, & \mu G(\bar{\omega}) &< G(\bar{\omega}) < \Gamma(\bar{\omega}) \\ G'(\bar{\omega}) &= \bar{\omega}dF(\bar{\omega}) > 0, & G''(\bar{\omega}) &= dF(\bar{\omega}) + \bar{\omega} \frac{d(dF(\bar{\omega}))}{d\bar{\omega}} \end{aligned} \tag{A.1}$$

$$\lim_{\bar{\omega} \rightarrow 0} \Gamma(\bar{\omega}) = 0, \quad \lim_{\bar{\omega} \rightarrow \infty} \Gamma(\bar{\omega}) = \bar{\omega}\mathbb{P}(\omega \geq \bar{\omega}) + \mathbb{P}(\omega < \bar{\omega})\mathbb{E}[\omega | \omega < \bar{\omega}] = 1$$

$$\lim_{\bar{\omega} \rightarrow 0} G(\bar{\omega}) = 0 \quad \text{and} \quad \lim_{\bar{\omega} \rightarrow \infty} G(\bar{\omega}) = 1$$

Then

$$\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega}) = (1 - F(\bar{\omega})) \left( 1 - \mu \frac{\bar{\omega}dF(\bar{\omega})}{1 - F(\bar{\omega})} \right) \begin{cases} > 0 & \text{if } \bar{\omega} < \bar{\omega} \\ = 0 & \text{if } \bar{\omega} = \bar{\omega} \\ < 0 & \text{if } \bar{\omega} > \bar{\omega} \end{cases} .$$

On the other hand, the investors break-even condition (15) defines a relationship between risk  $\bar{\omega}$  and leverage  $l_0$  that we can characterize for given market liquidity,  $\theta$ , as follows. Let  $\bar{\omega}^{ibec}(l_0)$  be the correspondence that gives the values of risk compatible with the break-even condition for a level of leverage, then these values of risk are implicitly defined by

$$U_s(\theta) = u_b(\theta)R^b [l_0, \bar{\omega}^{ibec}(l_0)] ,$$

where  $u_b(\theta) \equiv \delta [f(\theta)\Delta^{-1} + (1 - f(\theta))\beta] + (1 - \delta)$ .

Since investors and the firm take secondary market liquidity,  $\theta$ , as given, applying the Implicit Function Theorem for any  $\bar{\omega} \neq \bar{\omega}$  we have that

$$\frac{d\bar{\omega}^{ibec}}{dl_0} = -\frac{\frac{\partial U_b}{\partial l_0}}{\frac{\partial U_b}{\partial \bar{\omega}}} = -\frac{\frac{\partial R^b}{\partial l_0}}{\frac{\partial R^b}{\partial \bar{\omega}}} . \quad (\text{A.2})$$

In fact, from equation (4) we have that

$$\frac{\partial R^b}{\partial l_0} = -\frac{R^b}{l_0(l_0 - 1)} < 0 \quad \text{and} \quad \frac{\partial R^b}{\partial \bar{\omega}} = \frac{R^b[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]}{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})} , \quad (\text{A.3})$$

so we can apply the Implicit Function Theorem for  $\bar{\omega} \neq \bar{\bar{\omega}}$ . It follows that the firm will never choose a contract with risk  $\bar{\omega} > \bar{\bar{\omega}}$ , as firm profits are decreasing in  $\bar{\omega}$ , and for  $\bar{\omega} > \bar{\bar{\omega}}$  additional risk will reduce the return to investors and they will not be willing to extend additional credit (higher leverage) at these higher risk levels.

An equilibrium with  $\bar{\omega} = \bar{\bar{\omega}}$  constitutes a credit rationing equilibrium, since the firm cannot increase leverage by increasing the risk of the contract. We want to rule out that such an equilibrium exists. Note that using a similar argument as above we have that for a fixed  $\theta$  there exists a function  $l_0^{ibec}(\bar{\omega})$  that gives the single value of leverage consistent with the break-even condition. Let  $\bar{l}_0 = l_0^{ibec}(\bar{\bar{\omega}}) > 0$ , then there are three potential types of credit rationing equilibria: (i)  $l_0 < \bar{l}_0$ ; (ii)  $l_0 = \bar{l}_0$ ; and (iii)  $l_0 > \bar{l}_0$ .

Suppose in equilibrium the firm chooses  $(l_0, \bar{\omega})$  with  $l_0 < \bar{l}_0$ . Since  $(\bar{l}_0, \bar{\bar{\omega}})$  satisfies the IBEC, it must be that  $u_b(\theta)R^b(l_0, \bar{\omega}) > U_s(\theta)$  from equation (A.3). But then the firm can do better by lowering (increasing) the risk of the contract (leverage), while still offering enough compensation to investors to hold bonds, so this cannot be an equilibrium. On the other hand, if equilibrium is described by  $(l_0, \bar{\omega})$  with  $l_0 > \bar{l}_0$ , then  $u_b(\theta)R^b(l_0, \bar{\omega}) < U_s(\theta)$ . Then, investors at  $t = 0$  will allocate all their wealth to storage, which is a contradiction with  $\bar{l}_0 > 0$ .

Finally, consider the case where the equilibrium is given by  $(\bar{l}_0, \bar{\bar{\omega}})$ . This contract is suboptimal for the firm as

$$\Gamma'(\bar{\bar{\omega}}) = (1 - F(\bar{\bar{\omega}})) > 0 ,$$

which is incompatible with the optimality conditions (16) and (17). Intuitively, the firm can give up an infinitesimal amount of leverage for an infinite reduction of risk, so it will never choose these contract terms in equilibrium.

*Part 2.* Rewrite the equilibrium conditions as a single-valued equation  $\mathcal{H}(\bar{\omega})$ .

Note that from equation (18), which characterizes the optimal contract in a non-rationing equilibrium, we can rearrange to get

$$l_0(\bar{\omega}) = 1 + \frac{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})}{1 - \Gamma(\bar{\omega})} \frac{\Gamma'(\bar{\omega})}{\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})} . \quad (\text{A.4})$$

In addition, note that from equation (19) we have

$$\theta(\bar{\omega}) = \theta(l_0(\bar{\omega}), \bar{\omega}) = \frac{(1 - \delta)(1 + r)\Delta(e_0 - n_0(l_0(\bar{\omega}) - 1))}{\delta R^b(l_0(\bar{\omega}), \bar{\omega})n_0(l_0(\bar{\omega}) - 1)} . \quad (\text{A.5})$$

Finally, using equations (A.4) and (A.5) we can express the break-even condition as the zero of the function  $\mathcal{H}(\bar{\omega})$ , defined by

$$\mathcal{H}(\bar{\omega}) = U_s(\theta(\bar{\omega})) - u_b(\theta(\bar{\omega}))R^b(l_0(\bar{\omega}), \bar{\omega}) , \quad (\text{A.6})$$

Part 3. Existence of a non-credit rationing equilibrium.

Want to show that  $\mathcal{H}(\bar{\omega})$  as a zero in  $(0, \bar{\bar{\omega}})$ . But since  $\mathcal{H}(\bar{\omega})$  is continuous, it suffices to show that  $\mathcal{H}(0) < 0$  and  $\mathcal{H}(\bar{\bar{\omega}}) > 0$ .

Consider first the case  $\bar{\omega} = 0$ . From equation (A.4) we have that  $l_0(0) = 1$ , and differentiating equation (A.4) we get

$$\frac{dl_0}{d\bar{\omega}} = \frac{\Gamma'(\bar{\omega})}{1 - \Gamma(\bar{\omega})} + \frac{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})}{[1 - \Gamma(\bar{\omega})][\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]} \left\{ \frac{[\Gamma'(\bar{\omega})]^2}{1 - \Gamma(\bar{\omega})} + \frac{\mu[\Gamma'(\bar{\omega})G''(\bar{\omega}) - \Gamma''(\bar{\omega})G'(\bar{\omega})]}{\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})} \right\}, \quad (\text{A.7})$$

so  $l'_0(0) = 1$ . Also,  $\Gamma(0) = 1$  and  $G'(0) = 0$ , thus from equation (4),  $\lim_{\bar{\omega} \rightarrow 0} R^b(\bar{\omega})$  equals

$$\lim_{\bar{\omega} \rightarrow 0} \frac{l_0(\bar{\omega})}{l_0(\bar{\omega}) - 1} R^k[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})] = \lim_{\bar{\omega} \rightarrow 0} R^k \frac{l'_0(\bar{\omega})[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})] + l_0(\bar{\omega})[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]}{l'_0(\bar{\omega})} = R^k.$$

In addition, from equation (A.5) we have

$$\lim_{\bar{\omega} \rightarrow 0} \theta(\bar{\omega}) = \lim_{\bar{\omega} \rightarrow 0} \frac{(1 - \delta)(1 + r)\Delta(e_0 - n_0(l_0(\bar{\omega}) - 1))}{\delta R^b(\bar{\omega})n_0(l_0(\bar{\omega}) - 1)} = \infty.$$

This imply that  $p(\theta) = 0$  and  $f(\theta) = 1$ , and thus

$$\begin{aligned} \mathcal{H}(0) &= \delta(1 + r) + (1 - \delta)(1 + r)^2 - R^k [\delta\Delta^{-1} + 1 - \delta] \\ &= \delta [(1 + r) - R^k\Delta^{-1}] + (1 - \delta) [(1 + r)^2 - R^k] < 0, \end{aligned}$$

where the inequality follows from Assumption 1.

Consider now the case  $\bar{\omega} = \bar{\bar{\omega}}$ , in this case from equation (A.4) we have that

$$\lim_{\bar{\omega} \rightarrow \bar{\bar{\omega}}} l_0(\bar{\omega}) = \lim_{\bar{\omega} \rightarrow \bar{\bar{\omega}}} 1 + \frac{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})}{1 - \Gamma(\bar{\omega})} \frac{\Gamma'(\bar{\omega})}{\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})} = \infty.$$

In addition, from equation (4)

$$\lim_{\bar{\omega} \rightarrow \bar{\bar{\omega}}} R^b(\bar{\omega}) = \lim_{\bar{\omega} \rightarrow \bar{\bar{\omega}}} \frac{1}{1 - 1/l_0(\bar{\omega})} R^k[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})] = R^k[\Gamma(\bar{\bar{\omega}}) - \mu G(\bar{\bar{\omega}})].$$

Furthermore, if leverage diverges then investors are allocating all their wealth to bonds and none to storage, so  $s_0(\bar{\bar{\omega}}) = 0$ , then it follows from equation (A.5) that

$$\lim_{\bar{\omega} \rightarrow \bar{\bar{\omega}}} \theta(\bar{\omega}) = \lim_{\bar{\omega} \rightarrow \bar{\bar{\omega}}} \frac{(1 - \delta)(1 + r)\Delta s_0(\bar{\omega})}{\delta R^b(\bar{\omega})n_0(l_0(\bar{\omega}) - 1)} = 0.$$

This imply that  $p(\theta) = 1$  and  $f(\theta) = 0$ , and thus

$$\mathcal{H}(\bar{\bar{\omega}}) = \delta(1 + r) + (1 - \delta)(1 + r)\Delta - [\delta\beta + 1 - \delta] R^k[\Gamma(\bar{\bar{\omega}}) - \mu G(\bar{\bar{\omega}})].$$

To show that  $\mathcal{H}(\bar{\bar{\omega}}) > 0$  we proceed by contradiction. Suppose that

$$\delta(1 + r) + (1 - \delta)(1 + r)\Delta < [\delta\beta + 1 - \delta] R^k[\Gamma(\bar{\bar{\omega}}) - \mu G(\bar{\bar{\omega}})].$$

Then, at  $\bar{\omega} = \bar{\bar{\omega}}$  a portfolio with  $s_0 = 0$  and  $b_0 = e_0$  is optimal for investors, since in this case the



hold-to-maturity return of bonds,  $R^b = (e_0 + n_0)/e_0 R^k[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})] > R^k[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]$ . Moreover, with this portfolio allocation liquidity equals zero, so the previous inequalities capture the return on storage and bond investments. So we have found an equilibrium with credit rationing,  $\bar{\omega} = \bar{\omega}$ , which is a contradiction. Thus, we conclude that

$$\delta(1+r) + (1-\delta)(1+r)\Delta < [\delta\beta + 1 - \delta] R^k[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})],$$

and  $\mathcal{H}(\bar{\omega}) > 0$ .

