

FINANCIAL STABILITY REGULATION UNDER BORROWING AND LIQUIDITY EXTERNALITIES

Flora Lutz

Vienna Graduate School of Economics

Paul Pichler

University of Vienna

Abstract

We study financial stability regulation in an environment with pecuniary externalities and where banks face both a liability choice (between private money creation and long-term borrowing) and an asset choice (between liquid and illiquid investments). Return risk on illiquid assets gives rise to liquidity risk, because banks that learn to have low future returns find themselves unable to roll over “money-like” debt. Privately optimal borrowing and investment decisions by banks lead, in general, to socially inefficient outcomes. The nature of inefficiency depends critically on the degree to which liquidity risk is systemic: When risk is highly systemic, banks hold the socially optimal amount of liquid assets, but create an excessive amount of money and overinvest in risky assets; when risk is *not* highly systemic, banks hold too little liquidity, create insufficient private money, and underinvest in risky assets. Quantity- and price-based regulations to address the identified inefficiencies are discussed. (JEL: E44, E58, G21, G28)

1. Introduction

The 2007–2009 financial crisis has stimulated an intensive debate on the optimal design of financial stability regulation. There is a wide agreement today that the regulatory framework in place prior to the crisis failed to prevent banks and other financial institutions from issuing too much short-term debt and from overinvesting in illiquid assets, which led to an excessive maturity mismatch and massive liquidity risk in the financial system. When this risk materialized during the crisis, illiquidity in asset markets and substantial liquidity needs forced many banks to fire-sell assets to raise liquidity. Asset prices dropped significantly, which further weakened banks’ balance sheets and triggered even more asset fire sales. Central banks eventually had to inject

The editor in charge of this paper was Nicola Pavoni.

Acknowledgments: We have greatly benefitted from the comments and suggestions of three anonymous referees, the editor, and numerous colleagues, including, but not limited to, Philip Bond, Mathieu Darracq Paries, Zeno Enders, Hans Gersbach, Frank Heinemann, Markus Knell, Anton Korinek, Gernot Müller, Stefan Niemann, David Pothier, and Gerhard Sorger.

E-mail: flora.lutz@univie.ac.at (Lutz); paul.pichler@univie.ac.at (Pichler)

Journal of the European Economic Association 2021 19(2):1000–1040 DOI: 10.1093/jeea/jvaa014
© The Author(s) 2020. Published by Oxford University Press on behalf of European Economic Association. This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact journals.permissions@oup.com

huge amounts of liquidity to break this vicious circle and prevent a dramatic collapse of the global financial system.

The experience of the crisis led to calls for a fundamental redesign of bank regulation policies, including the introduction of prudential liquidity requirements. The Basel Committee on Banking Supervision soon acted on these calls and, starting in 2010, elaborated the reformed regulatory framework Basel III. The key elements of the Basel III framework are enhanced capital requirements for banks and two novel prudential liquidity requirements, the liquidity coverage ratio (LCR) and the net stable funding ratio (NSFR).¹ These two liquidity requirements provide rules governing both banks' debt structures and holdings of liquid assets, reflecting that liquidity problems can originate from banks' liability choices (e.g. when banks issue too much short-term debt and expose themselves to rollover risk) and from banks' asset choices (e.g. when banks hold too little liquid assets and face difficulties raising cash to cover liquidity needs).

The crisis has also spurred academic research on the optimal design of financial stability regulation. Several contributions have recently shown that, in environments with fire-sale externalities, unregulated banks overborrow and overinvest in risky assets relative to the social optimum, and that this inefficiency renders the economy prone to excessively severe crises (see e.g. Lorenzoni 2008; Gersbach and Rochet 2012; Stein 2012; Davila and Korinek 2018). These findings provide a rationale for macroprudential financial regulation policies such as Pigouvian taxes on borrowing or bank capital requirements. However, as emphasized by Allen and Gale (2017), there is still no wide agreement on the rationale for prudential liquidity requirements, as the literature on optimal liquidity regulation is still very limited.²

In this paper, we revisit the rationale for and optimal design of liquidity regulation in an environment where banks face *both* a nontrivial liability choice and a nontrivial asset choice. Banks raise resources by issuing short-term "money-like" debt and long-term debt, and they invest in productive illiquid assets and nonremunerated liquid assets. Short-term debt provides a cheap source of financing, but must be entirely risk-free from the creditors' perspective and hence fully collateralized by the value of the bank's assets in the worst state of the world on the date of maturity. Lenders are unwilling to roll over a bank's short-term debt when they learn that this bank is hit by an adverse asset return shock.³ In this case, the bank must draw on its liquid assets and sell illiquid assets to raise resources. Due to cash-in-the-market pricing, the market for illiquid assets may only clear at fire-sale prices. A lower equilibrium market price of fire-sold assets reduces the collateral value of banks' illiquid assets

1. See BIS (2017) for further details on Basel III reforms.

2. Two important recent contributions, which both examine liquidity regulation in environments with fire-sale externalities, are Stein (2012) and Kara and Ozsoy (2019), respectively. We discuss these contributions in detail in the next section.