*Part 4. Uniqueness:* Show that  $\mathcal{H}(\bar{\omega})$  is strictly increasing in  $(0, \bar{\omega})$ .

Differentiating equation (A.6) we obtain

$$\begin{aligned} \frac{d\mathcal{H}(\bar{\omega})}{d\bar{\omega}} &= \frac{dU_s(\theta(\bar{\omega}))}{d\theta} \frac{d\theta(\bar{\omega})}{d\bar{\omega}} \\ &\quad - \frac{du_b(\theta(\bar{\omega}))}{d\theta} \frac{d\theta(\bar{\omega})}{d\bar{\omega}} R^b(l_0(\bar{\omega}), \bar{\omega}) - u_b(\theta(\bar{\omega})) \left[ \frac{\partial R^b(l_0(\bar{\omega}), \bar{\omega})}{\partial l_0} \frac{dl_0(\bar{\omega})}{d\bar{\omega}} + \frac{\partial R^b(l_0(\bar{\omega}), \bar{\omega})}{\partial \bar{\omega}} \right], \end{aligned}$$

To sign this derivative note that

$$\frac{dU_s}{d\theta} = (1-\delta)(1+r)p'(\theta) [\Delta - (1+r)] \leq 0,$$

$$\text{and} \quad \frac{du_b}{d\theta} = \delta f'(\theta) [\Delta^{-1} - \beta] \geq 0.$$

where the inequalities follow from  $p'(\theta) \leq 0$ ,  $f'(\theta) \geq 0$ , and  $(1+r) \leq \Delta \leq \beta^{-1}$ .

Note that we can express

$$\frac{d\theta}{d\bar{\omega}} = \frac{\partial \theta}{\partial l_0} \frac{dl_0}{d\bar{\omega}} + \frac{\partial \theta}{\partial \bar{\omega}} < 0. \quad (\text{A.8})$$

In fact, from the definition of  $\theta$ , equation (19), and equation (A.3) we have that

$$\frac{\partial \theta}{\partial l_0} = -\frac{\theta(e_0 + n_0)}{l_0(e_0 - n_0(l_0 - 1))} < 0 \quad \text{and} \quad \frac{\partial \theta}{\partial \bar{\omega}} = -\frac{\theta[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]}{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})} < 0, \quad (\text{A.9})$$

where the first inequality follows from Assumption 4, whereas the second inequality follows from  $\bar{\omega} < \bar{\omega}$ . Moreover, from Assumption 2 for  $\bar{\omega} < \bar{\omega}$ ,  $dl_0/d\bar{\omega} > 0$ . In fact, evaluating equation (A.7) and using that  $\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega}) > 0$  for  $\bar{\omega} < \bar{\omega}$ ;  $\Gamma'(\bar{\omega})G''(\bar{\omega}) - \Gamma''(\bar{\omega})G'(\bar{\omega}) = \frac{d(\bar{\omega}h(\bar{\omega}))}{d\bar{\omega}}(1 - F(\bar{\omega}))^2 > 0$  from Assumption 2; and  $\Gamma'(\bar{\omega}) > 0$  and  $\Gamma(\bar{\omega}) < 1$  from (A.1). Therefore,  $d\theta/d\bar{\omega} < 0$ .

It is just left to show that

$$\frac{\partial R^b}{\partial l_0} \frac{dl_0}{d\bar{\omega}} + \frac{\partial R^b}{\partial \bar{\omega}} < 0, \quad (\text{A.10})$$

which is the case iff

$$\frac{1}{l_0} \frac{dl_0}{d\bar{\omega}} > (l_0 - 1) \frac{\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})}{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})} = \frac{\Gamma'(\bar{\omega})}{1 - \Gamma(\bar{\omega})} \quad \Leftrightarrow \quad \frac{1 - \Gamma(\bar{\omega})}{\Gamma'(\bar{\omega})} \frac{dl_0}{d\bar{\omega}} - l_0 > 0.$$

Substituting in the expressions for  $l_0(\bar{\omega})$  and  $\frac{dl_0}{d\bar{\omega}}$  from equations (A.4) and (A.7) we get

$$1 + \frac{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})}{\Gamma'(\bar{\omega})[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]} \left\{ \frac{[\Gamma'(\bar{\omega})]^2}{1 - \Gamma(\bar{\omega})} + \frac{\mu[\Gamma'(\bar{\omega})G''(\bar{\omega}) - \Gamma''(\bar{\omega})G'(\bar{\omega})]}{\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})} \right\} - 1$$

$$- \frac{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})}{1 - \Gamma(\bar{\omega})} \frac{\Gamma'(\bar{\omega})}{\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})} = \frac{[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]\mu[\Gamma'(\bar{\omega})G''(\bar{\omega}) - \Gamma''(\bar{\omega})G'(\bar{\omega})]}{\Gamma'(\bar{\omega})[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]^2} > 0 \blacksquare$$

**Proof of Proposition 1:** From the optimal default decision (2) we have that  $Z = l_0/(l_0 - 1)R^k \bar{\omega}$ . On the other hand, from equation (4) we have  $R^b = l_0/(l_0 - 1)R^k[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]$ . Then, the default premium is given by

$$\Phi^d(\bar{\omega}) = \frac{\bar{\omega}}{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})} \quad (\text{A.11})$$

Taking the derivative:

$$\frac{d\Phi^d(\bar{\omega})}{d\bar{\omega}} = \frac{1}{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})} - \frac{\bar{\omega}[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]}{[\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]^2}$$

which is larger than zero iff

$$\Gamma(\bar{\omega}) - \mu G(\bar{\omega}) > \bar{\omega}[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]$$

Using the definition of  $\Gamma(\bar{\omega}) = \bar{\omega}(1 - F(\bar{\omega})) + G(\bar{\omega})$  and that  $\Gamma'(\bar{\omega}) = 1 - F(\bar{\omega})$ , the previous inequality is equivalent to

$$(1 - \mu)G(\bar{\omega}) > -\bar{\omega}\mu G'(\bar{\omega})$$

But the previous inequality follows from  $1 - \mu > 0$ ,  $G(\bar{\omega}) \geq 0$  and  $G'(\bar{\omega}) = \bar{\omega}dF(\bar{\omega}) > 0$ , for any  $\bar{\omega} > 0$ .  $\blacksquare$

**Proof of Proposition 2:** When there is no need to compensate investors for liquidity risk, the expected return from lending to entrepreneurs is equal to the outside option of holding storage. In other words, the liquidity premium is zero, i.e.  $\Phi^\ell(\theta) = 1$ , and  $R^b = (1 + r)^2$  or  $k_0 R^k [\Gamma(\bar{\omega}) - \mu G(\bar{\omega})] = (k_0 - n_0)(1 + r)^2$ . This is equivalent to the benchmark costly state verification model where investors are only compensated for credit risk. Note that entrepreneurs' profits do not depend directly on secondary market liquidity. We proceed by showing that  $\Phi^\ell(\theta) = 1$  under the three alternative condition stated in Proposition 2.

*Condition 1:*  $\delta = 0$ . This implies that secondary market liquidity  $\theta \rightarrow \infty$ , hence  $p(\theta) = 0$ . Setting  $\delta = 0$  and  $p(\theta) = 0$  yields  $\Phi^\ell(\theta) = 1$ .

*Condition 2:*  $\beta = (1 + r)^{-1}$ . Simple substitution yields  $\Phi^\ell(\theta) = 1$ .

*Condition 3:*  $\psi = 1$  and  $f(\theta) = 1$ . Simple substitution yields  $\Phi^\ell(\theta) = 1$ .

For any given distribution for the idiosyncratic productivity shock  $\omega$ , the upper threshold  $\bar{\omega}$  that entrepreneurs can promise to investors under perfect secondary markets is given by  $\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega}) = 0$ , this also gives an upper bound on leverage  $\bar{l}_0$  (see the proof of Theorem 1). This implies a maximum amount of borrowing,  $\bar{b}_0$ , which is given by the break-even condition  $(\bar{b}_0 + n_0)R^k [\Gamma(\bar{\omega}) - \mu G(\bar{\omega})] = \bar{b}_0(1 + r)^2$ . In turn this implies a lower bound for investors' endow-

ment,  $\bar{e}_0$ , such that  $\theta > \bar{\theta}$  for  $e_0 > \bar{e}_0$  given that  $\theta = (1 - \delta)(1 + r)(e_0/n_0 + 1 - \bar{l}_0)/[\delta q_1(\bar{l}_0 - 1)]$  is increasing in  $e_0$  and the highest value for  $q_1$  is  $\bar{l}_0/(\bar{l}_0 - 1)R^k [\Gamma(\bar{\omega}) - \mu G(\bar{\omega})]$ .

*Condition 4:*  $\nu \rightarrow \infty$ . In this case  $f(\theta), p(\theta) \rightarrow 1$ . In other words all buy and sell orders are executed. Note that in this case the return in the secondary market  $\tilde{\Delta} = R^b/q_1$  will be endogenously determined by supply and demand rather than surplus splitting. Denote by  $y \in [0, 1]$  the fraction of bonds sold by impatient investors, and  $x \in [0, 1]$  the fraction of wealth that patient investors exchange for bonds in the secondary market. Then, market clearing in the secondary market requires that

$$q_1 \delta y b_0 = (1 - \delta)(1 + r) x s_0$$

Then, consumption for impatient investors at  $t = 1$  and  $t = 2$ , respectively, is given by  $c_1^I = (1 + r)s_0 + q_1 y b_0$  and  $c_2^I = (1 - y)b_0 R^b$ . Similarly, patient investors allocate to storage at  $t = 1$   $s_1^P = (1 - x)(1 + r)s_0$ , and consume in period 2  $c_2^P = (1 + r)s_1 + (b_0 + (1 + r)x s_0/q_1) R^b$ . Moreover, we can write investor's break-even condition equating the expected utility from storage and bonds at  $t = 0$ , with

$$U_s = \delta(1 + r) + (1 - \delta)(1 + r) [x \tilde{\Delta} + (1 - x)(1 + r)]$$

and  $U_b = \left\{ \delta [y \tilde{\Delta}^{-1} + (1 - y)\beta] + (1 - \delta) \right\} R^b$ .

There are four possible cases to consider depending whether patient and impatient investors are indifferent or strictly prefer to trade in the secondary market.

First, consider that patient investors are indifferent, i.e.,  $x \in [0, 1]$ , and impatient investors strictly prefer to trade, so  $y = 1$ . The former imply that  $\tilde{\Delta} = 1 + r$ . Substituting in the break-even condition we obtain that  $R^b = (1 + r)^2$  and  $q_1 = 1 + r$ . That is, there is no liquidity premium and the model would collapse to the benchmark CSV. In order for this to be an equilibrium the secondary market needs to clear, which is the case if

$$(1 + r)\delta n_0(l_0 - 1) = (1 - \delta)(1 + r)x(e_0 - n_0(l_0 - 1)) \quad \Leftrightarrow \quad n_0(l_0 - 1) < e_0(1 - \delta),$$

which follows from the patient investors' deep-pocket assumption.