3. When hit by an adverse shock, a bank learns that it will have a low (and potentially zero) future return on its illiquid investments, and hence it is no longer able to provide riskless collateral to secure short-term debt.

and thus impairs their ability to finance investment cheaply through money creation; this increases ex-ante borrowing costs and depresses banks' productive investments in illiquid assets, which leads to aggregate output and welfare losses. Individual atomistic banks do not account for the effect of their decisions on the fire-sale price, and thus do not internalize the full social costs of their short-term borrowing decisions as well as the full social benefits of their liquidity holdings. Due to these *borrowing* and *liquidity externalities*, banks' liability and asset choices are, in general, socially inefficient.

In contrast to most of the literature, we assume that asset return risk is not necessarily fully systemic: Only a (potentially large) group of banks is adversely affected in the bad state of the world. This assumption is well justified on empirical grounds,⁴ and it is critical in our setting (where liquidity needs arise from banks' inability to roll over short-term debt) to generate a role for liquid assets and their regulation. When adverse shocks hit all banks equally, the only motive for an individual bank to hold liquid assets is to reduce its own asset fire sales during crises. Yet, the same effect can be achieved by reducing short-term borrowing while not investing in liquid assets, which is more cost-effective as the zero net return on liquid assets is strictly dominated by the positive cost of short-term borrowing; thus, it is privately (and socially) optimal for banks not to hold liquid assets.⁵ When risk is not fully systemic, those banks that remain in good standing during a crisis are able to roll over their short-term debts, and at the same time can use their liquidity reserves to purchase assets sold from distressed banks at a fire-sale discount. This opportunity for banks to make windfall gains raises the expected net return on liquid assets. When the fire-sale discount is sufficiently large, the expected net return on liquid assets exceeds the banks' borrowing cost and it becomes optimal for banks to invest in liquid assets.⁶

Our paper makes two main contributions. First, we show that the nature of social inefficiencies arising in models with fire-sale externalities can depend critically on the nature of liquidity risk. In the current setting, if risk is highly systemic (a very large fraction of banks is hit simultaneously by the adverse shock in the crisis state of the world), banks create an *excessive* amount of private money and *overinvest* in illiquid assets in the unregulated equilibrium; they do not hold any liquid assets, which is, however, socially efficient. By contrast, if risk is *not* highly systemic, banks create an *insufficient* amount of private money and *underinvest* in both illiquid assets and liquid assets. Banks hold an insufficient amount of liquid assets because they do not internalize the full social benefit of their liquidity holdings. This leads to a shortage of

4. In Appendix A, we document that real-world banks differ greatly with respect to their asset portfolios, and hence are not affected equally by shocks originating in different sectors of the economy.

5. See the discussion in Stein (2012, p. 66).

6. In models where liquidity needs are not driven by short-term debt rollover problems but arise for other reasons, such as to cover investment restructuring costs, banks in general hold liquid assets also in environments with fully systemic risk; see Kara and Ozsoy (2019) for a recent example.

aggregate liquidity in the banking system, which causes an excessive fire-sale discount during crises. The low fire-sale price depresses the collateral value of banks' illiquid assets and impairs banks' ability to create private money, which raises banks' ex-ante financing costs and thereby reduces their incentive to invest in illiquid assets. Unless the social costs of fire sales are low because the cash in the market provided by investors outside the banking system is large, this effect is so strong that unregulated banks end up creating an *inefficiently low* amount of money and *underinvest* in illiquid assets.⁷

Our second main contribution is to characterize the optimal financial regulation policies to address the identified inefficiencies. If risk is highly systemic, the financial regulator should curb excessive money creation and investment using, for example, a Pigouvian tax on short-term debt. Quantity-based liquidity requirements are not appropriate, because it is socially efficient for banks not to hold liquid assets. By contrast, if risk is not highly systemic, the optimal regulatory policy is to impose such liquidity requirements to ensure sufficient market liquidity in the banking system. The optimal size of the requirement depends on how systemic liquidity risk is, that is, how many banks are simultaneously adversely affected by the crisis shock. In the current setting, a correctly specified liquidity requirement for banks is sufficient to implement the (constrained) efficient allocation.

An alternative way to achieve constrained efficiency is through a Pigouvian tax on short-term debt combined with a subsidy on liquid assets. Compared to the quantity-based approach, however, the price-based approach has two important drawbacks. First, it generates financial costs for the regulator, as subsidies on liquid assets would have to be larger than tax revenues. Second, price-based regulatory policy requires more information about the underlying economic environment than quantity-based regulation.

2. Related Literature

The two contributions most closely related to our work are Stein (2012) and Kara and Ozsoy (2019), respectively. Stein (2012) studies financial stability regulation in a model where banks face a liability choice between short-term “money-like” debt and long-term debt to finance investment into an illiquid asset. Liquidity risk emerges because banks are unable to roll over “money-like” debt in a financial crisis state of the world, forcing them to fire-sell assets to raise the resources necessary to repay short-term creditors. The crisis shock affects all banks equally, which makes it privately (and socially) optimal for banks not to invest in liquid assets. Unregulated banks expose themselves to excessive liquidity risk by issuing too much short-term debt and overinvesting in illiquid assets; a macroprudential policy-maker can improve

7. This channel, through which market liquidity shortages in the banking sector depress private money creation and investment, has received little attention so far in the literature.

welfare by regulating the liability side of banks' balance sheets, for example, through outright caps on money creation or a Pigouvian tax. Relative to Stein (2012), our paper shows that allowing liquidity risk to affect only a fraction of banks rather than all banks equally produces a nontrivial asset choice for banks between liquid and illiquid investments, and that the interaction of this asset choice with banks' liability choice can fundamentally change the nature of social inefficiencies arising in the competitive equilibrium. In particular, it can lead to *insufficient* rather than excessive money creation, as well as *underinvestment* rather than overinvestment in illiquid assets.

The latter finding also contrasts with Kara and Ozsoy (2019), who argue that unregulated banks overinvest in illiquid assets (and underinvest in liquid assets) in an environment with fire-sale externalities, and where banks finance investments through a fixed endowment of capital and deposit creation.⁸ Optimal regulation in Kara and Ozsoy (2019) imposes both capital and liquidity requirements on banks, to reduce the adverse effects of fire sales, but it is never socially optimal to fully prevent fire sales altogether.⁹ By contrast, our analysis shows that full insurance against fire sales can indeed be socially optimal. This is because even small amounts of fire sales can have large marginal (social) costs in our setting, as they impair banks' ability to borrow cheaply through money creation and hence raise banks' financing costs in the initial period. To reduce financing costs and stimulate investment, the social planner may find it optimal to fully prevent fire sales (depending on the parameters of the economic environment).

Our paper is also closely related to other recent contributions that advocate macroprudential liquidity regulation. Farhi, Golosov, and Tsyvinski (2009) show that a financial regulator can improve upon the unregulated competitive equilibrium by imposing a constraint on the portfolio share that financial intermediaries invest in short-term assets in a Diamond–Dybvig model with unobservable liquidity shocks and unobservable trades. Bianchi (2011) shows that reserve requirements implement constrained-efficient allocations in an open-economy business cycle model with credit constraints. Perotti and Suarez (2011) advocate price-based and quantity-based liquidity regulations in a model where banks differ with respect to credit opportunities and gambling incentives. Calomiris, Heider, and Hoerova (2015) develop a theory of cash reserve requirements, where greater cash holdings incentivize prudent behavior by banks and improve banks' management of portfolio risk. Diamond and Kashyap (2016) show that regulation similar to the LCR and the NSFR can reduce the probability of bank runs in environments where banks are not automatically incentivized to always

8. Deposits are not subject to rollover risk, but banks need liquidity in a financial crisis state of the world because illiquid investments require additional funds to remain productive.

9. In Kara and Ozsoy (2019), the social costs of small amounts of fire sales are moderate under their maintained assumptions on the technology operated by outside investors. At the same time, banks face a convex operational cost that increases with the size of their balance sheet; holding an extra unit of liquid assets thus becomes increasingly costly. As a consequence, full insurance against fire sales is not socially optimal; see Kara and Ozsoy (2019, p. 15).

hold enough liquid assets to survive runs. Our paper complements these contributions by pointing out that the optimal design of liquidity regulation policies may depend critically on how systemic liquidity risk is.