Second, consider that both type of investors strictly prefer to trade in the secondary market. In this case  $x = y = 1$ . Substituting these in the break-even condition we get that  $\tilde{\Delta} = R^b/(1 + r)$ , hence  $q_1 = 1 + r$ . In this case market clearing will require that

$$(1 + r)\delta n_0(l_0 - 1) = (1 - \delta)(1 + r)(e_0 - n_0(l_0 - 1)) \quad \Leftrightarrow \quad l_0 = \frac{e_0}{n_0}(1 - \delta) + 1,$$

i.e., firm borrowing is rationed by the "endowment of the patient investors",  $e_0(1 - \delta)$ . To support this equilibrium, investors' wealth should be "scarce" and the equilibrium in the primary market should support,  $\tilde{\Delta} \geq 1 + r$ , in the secondary market, or equivalently  $R^b \geq (1 + r)^2$ . Therefore, the firm can choose the lowest level of risk such that at the given leverage,  $R^b = (1 + r)^2$ . But then there is no liquidity premium, i.e.,  $\Phi^\ell = 1$ , as in the previous case with the exception that firm's borrowing is rationed. However, this cannot be an equilibrium as it contradicts the investor's deep-pocket assumption.

Third, consider that impatient investors are indifferent, i.e.,  $y \in [0, 1]$ , and patient investors strictly prefer to trade, so  $x = 1$ . The former imply that  $\tilde{\Delta} = \beta^{-1}$ . Substituting in the break-even

condition we get that  $R^b = \beta^{-1}(1+r)$ , hence  $q_1 = 1+r$ . Then, market clearing requires that

$$(1+r)\delta y n_0(l_0 - 1) = (1-\delta)(1+r)(e_0 - n_0(l_0 - 1)) \quad \Leftrightarrow \quad n_0(l_0 - 1) > e_0(1-\delta).$$

In this case, the firm is able to borrow more compared to the second case above, but needs to compensate (impatient) investors for the fact that they get a bigger discount in the secondary market, equal to  $\beta^{-1}$ . In this case, there is a liquidity premium  $\Phi^\ell = \beta^{-1}/(1+r) > 1$ , but importantly it does not depend on secondary market liquidity  $\theta$ . Note that this case encompasses a situation where the firm borrows all inventors' endowment,  $b_0 = e_0$ , and there is no trade in the secondary market. This is consistent with investors choices in the primary market as the return on bonds equals the return on storage, and the latter dominates the autarky return  $\delta(1+r) + (1-\delta)(1+r)^2$ . However, this cannot be an equilibrium as it contradicts the patient investor's deep-pocket assumption.

Comparing cases two and three above, we observe that the firm in case two is borrowing up to the endowment of the patient investors, but faces lower financing cost. This is because the return in secondary markets is the lowest,  $1+r$ , and this is priced in the primary market, through  $R^b$ . Alternatively, in case three the firm borrows more than can be financed by the endowment of patient investors, but faces higher financing cost: there is a liquidity premium. In this case, the return on the secondary market and thus on debt is the highest. Whether the firm will chose one or the other will be determined in equilibrium by the trade-off between leverage and financing cost that depends on firm's technology and investor's preferences and endowments.

Finally, consider the case that both type of investors are indifferent. Then, it must be that  $1+r = \tilde{\Delta} = \beta^{-1}$ , which is a contradiction if  $\beta < 1/(1+r)$ . If, on the other hand,  $\beta = 1/(1+r)$  then the investor's break-even condition imply that  $R^b = (1+r)^2$ , or alternatively that  $\Phi^\ell = 1$ . ■

**Proof of Lemma 1:** We want to show that the derivative of the liquidity premium *wrt* liquidity is negative. Denote by  $C$  and  $D$  the numerator and denominator in  $\Phi^\ell(\theta)$  given by 21. Then,

$$C = \delta + (1-\delta)[(1-p)(1+r) + p\Delta] > 0 \quad (\text{A.12})$$

$$D = \delta[f\Delta^{-1} + \beta(1-f)] + (1-\delta) > 0$$

where the inequalities follow from the fact that probabilities and returns are non-negative. In addition, denote  $C_\theta$  and  $D_\theta$  the derivatives of  $C$  and  $D$ , respectively, *wrt*  $\theta$ . Then

$$C_\theta = \frac{\partial C}{\partial \theta} = (1-\delta)[\Delta - (1+r)] \frac{dp(\theta)}{d\theta} \leq 0$$

$$D_\theta = \frac{\partial D}{\partial \theta} = \delta[\Delta^{-1} - \beta] \frac{df(\theta)}{d\theta} \geq 0$$

where the inequalities follow from  $\beta < 1/(1+r)$ , equations (6) and (7), and that the matching function  $m(A,B)$  is increasing in both arguments. From equation (21) we have that

$$\frac{d\Phi^\ell}{d\theta} = \frac{1}{1+r} \left[ \frac{C_\theta}{D} - \frac{CD_\theta}{D^2} \right] \leq 0 \quad (\text{A.13})$$

where the inequality follows from the previously established inequalities:  $D, C > 0$ ,  $D_\theta \geq 0$  and  $C_\theta \leq 0$ .

In the case where  $\theta < \underline{\theta}$  and  $\psi > 0$ , then  $D_\theta > 0$ , so  $d\Phi^\ell/d\theta < 0$ . Alternatively, if  $\theta \geq \bar{\theta}$ , i.e.,  $f(\theta) = 1$ , our assumptions require that  $\psi < 1$ . In addition,  $dp(\theta)/d\theta < 0$ . With  $\psi < 1$  and

$dp(\theta)/d\theta < 0$  then  $C_\theta < 0$ , so  $d\Phi^\ell/d\theta < 0$ . Moreover, when  $\theta \in (\underline{\theta}, \bar{\theta})$  we have that  $dp(\theta)/d\theta < 0$  and  $df(\theta)/d\theta > 0$ , so  $d\Phi^\ell/d\theta < 0$ . Therefore, we conclude that  $d\Phi^\ell/d\theta < 0$  when OTC trade is relevant, apart from the case were  $\theta < \underline{\theta}$  and  $\psi = 0$ .

Regarding the second part of the Lemma, the elasticity of the liquidity premium,  $\Phi^\ell$ , with respect to the secondary market liquidity,  $\theta$ , is written, using equation (A.13), as:

$$\zeta_{\Phi^\ell, \theta} = \frac{\theta}{\Phi^\ell} \frac{d\Phi^\ell}{d\theta} = \frac{\theta}{1+r} \frac{C_\theta D - CD_\theta}{CD}, \quad (\text{A.14})$$

Then  $|\zeta_{\Phi^\ell, \theta}| < 1$  requires:

$$-\frac{\theta}{1+r} \frac{C_\theta D - CD_\theta}{D^2} < \frac{1}{1+r} \frac{C}{D} \quad \Leftrightarrow \quad CD + \theta C_\theta D - \theta CD_\theta > 0$$

First, lets consider the case where  $\theta \in (\underline{\theta}, \bar{\theta})$ . In this case,  $f(\theta) = \nu\theta^{1-\alpha}$  and  $p(\theta) = \nu\theta^{-1}$ . Thus,  $\theta \frac{df(\theta)}{d\theta} = (1-\alpha)f(\theta)$  and  $\theta \frac{dp(\theta)}{d\theta} = -\alpha p(\theta)$ . Then,

$$C_\theta \theta = -\alpha C + \alpha[\delta + (1-\delta)(1+r)] \leq 0 \quad (\text{A.15})$$

$$D_\theta \theta = (1-\alpha)D - (1-\alpha)[\beta\delta + (1-\delta)] \geq 0 \quad (\text{A.16})$$

Then,

$$\begin{aligned} CD + \theta C_\theta D - \theta CD_\theta &= CD + D\{-\alpha C + \alpha[\delta + (1-\delta)(1+r)]\} - C\{(1-\alpha)D - (1-\alpha)[\beta\delta + (1-\delta)]\} \\ &= \alpha D[\delta + (1-\delta)(1+r)] + C(1-\alpha)[\beta\delta + (1-\delta)] > 0. \end{aligned}$$

Second, consider the case where  $\theta < \underline{\theta}$ . In this case,  $p(\theta) = 1$  and  $f(\theta) = \theta$ , so  $df(\theta)/d\theta = 1$  and  $dp(\theta)/d\theta = 0$ . Want to show that  $D - \theta D_\theta > 0$ . From above  $D_\theta = \delta[\Delta^{-1} - \beta]$ . Then,

$$D - \theta D_\theta = \delta\beta + (1-\delta) > 0.$$

Finally, consider the case where  $\theta > \bar{\theta}$  and  $\psi < 1$ . In this case,  $\theta df(\theta)/d\theta = \theta D_\theta = 0$  and  $p(\theta) = \theta^{-1}$ . Thus, we want to show that  $C + \theta C_\theta > 0$ . From above,  $\theta C_\theta = -\theta^{-1}(1-\delta)[\Delta - (1+r)]$ . Then,

$$C + \theta C_\theta = \delta + (1-\delta)(1+r) > 0. \quad \blacksquare$$

**Proof of Proposition 3:** From the investors' break-even condition (20), we see that an increase in the liquidity premium,  $\Phi^\ell$  induces investors to require a higher expected return  $R^b$  to invest in corporate bonds. Hence, the liquidity premium  $\Phi^\ell$  and the hold-to-maturity bond return  $R^b$  are proportional to one another. In fact,

$$(1+r)^2 \Phi^\ell = R^b \quad \Rightarrow \quad \frac{dR^b}{d\Phi^\ell} = \frac{R^b}{\Phi^\ell} > 0$$

For this proof we consider the liquidity premium a function of both secondary market liquidity,  $\theta$ , and model parameters  $\delta$  and  $\beta$ . That is, we can write the liquidity premium as  $\Phi^\ell(\theta, \delta, \beta)$ .

*Case 1:* Effect of  $\delta$ . Want to show that

$$\frac{d\Phi^\ell}{d\delta} = \frac{\partial\Phi^\ell}{\partial\delta} + \frac{\partial\Phi^\ell}{\partial\theta} \frac{\partial\theta}{\partial\delta} > 0$$

From the definition of secondary market liquidity, given in equation (19), and considering the dependence of secondary market pricing on liquidity premia, we have that

$$\frac{\partial\theta}{\partial\delta} = -\frac{\theta}{\delta(1-\delta)} - \frac{\theta}{q_1} \frac{dq_1}{dR^b} \frac{dR^b}{d\Phi^\ell} \frac{d\Phi^\ell}{d\delta} = -\frac{\theta}{\delta(1-\delta)} - \frac{\theta}{\Phi^\ell} \frac{d\Phi^\ell}{d\delta}$$

Using this expression we get

$$\frac{d\Phi^\ell}{d\delta} = \frac{\frac{\partial\Phi^\ell}{\partial\delta} - \frac{1}{\delta(1-\delta)} \zeta_{\Phi^\ell, \theta}}{1 + \zeta_{\Phi^\ell, \theta}}$$

where  $\zeta_{\Phi^\ell, \theta}$  is the elasticity of the liquidity premium with respect to secondary market liquidity, which is negative and strictly greater than  $-1$  (Lemma 1). Therefore,  $1 + \zeta_{\Phi^\ell, \theta} > 0$ .