More generally, our paper connects to the large literature that studies macroprudential policy as a means to address social inefficiencies arising in environments with fire-sale externalities.¹⁰ A common finding in this literature is that a macroprudential regulator should impose a Pigouvian tax on debt issuance or outright caps on borrowing, to make agents internalize the social losses associated with excessive borrowing. This policy prescription carries over to our model environment as long as crisis risk is highly systemic, but is no longer true when crisis risk is not highly systemic. In this case, the best way for the regulator to implement a constrained-efficient outcome is by imposing liquidity requirements on banks.

Finally, the feature that liquidity risk does not affect all banks symmetrically connects our paper to the literature on banks' asset choice in the presence of fire-sale externalities.¹¹ A key finding of this literature is that whether banks hold too little or too much liquidity depends on their rationale for holding liquid assets. When banks hold liquidity for precautionary reasons, they are typically found to invest too little in liquid assets, which causes excessive fire-sale losses during crises. When banks hold liquidity for strategic reasons, that is, to make windfall gains when other banks are in distress, they may overinvest in liquid assets. Our paper provides a joint analysis of banks' asset *and* liability choices in an environment where banks hold liquidity for both precautionary and strategic reasons. We find that banks in such an environment hold too little liquid assets and that the shortage of aggregate liquidity not only provokes excessive fire-sale losses, but also distorts banks' liability choice between secured and unsecured debt.

3. The Model

We develop a model economy, building on Stein (2012), where agents live for three time periods, $t = 0, 1, 2$. There are four types of agents: households, banks, investors, and international lenders. Households consume a single perishable consumption good, which also serves as a numeraire, and there are two states of the world, $\theta \in \{g, b\}$, which can be interpreted as a good state and a bad state. In what follows, we often refer to the bad state realization as a *financial crisis*.

10. Important contributions to this literature include, but are not limited to, Caballero and Krishnamurthy (2003), Lorenzoni (2008), Stein (2012), Gersbach and Rochet (2012), Benigno et al. (2013), Jeanne and Korinek (2013), Ahnert and Perotti (2015), Gale and Gottardi (2015), He and Kondor (2016), Segura and Suarez (2017), and Korinek (2018).

11. See Bhattacharya and Gale (1987), Caballero and Krishnamurthy (2001, 2004), Allen and Gale (2004a, 2004b), Gorton and Huang (2004), Brunnermeier and Pedersen (2009), Diamond and Rajan (2011), Gale and Yorulmazer (2013, 2017), and Malherbe (2014), among others.

3.1. Households

Households are endowed with X goods in period 0. They derive utility from consumption in periods 0 and 2,

$$U = C_0 + \beta \mathbb{E}C_2(\theta), \quad (1)$$

where C_0 denotes period-0 consumption, $C_2(\theta)$ denotes period-2 consumption in state θ , and β denotes the households' time discount factor.¹² Consumption in the interim period 1 does not generate any utility. It is best to think of period 1 not as a full-fledged time period, but rather an interim stage (right before the start of period 2) where the state of the world prevailing in period 2 is revealed and agents can trade in asset markets.

In period 0, households consume and save by purchasing long-term (maturing at time 2) bonds issued by banks. Denoting bond holdings by \tilde{B} , the period 0 budget constraint reads

$$C_0 + \tilde{B} \leq X. \quad (2)$$

In period 2, households receive income from their ownership of banks, $\Pi^B(\theta)$, as well as from investors, $\Pi^I(\theta)$, who transfer their earnings to the household sector at the end of the period. Denoting by $\tilde{R}^b(\theta)$ the return on risky long-term bonds in state θ , the budget constraint in period 2 reads

$$C_2(\theta) \leq \tilde{R}^b(\theta)\tilde{B} + \Pi^B(\theta) + \Pi^I(\theta). \quad (3)$$

Households take $\{X, \tilde{R}^b(\theta), \Pi^B(\theta), \Pi^I(\theta)\}$ as given and choose $\{\tilde{B}, C_0, C_2(\theta)\}$ such as to maximize (1) subject to (2)–(3). It is immediate that households will find it optimal to purchase long-term bonds as long as the expected return compensates them for postponing consumption,

$$\mathbb{E}\tilde{R}^b(\theta) \equiv R^b = \frac{1}{\beta}.$$

3.2. Banks

Our modelling of banks builds on the framework developed in Stein (2012). There exists a continuum $[0, 1]$ of banks, each of which has access to a bank-specific investment project with variable scale I . A project of scale I requires an input of I consumption goods in period 0 and delivers a stochastic output in period 2; it cannot be terminated in the interim period 1. As in Gersbach and Rochet (2012), one can think of bank projects as banks lending to households or entrepreneurs operating in the “banking sector” of the economy, who need to be monitored and therefore cannot be directly financed by