It is left to show that  $\partial\Phi^\ell/\partial\delta > 0$ . For that we use the notation introduced in equation (A.12). In addition, denote  $C_\delta$  and  $D_\delta$  the derivatives of  $C$  and  $D$ , respectively, wrt  $\delta$ . Then

$$C_\delta = \frac{\partial C}{\partial\delta} = 1 - [(1-p)(1+r) + p\Delta]$$

$$D_\delta = \frac{\partial D}{\partial\delta} = [f\Delta^{-1} + (1-f)\beta] - 1$$

Then, from equation (21) we have that

$$\frac{\partial\Phi^\ell}{\partial\delta} = \frac{1}{1+r} \left[ \frac{C_\delta}{D} - \frac{CD_\delta}{D^2} \right]$$

which is strictly greater than zero if and only if

$$C_\delta D > CD_\delta$$

$$C_\delta [\delta D_\delta + 1] > [\delta C_\delta + 1 - C_\delta] D_\delta$$

$$C_\delta > [1 - C_\delta] D_\delta$$

or

$$1 - [(1-p)(1+r) + p\Delta] > [(1-p)(1+r) + p\Delta] \left\{ [f\Delta^{-1} + (1-f)\beta] - 1 \right\}$$

$$\Leftrightarrow 1 > [(1-p)(1+r) + p\Delta] [f\Delta^{-1} + (1-f)\beta]$$

It is easy to check that after distributing terms in the previous expression the four remaining terms, are a weighted average of terms strictly smaller than 1, with the weights given by the product of probabilities  $f$  and  $p$  adding up to 1. In fact,  $\beta < 1/(1+r)$  imply that

$$\beta(1+r) < 1, \quad \Delta^{-1}(1+r) < 1, \quad \text{and} \quad \Delta\beta < 1.$$

Case 2: Effect of  $\beta$ . Want to show that

$$\frac{d\Phi^\ell}{d\beta} = \frac{\partial\Phi^\ell}{\partial\beta} + \frac{\partial\Phi^\ell}{\partial\theta} \frac{\partial\theta}{\partial\beta} < 0.$$

For that we use the notation introduced in equation (A.12). In addition, denote  $C_\beta$  and  $D_\beta$  the derivatives of  $C$  and  $D$ , respectively, wrt  $\beta$ . Then

$$C_\beta = \frac{\partial C}{\partial \beta} = -(1 - \delta)p\Delta^2(1 - \psi) < 0 ,$$

and  $D_\beta = \frac{\partial D}{\partial \beta} = \delta[f(1 - \psi) + 1 - f] = \delta(1 - \psi f) > 0 .$

where the inequalities follow from our assumption about  $\delta$ ,  $\psi$ , and  $f(\theta)$ . Then,

$$\frac{\partial \Phi^\ell}{\partial \beta} = \frac{1}{1 + r} \left[ \frac{C_\beta}{D} - \frac{CD_\beta}{D^2} \right] < 0 ,$$

as  $C_\beta < 0$  and  $D_\beta, C, D > 0$ .

From the definition of secondary market liquidity, given in equation (19), and considering the dependence of the secondary market price on liquidity premia, we have that

$$\frac{\partial \theta}{\partial \beta} = -\frac{\theta}{q_1} \left[ \frac{\partial q_1}{\partial \beta} + \frac{\partial q_1}{\partial R^b} \frac{dR^b}{d\Phi^\ell} \frac{d\Phi^\ell}{d\beta} \right] = -\theta \left[ (1 - \psi)\Delta + \frac{1}{\Phi^\ell} \frac{d\Phi^\ell}{d\beta} \right]$$

Thus,

$$\frac{d\Phi^\ell}{d\beta} = \frac{\frac{\partial \Phi^\ell}{\partial \beta} - (1 - \psi)\Delta\theta \frac{\partial \Phi^\ell}{\partial \theta}}{1 + \zeta_{\Phi^\ell, \theta}}$$

where  $\zeta_{\Phi^\ell, \theta}$  is the elasticity of the liquidity premium with respect to secondary market liquidity. From Lemma 1 the denominator,  $1 + \zeta_{\Phi^\ell, \theta}$ , is strictly positive. But the sign of the numerator is ambiguous. The reason is that a higher  $\beta$  on one hand reduces the preference for liquidity by impatient households, i.e.,  $\partial \Phi^\ell / \partial \beta < 0$ . But on the other hand it increases the secondary market price,  $q_1$ , which pushes market liquidity  $\theta$  down and liquidity premia up. This second force, represented by the second term in the numerator, depends crucially on the bargaining power of impatient investors: the lower their bargaining power the more important the effect of their valuation, i.e.,  $\beta$ , will be on the price.

The numerator is negative if and only if

$$(1 - \psi)\Delta\theta[C_\theta D - CD_\theta] - C_\beta D + CD_\beta > 0$$

Using the expressions derived above for  $C$ ,  $D$ ,  $C_\theta$ ,  $D_\theta$ ,  $C_\beta$ , and  $D_\beta$ , we have

$$\begin{aligned} & (1 - \psi)\Delta\theta[C_\theta D - CD_\theta] - C_\beta D + CD_\beta \\ &= -(1 - \psi)\Delta p(1 - \delta)[\Delta - (1 + r)][\delta(f\Delta^{-1} + (1 - f)\beta) + (1 - \delta)] \\ & \quad - (1 - \psi)\Delta(1 - \alpha)f\delta[\Delta^{-1} - \beta][\delta + (1 - \delta)[(1 - p)(1 + r) + p\Delta]] \\ & \quad + (1 - \psi)p(1 - \delta)\Delta^2[\delta[f\Delta^{-1} + (1 - f)\beta] + (1 - \delta)] \\ & \quad + \delta[f(1 - \psi) + 1 - f][\delta + (1 - \delta)[(1 - p)(1 + r) + p\Delta]] \end{aligned}$$

$$\begin{aligned}
& (1 - \psi)\Delta\theta[C_\theta D - CD_\theta] - C_\beta D + CD_\beta \\
&= (1 - \psi)[\delta(f\Delta^{-1} + (1 - f)\beta) + (1 - \delta)] \left\{ (1 - \alpha)p(1 - \delta)\Delta^2 + p(1 - \delta)(1 + r) \right\} \\
&+ (1 - \psi)[\delta + (1 - \delta)][(1 - p)(1 + r) + p\Delta] \{ \alpha f\delta + (1 - \alpha)f\delta\Delta\beta \} \\
&+ (1 - f)\delta[\delta + (1 - \delta)][(1 - p)(1 + r) + p\Delta] > 0
\end{aligned}$$

Case 3: Effect of  $e_0$ . Want to show that

$$\frac{d\Phi^\ell}{de_0} < 0. \quad (\text{A.17})$$

Note that investors' endowment  $e_0$  affects liquidity premium  $\Phi^\ell$  only through its effect on secondary market liquidity  $\theta$ . In particular, it has an effect only through  $s_0 = e_0 - b_0$  given that we have fixed leverage in this exercise. Thus,

$$\frac{d\Phi^\ell}{de_0} = \frac{\partial\Phi^\ell}{\partial\theta} \frac{\partial\theta}{\partial s_0} \frac{ds_0}{de_0} = \frac{\partial\Phi^\ell}{\partial\theta} \frac{\theta}{s_0} < 0$$

where the inequality follows from Lemma 1. ■

#### Proof of Proposition 4:

Case 1: *Comparative Statics on  $\delta$* . Recall that from equation (18) we can rearrange terms to get leverage as a function of risk,  $l_0(\bar{\omega})$ , equation (A.4). In addition, from equation (19) we can express  $\theta$  as a function of  $l_0(\bar{\omega})$ ,  $\bar{\omega}$ , and  $\delta$ , i.e.,  $\theta(l_0(\bar{\omega}), \bar{\omega}, \delta)$ . Using these expressions, equilibrium conditions boil down to the investors' break-even condition, which can be expressed as

$$(1 + r)^2 \Phi^\ell(\theta(l_0(\bar{\omega}), \bar{\omega}, \delta), \delta) = R^b(l_0(\bar{\omega}), \bar{\omega})$$

By the Implicit Function Theorem, if the derivative of the previous expression wrt  $\bar{\omega}$  is different than 0, then we can define  $\bar{\omega}(\delta)$  and calculate its derivative from the previous expression. We want to show that  $\frac{d\bar{\omega}}{d\delta} < 0$ .

Fully differentiating wrt to  $\bar{\omega}$  we obtain

$$(1 + r)^2 \left\{ \frac{\partial\Phi^\ell}{\partial\theta} \left[ \frac{\partial\theta}{\partial l_0} \frac{dl_0}{d\bar{\omega}} \frac{d\bar{\omega}}{d\delta} + \frac{\partial\theta}{\partial \bar{\omega}} \frac{d\bar{\omega}}{d\delta} + \frac{\partial\theta}{\partial \delta} \right] + \frac{\partial\Phi^\ell}{\partial \delta} \right\} = \frac{\partial R^b}{\partial l_0} \frac{dl_0}{d\bar{\omega}} \frac{d\bar{\omega}}{d\delta} + \frac{\partial R^b}{\partial \bar{\omega}} \frac{d\bar{\omega}}{d\delta}$$

Thus,

$$\frac{d\bar{\omega}}{d\delta} = \frac{H_\delta}{J}$$

with

$$\begin{aligned}
H_\delta &= -(1 + r)^2 \left\{ \frac{\partial\Phi^\ell}{\partial\theta} \frac{\partial\theta}{\partial \delta} + \frac{\partial\Phi^\ell}{\partial \delta} \right\} \\
J &= (1 + r)^2 \left\{ \frac{\partial\Phi^\ell}{\partial\theta} \left[ \frac{\partial\theta}{\partial l_0} \frac{dl_0}{d\bar{\omega}} + \frac{\partial\theta}{\partial \bar{\omega}} \right] \right\} - \frac{\partial R^b}{\partial l_0} \frac{dl_0}{d\bar{\omega}} - \frac{\partial R^b}{\partial \bar{\omega}}
\end{aligned} \quad (\text{A.18})$$



From Proposition 3  $\frac{\partial \Phi^\ell}{\partial \delta} > 0$ . In addition,

$$\frac{\partial \theta}{\partial \delta} = -\frac{\theta}{\delta(1-\delta)} < 0$$

and  $\partial \Phi^\ell / \partial \theta < 0$  from Lemma 1. Thus,  $H_\delta < 0$ .

Next we want to show that  $J > 0$ . For that first recall that from equation (A.8) we have that  $(\partial \theta / \partial l_0)(dl_0 / d\bar{\omega}) + (\partial \theta / \partial \bar{\omega}) < 0$ . Second, note that from equation (A.10) we have that  $(\partial R^b / \partial l_0)(dl_0 / d\bar{\omega}) + \partial R^b / \partial \bar{\omega} < 0$ .

Therefore, we conclude that  $J > 0$  and  $d\bar{\omega} / d\delta < 0$ . It follows from  $dl_0 / d\bar{\omega} > 0$ , equation (A.7), that  $dl_0 / d\delta < 0$ . ■

**Proof of Corollary 1:** The effect of any parameter  $\varrho$  on the default premium is described by

$$\frac{d\Phi^d}{d\varrho} = \frac{d\Phi^d}{d\bar{\omega}} \frac{\partial \bar{\omega}}{\partial \varrho}.$$

Since  $\frac{d\Phi^d}{d\bar{\omega}} > 0$  from Proposition 1, the result on the default premium follows from Proposition 4. ■

**Proof of Proposition 5:** We want to show that if the competitive equilibrium is constrained efficient, then  $(\alpha, \psi, r) \in \emptyset$ , a set of measure zero.

Suppose  $(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}, q_1^{ce})$ , the competitive equilibrium, is constrained efficient. Since  $(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}, q_1^{ce})$  is a competitive equilibrium the investor break-even condition (15) holds, i.e.,  $U_s = U_b$ , and from equation (18) it must be that

$$\frac{1 - \Gamma(\bar{\omega}^{ce})}{l_0^{ce} \Gamma'(\bar{\omega}^{ce})} = -\frac{\partial U_b / \partial l_0}{\partial U_b / \partial \bar{\omega}}.$$

On the other hand, since  $(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}, q_1^{ce})$  is constrained efficient, from equation (26) it must be that

$$\frac{[1 - \Gamma(\bar{\omega}^{ce})]}{l_0^{ce} \Gamma'(\bar{\omega}^{ce})} = -\frac{n_0(U_b - U_s) + b_0^{ce} \frac{\partial U_b}{\partial l_0} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial l_0}}{b_0^{ce} \frac{\partial U_b}{\partial \bar{\omega}} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{\omega}}}.$$

Using that  $U_s = U_b$ , then

$$\frac{b_0^{ce} \frac{\partial U_b}{\partial l_0} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial l_0}}{b_0^{ce} \frac{\partial U_b}{\partial \bar{\omega}} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{\omega}}} = \frac{\frac{\partial U_b}{\partial l_0}}{\frac{\partial U_b}{\partial \bar{\omega}}},$$

which is the case iff

$$\frac{\partial \mathbb{U}}{\partial \theta} \left[ \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial l_0} - \frac{\partial U_b}{\partial l_0} \frac{\partial \theta}{\partial \bar{\omega}} \right] = 0 \quad (\text{A.19})$$

Note that,

$$\frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial l_0} - \frac{\partial U_b}{\partial l_0} \frac{\partial \theta}{\partial \bar{\omega}} < 0, \quad (\text{A.20})$$

since

$$\frac{\partial U_b}{\partial l_0} = -\frac{U_b}{l_0(l_0 - 1)} < 0 \quad \text{and} \quad \frac{\partial U_b}{\partial \bar{\omega}} = \frac{U_b[\Gamma'(\bar{\omega}) - \mu G'(\bar{\omega})]}{\Gamma(\bar{\omega}) - \mu G(\bar{\omega})} > 0 \quad (\text{A.21})$$

where the last inequality follows from Theorem 1; and  $\partial \theta / \partial l_0, \partial \theta / \partial \bar{\omega} < 0$  from equation (A.9).

Then, A.19 holds iff  $\partial\mathbb{U}/\partial\theta = 0$ , which is the case iff

$$\begin{aligned} s_0^{ce} \frac{\partial U_s}{\partial \theta} + b_0^{ce} \frac{\partial U_b}{\partial \theta} &= 0 \\ s_0^{ce}(1-\delta)(1+r)[\Delta - (1+r)]p'(\theta^{ce}) + b_0^{ce}\delta[\Delta^{-1} - \beta]f'(\theta^{ce})R^b &= 0 \\ p(\theta^{ce})\frac{\alpha}{\theta^{ce}}s_0^{ce}(1-\delta)(1+r)[\Delta - (1+r)] &= f(\theta^{ce})\frac{1-\alpha}{\theta^{ce}}b_0^{ce}\delta[\Delta^{-1} - \beta]R^b \\ \theta^{ce} &= \frac{\alpha s_0^{ce}(1-\delta)(1+r)[\Delta - (1+r)]}{(1-\alpha)b_0^{ce}\delta[\Delta^{-1} - \beta]R^b} \end{aligned}$$

But from equation (19)  $\theta^{ce} = (1-\delta)(1+r)\Delta s_0^{ce}/(\delta b_0^{ce}R^b)$ , then

$$\begin{aligned} \frac{\alpha[\Delta - (1+r)]}{(1-\alpha)[\Delta^{-1} - \beta]} &= \Delta \quad \Leftrightarrow \quad \Delta[\alpha + (1-\alpha)\beta] = 1 + \alpha r \\ \Leftrightarrow \quad \frac{\psi}{1+r} + (1-\psi)\beta &= \frac{\alpha + (1-\alpha)\beta}{1 + \alpha r} \quad \Leftrightarrow \quad \psi = \frac{\alpha(1-\beta(1+r))}{1 + \alpha r} \frac{1+r}{(1-\beta(1+r))} \\ &\Leftrightarrow \quad \psi(1 + \alpha r) = \alpha(1+r) \end{aligned} \tag{A.22}$$

The set of  $(\alpha, \psi, r)$  satisfying (A.22) is, thus, of measure zero. ■

### Proof of Proposition 6:

*Part 1.* The sign of the externality determines the socially optimal level of secondary market liquidity.

Let  $\mathcal{L}$  be the Lagrangian of the planner's problem, which is given

$$\mathcal{L} = [1 - \Gamma(\bar{\omega})]R^k l_0 - \lambda[\mathbb{U}^{ce} - s_0 U_s - b_0 U_b],$$

Fully differentiating and evaluating at the competitive equilibrium allocation  $(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce})$  we have

$$d\mathcal{L}(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}) = \lambda \frac{\partial \mathbb{U}}{\partial \theta} d\theta,$$

where we have substituted the optimality conditions in the competitive equilibrium. Thus, the planner, who internalizes the effect of liquidity on the investor's utility, would like to increase liquidity in secondary markets when the externality is positive, i.e.,  $\partial\mathbb{U}/\partial\theta > 0$ , and decrease liquidity if the externality is negative, i.e.,  $\partial\mathbb{U}/\partial\theta < 0$ .

*Part 2.* Show that the sign of the externality depends on the relationship between the parameters  $(\alpha, r, \psi)$ .

Want to show that

$$\psi(1 + \alpha r) > \alpha(1+r) \quad \Leftrightarrow \quad \frac{\partial \mathbb{U}}{\partial \theta} > 0.$$

In fact,

$$\begin{aligned}
\psi(1 + \alpha r) > \alpha(1 + r) &\Leftrightarrow \Delta > \frac{\alpha[\Delta - (1 + r)]}{(1 - \alpha)[\Delta^{-1} - \beta]} \\
&\Leftrightarrow \theta > \frac{\alpha s_0(1 - \delta)(1 + r)[\Delta - (1 + r)]}{(1 - \alpha)b_0\delta[\Delta^{-1} - \beta]R^b} \\
&\Leftrightarrow b_0 \frac{\partial U_b}{\partial \theta} + s_0 \frac{\partial U_s}{\partial \theta} > 0 \quad \Leftrightarrow \frac{\partial \mathbb{U}}{\partial \theta} > 0.
\end{aligned}$$

*Part 3. Characterization of the efficient contract.*

Let  $\bar{\omega}^{pi}(l_0)$  be the function implicitly defined by the Pareto improvement constraint in the planner's problem (23). Using the Implicit Function Theorem and equation (A.20) we have that

$$\frac{d\bar{\omega}^{pi}}{dl_0} = - \frac{\frac{\partial \mathbb{U}}{\partial l_0} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial l_0}}{\frac{\partial \mathbb{U}}{\partial \bar{\omega}} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{\omega}}}$$

Similarly, using the notation introduced in the proof of Theorem 1, where  $\bar{\omega}^{ibec}(l_0)$  denotes the function implicitly defined by the investors' break-even condition in the competitive economy for  $\bar{\omega} < \bar{\omega}$ . From equation (A.2) we had that

$$\frac{d\bar{\omega}^{ibec}}{dl_0} = - \frac{\frac{\partial U_b}{\partial l_0}}{\frac{\partial U_b}{\partial \bar{\omega}}}$$

Note that the competitive equilibrium is a feasible point of the pareto improvement constraint, so  $\bar{\omega}^{pi}(l_0^{ce}) = \bar{\omega}^{ibec}(l_0^{ce})$ . Moreover, note that

$$\frac{d\bar{\omega}^{pi}(l_0^{ce})}{dl_0} - \frac{d\bar{\omega}^{ibec}(l_0^{ce})}{dl_0} = \frac{\frac{\partial \mathbb{U}}{\partial \theta} \left[ \frac{\partial \theta}{\partial \bar{\omega}} \frac{\partial U_b}{\partial l_0} - \frac{\partial \theta}{\partial l_0} \frac{\partial U_b}{\partial \bar{\omega}} \right]}{\frac{\partial U_b}{\partial \bar{\omega}} \left[ b_0 \frac{\partial U_b}{\partial \bar{\omega}} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{\omega}} \right]}$$

where all the derivatives on the RHS are evaluated at  $(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce})$ , and we used that

$$\frac{\partial \mathbb{U}(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce})}{\partial l_0} = n_0(U_b(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}) - U_s(\theta^{ce})) + b_0^{ce} \frac{\partial U_b(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce})}{\partial l_0} = b_0^{ce} \frac{\partial U_b(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce})}{\partial l_0}$$

It follows from above and equation (A.20) that

$$\frac{d\bar{\omega}^{pi}(l_0^{ce})}{dl_0} - \frac{d\bar{\omega}^{ibec}(l_0^{ce})}{dl_0} > 0 \quad \Leftrightarrow \quad \frac{\partial \mathbb{U}}{\partial \theta} > 0.$$

Then, if  $\psi(1 + \alpha r) > \alpha(1 + r)$ , from Part 2,  $\partial \mathbb{U} / \partial \theta > 0$ , and, thus,

$$\frac{d\bar{\omega}^{pi}(l_0^{ce})}{dl_0} > \frac{d\bar{\omega}^{ibec}(l_0^{ce})}{dl_0} > 0$$

where the last inequality follows from equation (A.21). That means there are points that are feasible for the planner where  $(l_0, \bar{\omega}) \ll (l_0^{ce}, \bar{\omega}^{ce})$  that achieve higher profits for the firm, so the planner will

choose an allocation with lower leverage and risk. (Note that by equation (A.9) this imply that the planner will set a higher secondary market liquidity:  $\theta > \theta^{ce}$ .)

Similarly, if  $\psi(1 + ar) < \alpha(1 + r)$ , from Part 2,  $\partial U / \partial \theta < 0$ , so

$$0 < \frac{d\bar{\omega}^{pi}(l_0^{ce})}{dl_0} < \frac{d\bar{\omega}^{ibec}(l_0^{ce})}{dl_0}$$

That means there are points that are feasible for the planner where  $(l_0, \bar{\omega}) \gg (l_0^{ce}, \bar{\omega}^{ce})$  and higher firm's profits, so the planner will choose an allocation with higher leverage and risk. ■

### Proof of Proposition 7:

*Part 1. Deriving the tax instruments.*

The firm's problem with taxes on storage and leverage can be written as

$$[1 - \Gamma(\bar{\omega})]R^k l_0 - \tau^l \lambda l_0 + T^l \quad (\text{A.23})$$

subject to

$$U_b = (1 - \tau^s)U_s \quad (\text{A.24})$$

We write the Lagrangian for this problem as

$$\mathcal{L} = [1 - \Gamma(\bar{\omega})]R^k l_0 - \tau^l \lambda l_0 + T^l - \lambda[(1 - \tau^s)U_s - U_b] \quad (\text{A.25})$$

Then, the optimality conditions are

$$[1 - \Gamma(\bar{\omega})]R^k = \tau^l \lambda - \lambda \frac{\partial U_b}{\partial l_0} \quad (\text{A.26})$$

$$\Gamma'(\bar{\omega})R^k l_0 = \lambda \frac{\partial U_b}{\partial \bar{\omega}} \quad (\text{A.27})$$

Note that the FOC for  $(\bar{\omega})$ , equation (A.27), together with equation (A.21) ensures that  $\lambda > 0$ , which is not necessarily the case with equality constraints. And the optimal contract is described by

$$\frac{1 - \Gamma(\bar{\omega})}{l_0 \Gamma'(\bar{\omega})} = - \frac{\frac{\partial U_b}{\partial l_0} - \tau^l}{\frac{\partial U_b}{\partial \bar{\omega}}}. \quad (\text{A.28})$$

Equating the previous expression and equation (26), and using that  $U_b - U_s = -\tau^s U_s$ , we derive the tax on leverage:

$$\tau^l = \frac{n_0 U_s \frac{\partial U_b}{\partial \bar{\omega}} \tau^s + \left[ \frac{\partial U_b}{\partial l_0} \frac{\partial \theta}{\partial \bar{\omega}} - \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial l_0} \right] \frac{\partial U}{\partial \theta}}{b_0 \frac{\partial U_b}{\partial \bar{\omega}} + \frac{\partial \theta}{\partial \bar{\omega}} \frac{\partial U}{\partial \theta}}$$

The term in square brackets is positive from equation (A.20). On the other hand, using equations (A.9) and (A.21) the denominator is positive iff

$$b_0 \left\{ \delta \left[ f(\theta) \Delta^{-1} + (1 - f(\theta)) \beta \right] + 1 - \delta \right\} R^b - s_0 (1 - \delta) (1 + r) [\Delta - (1 + r)] p'(\theta) \theta - b_0 \delta \left[ \Delta^{-1} - \beta \right] f'(\theta) \theta R^b > 0.$$

Using that  $p'(\theta)\theta = -\alpha p(\theta)$  and  $f'(\theta)\theta = (1 - \alpha)f(\theta)$  the previous expression equals

$$b_0 \{\delta\beta + 1 - \delta\} R^b + \alpha s_0(1 - \delta)(1 + r) [\Delta - (1 + r)] p(\theta) + \alpha b_0 \delta [\Delta^{-1} - \beta] f(\theta) R^b > 0,$$

where the inequality follows from  $\Delta > 1 + r$  and  $\Delta^{-1} > \beta$ , since  $\beta < 1/(1 + r)$ .

On the other hand, the break-even condition of investors with a tax on storage was given by equation (A.24). Combining it with constraint (23) we derive the tax on storage:

$$\tau^s = \frac{e_0}{b_0} \left( 1 - \frac{U_s(\theta^{ce})}{U_s(\theta)} \right)$$

*Part 2. Signing the tax on storage.*

If  $\psi(1 + ar) > \alpha(1 + r)$  then from Proposition 6 the planner wants to increase secondary market liquidity so  $\theta > \theta^{ce}$ . Thus, the storage technology is subsidized:  $\tau^s \leq 0$ . In fact, the tax on storage is negative from equation (27) if  $\psi < 1$  and is zero if  $\psi = 0$ .

On the contrary, if  $\psi(1 + ar) < \alpha(1 + r)$ , then the externality is negative, the planner wants to reduce secondary market liquidity, and, therefore,  $\tau^s > 0$ .

*Part 3. Signing the tax on leverage.*

We start by describing the feasible allocations for a firm that chooses the optimal contract and faces the the optimal tax on storage, and the efficient level of secondary market liquidity. That is,  $\tau^s$  is given by equation (27) and  $\theta$  is the one that the planner would choose optimally. In this case we have

$$(1 - \tau^s)U_s(\theta) = \left( 1 - \frac{e_0}{b_0} \frac{U_s(\theta) - U_s(\theta^{ce})}{U_s(\theta)} \right) U_s(\theta) = \frac{b_0 U_b(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}) + s_0 U_s(\theta^{ce}) - s_0 U_s(\theta)}{b_0}$$

where we used that in the competitive equilibrium  $U_s(\theta^{ce}) = U_b(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce})$ , and  $b_0^{ce} + s_0^{ce} = e_0$ .

Lets consider first the case when  $\psi(1 + ar) > \alpha(1 + r)$ . In this case  $\partial \mathbb{U} / \partial \theta > 0$  and  $\theta > \theta^{ce}$ , then

$$b_0 U_b(l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}) + s_0 U_s(\theta^{ce}) < b_0 U_b(l_0^{ce}, \bar{\omega}^{ce}, \theta) + s_0 U_s(\theta)$$

So we conclude that

$$(1 - \tau^s)U_s(\theta) < U_b(l_0^{ce}, \bar{\omega}^{ce}, \theta)$$

Since  $\partial U_b / \partial \bar{\omega} > 0$ , for the leverage of the competitive equilibrium  $l_0^{ce}$  a feasible level of risk lies below the risk in the competitive equilibrium. So the investor's break-even condition with the optimal tax and the efficient level of liquidity will lie below the investor's break-even condition in the competitive problem. Moreover, from equation (A.2) the slope of this constraint at  $l_0^{ce}$ , which has the same expression regardless of the tax, will be flatter.

The firm, then, if it were to face this constraint without a tax on leverage will choose a higher leverage, at odds with the planner optimal prescriptions. The planner then will distort the firm's decision to disincentivize the use of leverage by levying a tax on leverage. One way to see this is that the planner will introduce a distortion such that the distorted isoprofit lines are flatter in the  $(l_0, \bar{\omega})$ -space.

Let  $\Pi^\tau = [1 - \Gamma(\bar{\omega})]R^k l_0 - \tau^l \lambda l_0 + T^l$ , and denote by  $\bar{\omega}^{\Pi^\tau}(l_0)$  the function that for any  $l_0$  gives the associated risk level  $\bar{\omega}$  along the taxed firm isoprofit line. Then, the Implicit Function Theorem

implies that

$$\frac{d\bar{\omega}^{\Pi}}{dl_0} = \frac{[1 - \Gamma(\bar{\omega})]R^k - \tau^l \lambda}{\Gamma'(\bar{\omega})R^k l_0}$$

so a flatter slope requires a positive  $\tau^l$ .

Using the same reasoning we conclude that if  $\psi(1 + \alpha r) < \alpha(1 + r)$ , then  $\tau^l < 0$ . ■

**Proof of Proposition 8:** In the presence of quantitative easing, firms' borrowing is given by  $b_0 + \bar{b}_0$ , whereas investors' lending is given by  $b_0$ . Then from the budget constraint of entrepreneurs we have that  $k_0 = n_0 + b_0 + \bar{b}_0$ , so investors' lending can be written in terms of entrepreneurs leverage and QE as  $b_0 = n_0(l_0 - 1 - \bar{b}_0/n_0)$ . On the other hand, from the investors' budget constraint,  $b_0 + s_0 + \bar{s}_0 = e_0$ , so we can express the amount invested in the storage technology in terms of entrepreneurs leverage as  $s_0 = n_0(e_0/n_0 - (l_0 - 1))$ . Note that the size of the QE program does not affect the amount ultimately invested in storage, as the bonds the central bank purchases are offset with the reserves it takes from investors. Finally, from the central bank's budget constraint we have that  $\bar{s}_0 = \bar{b}_0$ .

Using the previous expressions we can express secondary market liquidity in terms of entrepreneurs leverage and QE, conditional on the interest on reserves relative to the return on the OTC market. Note that the number of sell orders is always equal to  $A = \delta b_0$ , as impatient investors will put all their bond holdings for sale in the OTC market.

If  $\Delta > 1 + \bar{r}$  patient investors pledge all their liquid assets to place buy orders in the OTC market so the number of buy orders  $B = (1 - \delta)[(1 + r)s_0 + (1 + \bar{r})\bar{s}_0]/q_1$  and market liquidity is given by

$$\theta = \frac{(1 - \delta)[(1 + r)s_0 + (1 + \bar{r})\bar{s}_0]}{\delta b_0 q_1} = \frac{(1 - \delta)\Delta [(1 + r)(e_0 - n_0(l_0 - 1)) + (1 + \bar{r})\bar{b}_0]}{\delta R^b (n_0(l_0 - 1) - \bar{b}_0)} \quad (\text{A.29})$$

Then,

$$\frac{\partial \theta}{\partial \bar{b}_0} = \frac{(1 - \delta)\Delta(1 + \bar{r})}{\delta R^b (n_0(l_0 - 1) - \bar{b}_0)} + \frac{(1 - \delta)\Delta [(1 + r)(e_0 - n_0(l_0 - 1)) + (1 + \bar{r})\bar{b}_0]}{\delta R^b (n_0(l_0 - 1) - \bar{b}_0)^2} > 0 \quad (\text{A.30})$$

On the other hand, when  $1 + \bar{r} > \Delta$  patient investors place buy orders in the OTC market only using the liquid assets they hold after funding the reserves liquidated by impatient investors, so the number of buy orders  $B = (1 - \delta)[(1 + r)s_0 - \delta/(1 - \delta)(1 + \bar{r})\bar{s}_0]/q_1$  and market liquidity is given by

$$\theta = \frac{(1 - \delta)[(1 + r)s_0 - \frac{\delta}{1 - \delta}(1 + \bar{r})\bar{s}_0]}{\delta b_0 q_1} = \frac{(1 - \delta)\Delta [(1 + r)(e_0 - n_0(l_0 - 1)) - \frac{\delta}{1 - \delta}(1 + \bar{r})\bar{b}_0]}{\delta R^b (n_0(l_0 - 1) - \bar{b}_0)}$$

Then,

$$\begin{aligned} \frac{\partial \theta}{\partial \bar{b}_0} &= -\frac{\Delta(1 + \bar{r})}{R^b (n_0(l_0 - 1) - \bar{b}_0)} + \frac{(1 - \delta)\Delta [(1 + r)(e_0 - n_0(l_0 - 1)) - \frac{\delta}{1 - \delta}(1 + \bar{r})\bar{b}_0]}{\delta R^b (n_0(l_0 - 1) - \bar{b}_0)^2} \\ &= \frac{(1 - \delta)\Delta [(1 + r)e_0 - (1 + \bar{r})n_0(l_0 - 1) + (\bar{r} - r)n_0(l_0 - 1)]}{\delta R^b (n_0(l_0 - 1) - \bar{b}_0)^2} > 0 \end{aligned}$$

where the inequality follows from Assumption 4. Then,  $\partial\theta/\partial\bar{b}_0 > 0$ . ■

**Proof of Proposition 9:** We want to show that a planner that has access to QE as an additional policy tool will only use it when the return on storage  $r$  is strictly lower than  $(\psi - \alpha)/(\alpha - \alpha\psi)$ , or equivalently, when  $\psi(1 + \alpha r) > \alpha(1 + r)$ . Let  $(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp})$  be the allocations chosen by the social planner studied in section 4 and denote by  $\lambda^{sp}$  the lagrange multiplier on the constraint of this planner (23).

Let  $\mathcal{L}$  be the Lagrangian of the central bank, which can be written as

$$\mathcal{L} = [1 - \Gamma(\bar{\omega})] R^k l_0 - \lambda \left[ \mathbb{U}^{ce} - \mathbb{U}(l_0, \bar{\omega}, \theta(l_0, \bar{\omega}, \bar{b}_0, \bar{r}), \bar{b}_0, \bar{r}) \right] - \gamma \left[ (1 + \bar{r})^2 - \bar{R}^b \right] - \nu[r - \bar{r}] + \eta \bar{b}_0$$

where we are considering the constraint imposed by the definition of secondary market liquidity (19) writing  $\theta(l_0, \bar{\omega}, \bar{b}_0, \bar{r})$  and where we have already substituted in  $\bar{s}_0 = \bar{b}_0$ . An optimal allocation for this planner needs to satisfy the following FOCs:

$$\begin{aligned} (l_0) \quad 0 &= \frac{\partial \mathcal{L}}{\partial l_0} = [1 - \Gamma(\bar{\omega})] R^k + \lambda \left[ \frac{\partial \mathbb{U}}{\partial l_0} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial l_0} \right] + \gamma \frac{\partial \bar{R}^b}{\partial l_0} \\ (\bar{\omega}) \quad 0 &= \frac{\partial \mathcal{L}}{\partial \bar{\omega}} = -\Gamma'(\bar{\omega}) R^k l_0 + \lambda \left[ \frac{\partial \mathbb{U}}{\partial \bar{\omega}} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{\omega}} \right] + \gamma \frac{\partial \bar{R}^b}{\partial \bar{\omega}} \\ (\bar{b}_0) \quad 0 &= \frac{\partial \mathcal{L}}{\partial \bar{b}_0} = \lambda \left[ \frac{\partial \mathbb{U}}{\partial \bar{b}_0} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{b}_0} \right] + \eta \\ (\bar{r}) \quad 0 &= \frac{\partial \mathcal{L}}{\partial \bar{r}} = \lambda \left[ \frac{\partial \mathbb{U}}{\partial \bar{r}} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{r}} \right] - 2\gamma(1 + \bar{r}) + \nu \end{aligned}$$

Note that the size of the bond buying program  $\bar{b}_0$  does not affect firm's profits directly, as the additional funds that the firm receives from the central bank,  $\bar{b}_0$ , are perfectly offset by the reduction in the amount of funds received from investors,  $b_0 = n_0(l_0 - 1) - \bar{b}_0$ , as long as firm leverage is unchanged.

The next step is to evaluate the FOCs at the constrained efficient allocation (without QE), i.e.,  $(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)$ . If  $\bar{R}^b(l_0^{sp}, \bar{\omega}^{sp}) \leq (1+r)^2$  the central bank cannot implement QE without violating its funding constraint (30). So we consider that we are in the interesting case where  $\bar{R}^b(l_0^{sp}, \bar{\omega}^{sp}) > (1+r)^2$  and the central bank has some scope to offer a higher return on reserves relative to the storage technology. In this case the multiplier of this constraint at  $(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)$  equals zero, i.e.,  $\gamma = 0$ . Moreover, note that at  $\bar{b}_0 = 0$ , investors' expected utility  $\mathbb{U}$  has the same functional form as in the case of the planner studied in section 4. Similarly, at  $\bar{b}_0 = 0$  secondary market liquidity  $\theta$ , equation (A.29), is the same function of choice variables as in the case without QE, equation (19). So we conclude that the FOCs wrt leverage  $l_0$  and risk  $\bar{\omega}$  are satisfied at  $(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)$ . (In fact, we can use either FOC to obtain that  $\lambda = \lambda^{sp}$ , from where the other FOC follows.)

Next, note that

$$\frac{\partial \mathbb{U}}{\partial \bar{r}} = \bar{s}_0 \frac{\partial U_{\bar{s}}}{\partial \bar{r}} = \bar{b}_0 \frac{\partial U_{\bar{s}}}{\partial \bar{r}} \quad \Rightarrow \quad \frac{\partial \mathbb{U}(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)}{\partial \bar{r}} = 0$$

And given that  $(1 + \bar{r}) = (1 + r) < \Delta$  from equation (A.29) we have that

$$\frac{\partial \theta}{\partial \bar{r}} = \frac{(1 - \delta)\Delta \bar{b}_0}{\delta R^b (n_0(l_0 - 1) - \bar{b}_0)} \Rightarrow \frac{\partial \theta (l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)}{\partial \bar{r}} = 0$$

So the FOC *wrt* on interest on reserves  $\bar{r}$  is trivially satisfied, with  $\nu = 0$ .

Finally, we need to evaluate the FOC *wrt*  $\bar{b}_0$  at  $(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)$ . From this condition it follows that

$$\frac{\partial \mathbb{U}}{\partial \bar{b}_0} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{b}_0} < 0 \quad \Rightarrow \quad \eta > 0 \quad \text{and} \quad \bar{b}_0 = 0$$

To sign  $\partial \mathbb{U} / \partial \bar{b}_0 + (\partial \mathbb{U} / \partial \theta) (\partial \theta / \partial \bar{b}_0)$  we proceed to compute these derivatives and evaluate at  $(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)$ . One, note that

$$\mathbb{U}(l_0, \bar{\omega}, \theta, \bar{b}_0, \bar{r}) = [e_0 - n_0(l_0 - 1)]U_s + \bar{b}_0 U_{\bar{s}} + [n_0(l_0 - 1) - \bar{b}_0]U_b$$

Then,

$$\frac{\partial \mathbb{U} (l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)}{\partial \bar{b}_0} = U_{\bar{s}} (\theta^{sp}, r) - U_b (l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}) = U_s (\theta^{sp}) - U_b (l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp})$$

where we used that if interest on reserves are equal to the return on the storage technology then  $U_{\bar{s}} (\theta^{sp}, r) = U_s (\theta^{sp})$ , from equation (34). On the other hand, from the conditions that describe the planner's allocations we have that

$$\begin{aligned} s_0^{sp} U_s (\theta^{sp}) + b_0^{sp} U_b (l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}) &= s_0^{ce} U_s (\theta^{ce}) + b_0^{ce} U_b (l_0^{ce}, \bar{\omega}^{ce}, \theta^{ce}) = e_0 U_s (\theta^{ce}) \\ \Rightarrow U_b (l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}) - U_s (\theta^{sp}) &= \frac{e_0 [U_s (\theta^{ce}) - U_s (\theta^{sp})]}{b_0^{sp}} = -\tau^s U_s (\theta^{sp}) \end{aligned} \quad (\text{A.31})$$

where we used the definition of the optimal tax on storage (27) in the last equality.

Then, from the characterization of the optimal tax on leverage in section 4.1 we have that if  $r > (\psi - \alpha) / [\alpha(1 - \psi)]$ , or equivalently  $\psi(1 + \alpha r) < \alpha(1 + r)$ , then

$$\tau^l < 0 \quad \Leftrightarrow \quad n_0 \frac{\partial U_b}{\partial \bar{\omega}} [U_s (\theta^{sp}) - U_b (l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp})] + \left[ \frac{\partial U_b}{\partial l_0} \frac{\partial \theta}{\partial \bar{\omega}} - \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial l_0} \right] \frac{\partial \mathbb{U}}{\partial \theta} < 0 \quad (\text{A.32})$$

where we have substituted (A.31) into the expression for the optimal tax on leverage (28).

Two, from Proposition 8 we had that  $\partial \theta / \partial \bar{b}_0 > 0$  and evaluating equation (A.30) at  $(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)$  we get

$$\frac{\partial \theta (l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)}{\partial \bar{b}_0} = \frac{\theta^{sp} e_0}{[e_0 - n_0 (l_0^{sp} - 1)] n_0 (l_0^{sp} - 1)} \quad (\text{A.33})$$

Three, note that if  $r > (\psi - \alpha) / [\alpha(1 - \psi)]$  we have that from equation (A.32) that

$$n_0 \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \mathbb{U}}{\partial \bar{b}_0} + n_0 \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial \bar{b}_0} \frac{\partial \mathbb{U}}{\partial \theta} < \left\{ -\frac{\partial U_b}{\partial l_0} \frac{\partial \theta}{\partial \bar{\omega}} + \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial l_0} + n_0 \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial \bar{b}_0} \right\} \frac{\partial \mathbb{U}}{\partial \theta}$$



But the term in curly brackets evaluated at  $(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)$  is zero. In fact, using equations (A.9), (A.21), and (A.33) we have

$$-\frac{\partial U_b}{\partial l_0} \frac{\partial \theta}{\partial \bar{\omega}} + \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial l_0} + n_0 \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial \bar{b}_0} = \frac{U_b^{sp} \theta^{sp} [\Gamma'(\bar{\omega}^{sp}) - \mu G'(\bar{\omega}^{sp})]}{\Gamma(\bar{\omega}^{sp}) - \mu G(\bar{\omega}^{sp})} \left[ \frac{-1}{l_0^{sp} (l_0^{sp} - 1)} - \frac{e_0 + n_0}{l_0^{sp} [e_0 - n_0 (l_0^{sp} - 1)]} + \frac{e_0}{[e_0 - n_0 (l_0^{sp} - 1)] (l_0^{sp} - 1)} \right] = 0$$

So we conclude that

$$n_0 \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \mathbb{U}}{\partial \bar{b}_0} + n_0 \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial \bar{b}_0} \frac{\partial \mathbb{U}}{\partial \theta} < 0$$

And since  $\partial U_b / \partial \bar{\omega} > 0$ , then  $\partial \mathbb{U} / \partial \bar{b}_0 + (\partial \mathbb{U} / \partial \theta) (\partial \theta / \partial \bar{b}_0) < 0$ . Thus, it must be that if  $r > (\psi - \alpha) / [\alpha(1 - \psi)]$  then  $\eta > 0$  and the optimal QE designs calls for not buying bonds, i.e.,  $\bar{b}_0 = 0$ .

Alternatively, when  $r < (\psi - \alpha) / [\alpha(1 - \psi)]$  we can follow the previous line of argument to show that the tax on leverage is positive so

$$n_0 \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \mathbb{U}}{\partial \bar{b}_0} + n_0 \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial \bar{b}_0} \frac{\partial \mathbb{U}}{\partial \theta} > \left\{ -\frac{\partial U_b}{\partial l_0} \frac{\partial \theta}{\partial \bar{\omega}} + \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial l_0} + n_0 \frac{\partial U_b}{\partial \bar{\omega}} \frac{\partial \theta}{\partial \bar{b}_0} \right\} \frac{\partial \mathbb{U}}{\partial \theta} = 0$$

where the derivatives are evaluated at  $(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)$ . Thus,

$$\frac{\partial \mathbb{U}}{\partial \bar{b}_0} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{b}_0} > 0$$

since  $\partial U_b / \partial \bar{\omega} > 0$ . That is, the central bank wants to buy bonds, so  $\eta = 0$ . Finally, fully differentiating the Lagrangean  $\mathcal{L}$  of the central bank's problem and evaluating at the constrained efficient allocation with out QE  $(l_0^{sp}, \bar{\omega}^{sp}, \theta^{sp}, 0, r)$ , we have that

$$d\mathcal{L} = \lambda \left[ \frac{\partial \mathbb{U}}{\partial \bar{b}_0} + \frac{\partial \mathbb{U}}{\partial \theta} \frac{\partial \theta}{\partial \bar{b}_0} \right] d\bar{b}_0 > 0.$$

So we conclude that when  $r < (\psi - \alpha) / [\alpha(1 - \psi)]$  a central bank will set positive bond buying program, improving upon the constrained efficient allocation. When  $\bar{b}_0$  it follows from the FOC wrt  $\bar{r}$  that the central bank will pay a higher interest on reserves relative to the return on the storage technology. In fact,  $\gamma$  will be strictly positive and the central bank's funding constraint will be binding. ■

## Tables and Figures

Table 1: Planning outcomes and Implementation

$\psi$	1.0	0.8	0.6	0.4	0.2	0.0
% change in $l_0$	-8.62%	-5.03%	-1.63%	1.72%	5.13%	8.63%
% change in $\bar{\omega}$	-5.27%	-3.06%	-0.99%	1.04%	3.08%	5.17%
% change in $\theta$	62.01%	27.75%	7.44%	-6.70%	-17.42%	-26.03%
% change in $\Pi$	0.23%	0.07%	0.01%	0.01%	0.06%	0.16%
% change in $\mathbb{U}$	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
$\tau^l$	0.27%	0.15%	0.05%	-0.05%	-0.13%	-0.21%
$\tau^s$	0.00%	-0.05%	-0.03%	0.04%	0.14%	0.27%

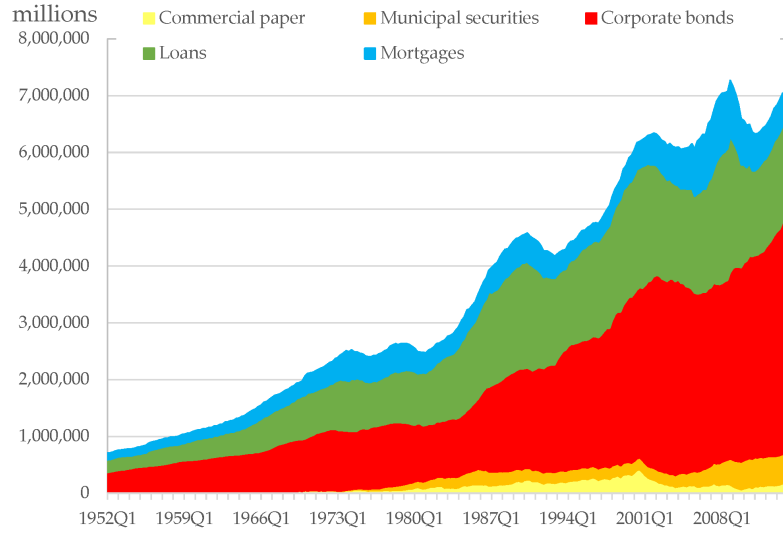
Note: Percentages correspond to deviations with respect to the competitive equilibrium for variables: leverage ( $l_0$ ), risk ( $\bar{\omega}$ ), market liquidity ( $\theta$ ), firms' profits ( $\Pi$ ), and investors' utility ( $\mathbb{U}$ ); and to the level of the optimal taxes on leverage ( $\tau^l$ ) and storage ( $\tau^s$ ). Negative values for taxes corresponds to subsidies. For details see section 4.2.

Table 2: Outcomes with Quantitative Easing

	Constrained Efficient Allocations	Quantitative Easing with $\tau^s = \tau^l = 0$	Quantitative Easing with $\tau^s, \tau^l$ Chosen Optimally
% change in $l_0$	-6.78%	1.68%	-3.05%
% change in $\bar{\omega}$	-4.13%	0.72%	-2.35%
% change in $\theta$	42.19%	43.37%	167.72%
% change in $\Pi$	0.14%	0.42%	0.98%
% change in $\mathbb{U}$	0.00%	0.00%	0.00%
$\bar{r}$		1.16%	1.10%
$\bar{s}_0$		0.09	0.18
$\tau^l$	0.21%		0.17%
$\tau^s$	-0.04%		-0.05%

Note: Percentages correspond to deviations with respect to the competitive equilibrium for variables: leverage ( $l_0$ ), risk ( $\bar{\omega}$ ), market liquidity ( $\theta$ ), firms' profits ( $\Pi$ ), and investors' utility ( $\mathbb{U}$ ); and to the level of: tax on leverage ( $\tau^l$ ), tax on storage ( $\tau^s$ ), and interest rate on reserves ( $\bar{r}$ ). Values for reserves ( $\bar{s}_0$ ) are in levels. Negative values for taxes corresponds to subsidies. For details see section 5.4.

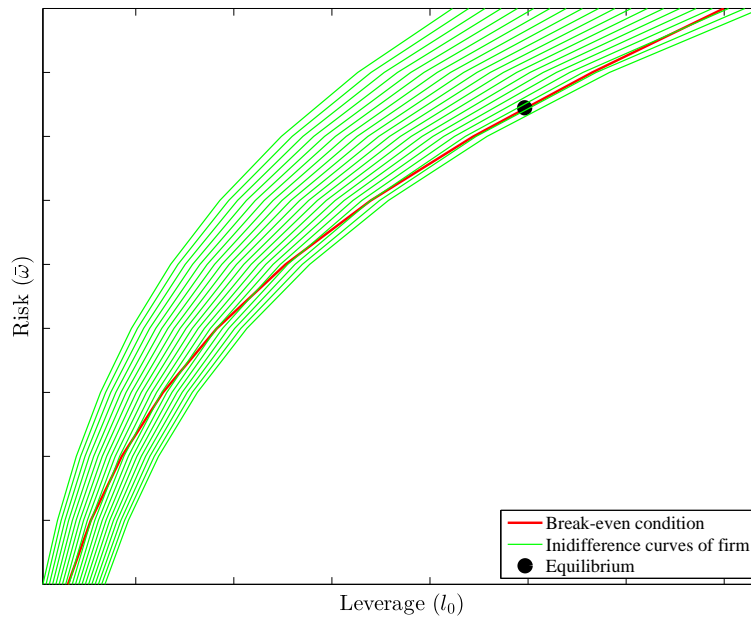
**Figure 3: Credit Market Instrument Liabilities**  
(Nonfinancial corporate business, millions 2013 dollars)



Source: Balance Sheet of Nonfinancial Corporate Business (B.103), Financial Accounts of the United States; Federal Reserve Economic Data (FRED) St. Louis Fed.

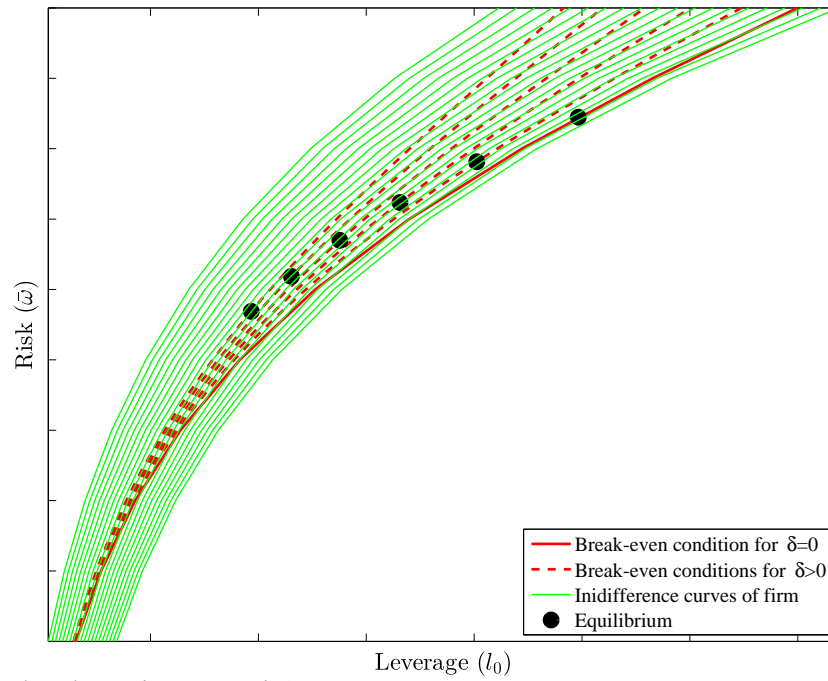
Notes: The data corresponds to the following series in the Financial Accounts: commercial paper (FL103169100); municipal securities and loans (FL103162000); corporate bonds (FL103163003); loans corresponds to the sum of depository institution loans n.e.c. (FL103168005) and other loans and advances (FL103169005); and total mortgages (FL103165005).

**Figure 4: Equilibrium in the Frictionless Benchmark**



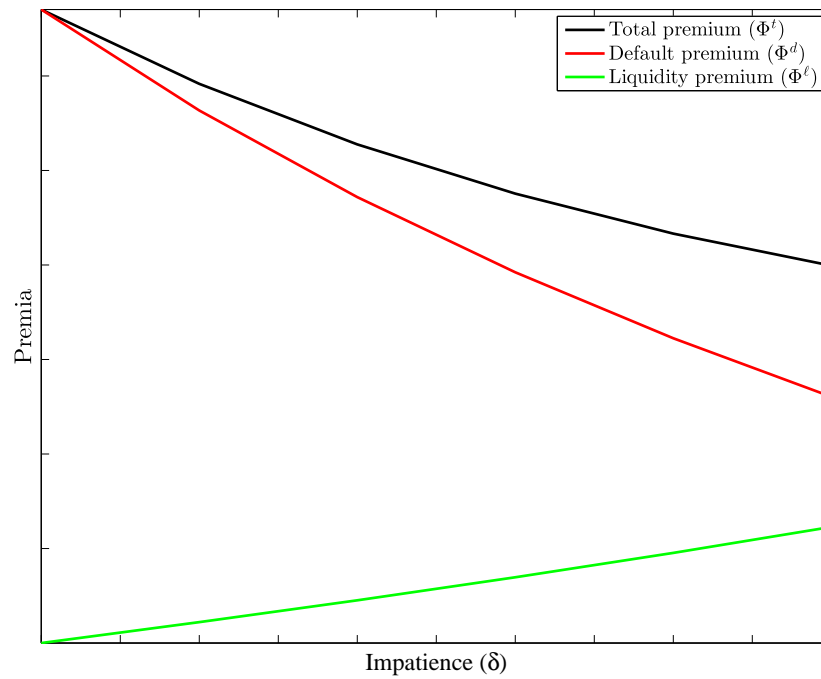
Note: For details see section 3.3.

Figure 5: Comparative Statics on  $\delta$ .



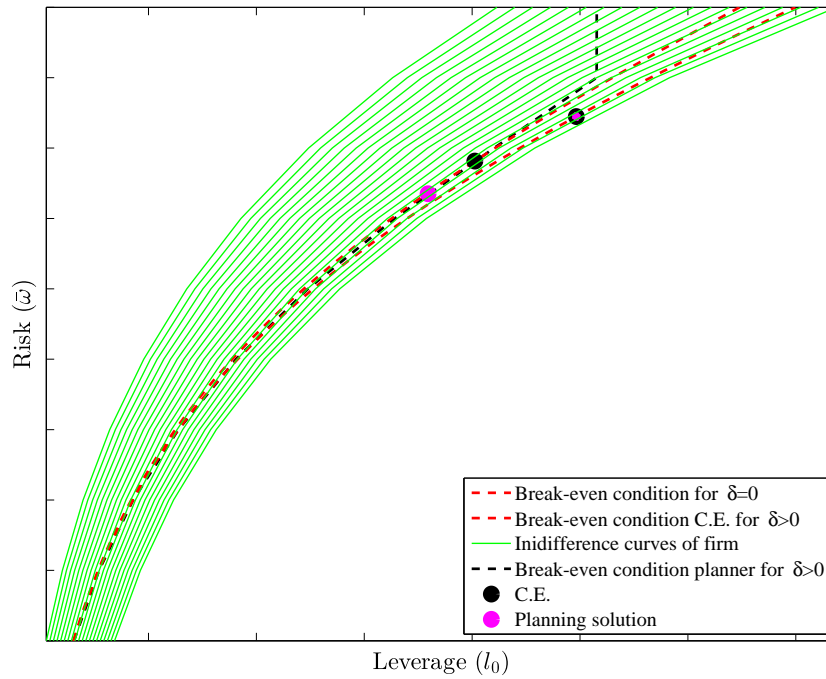
Note:  $\delta$  take values in  $\{0, 0.1, \dots, 0.5\}$ . See section 3.3.

Figure 6: Bond Premia Decomposition



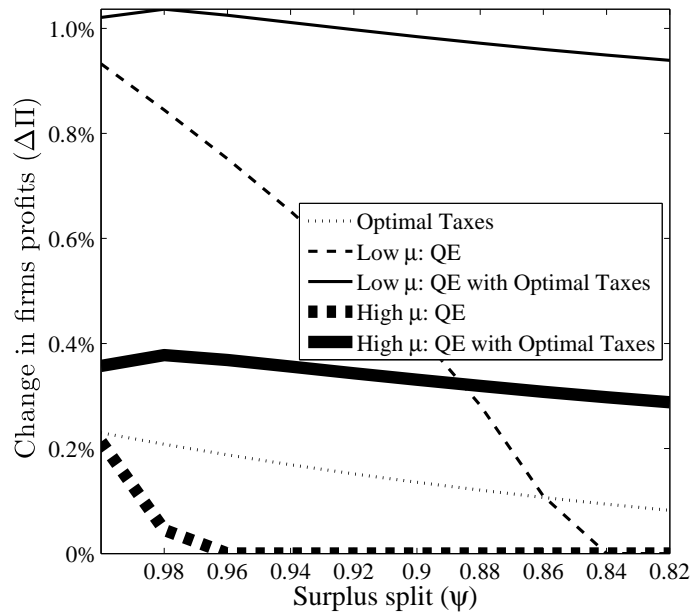
Note: For details see section 3.3.

Figure 7: Constrained Efficient Equilibrium



Note: For details see section 4.2.

Figure 8: Effect of Quantitative Easing



Note: For details see section 5.4.