12. Note that we abstract from the *convenience yield* of money emphasized by Stein (2012). As will become clear shortly, money-like debt issued by banks in our model will be held by foreign lenders rather than domestic households.

agents other than banks. Finally, banks can also invest in safe liquid assets, L , that yield zero net return. These assets can be best thought of as storage or nonremunerated reserve holdings with a central bank.¹³

In period 1, the state of the world is revealed. If the state is *good*, which happens with probability $1 - p$, the projects of *all* banks will have a high return $f(I)$ in period 2, where I is the investment scale and f is a concave function.¹⁴ By contrast, if the state of the world is *bad*, which happens with probability p , then the projects of $q \in (0, 1]$ banks will have a low return, whereas $1 - q$ banks will still have a high return $f(I)$. Whether an individual bank falls into the first or second category is determined by an idiosyncratic shock, which is i.i.d. across banks and publicly observed together with the state of the world. Accordingly, an individual bank's risk of experiencing a low return is equal to $\pi = p \cdot q$.¹⁵ In period 1, the expected period-2 output of low-return projects is equal to λI , where $\lambda \in (0, 1]$, and with a small probability this output may drop all the way to zero in period 2.¹⁶ We refer to banks with high-return projects as *sound* banks and to banks with low-return projects as *distressed* banks.

Banks have no initial endowment but must raise all funds externally.¹⁷ They can do so by issuing risky long-term bonds, B , and selling these bonds to domestic households. Due to the inherent risk, it is best to think of these bonds as subordinated debt or conditional convertible bonds issued by banks. Moreover, banks can issue entirely riskless short-term bonds, M , and sell these to international lenders. Due to their "money-like" characteristics, we refer to entirely riskless short-term bonds as "private money" created by banks. As will become clear shortly (see Section 3.4), private money has a lower expected rate of return R^m in equilibrium than risky bonds, that is, $R^m < R^b$. By creating private money, banks can thus access a cheap source of financing.

The banks' balance sheet is visualized in Figure 1. Note that banks can choose the size of their balance sheet, as well as the composition of both the asset and the liability sides. However, they cannot create private money without bounds, because banks can make short-term debt issued in period 0 entirely riskless only as long as they can pay out short-term creditors in full even when distressed in period 1. This limits

13. Banks cannot rent out their liquidity holdings in period 2 to investors. This assumption is not critical but helps to sharpen the analysis, because the return on liquidity is pinned down at zero in the good state of the world.

14. We assume that f satisfies the standard properties $f(0) = 0$ and $f'(0) = \infty$. Moreover, we assume that $f'(I)$ is not too close to zero as long as $f(I) > 1$. The latter assumption ensures that the level of investment does not react excessively to small changes in the return. We will come back to this assumption later (cf. the proof of Proposition 3).

15. In the following, we treat π and q as primitive parameters, whereas p is determined as $p = \pi/q$.

16. A low-return project's period 2 return is $\lambda I/(1 - \varepsilon)$ with probability $1 - \varepsilon$ and 0 with probability ε , where we assume that ε is sufficiently small such that $\lambda I/(1 - \varepsilon) < I$; whether the output of failed projects collapses to zero or not is observed only in period 2. This assumption simplifies the analysis, because it implies that long-term debt issued by banks can never be made entirely riskless (cf. Stein 2012).

17. Our results do not depend on this assumption, but are robust to environments where banks are endowed with an initial stock of equity; see Online Appendix F.

Assets	Liabilities
I	B
L	M

FIGURE 1. Bank balance sheet.

the potential amount of money creation to

$$M \leq \frac{k\lambda I + L}{R^m}, \quad (4)$$

where k is the market price of a share in the bank project delivering in expectation one consumption good in period 2.

The collateral constraint (4) reflects that distressed banks can raise resources only by drawing on their own liquid assets and by selling risky project shares to other banks and investors. They cannot roll over their existing short-term “money-like” debt when the “financial crisis” state of the world is revealed in period 1, because they no longer have access to entirely riskless collateral. Moreover, they cannot issue new risky debt, which can easily be justified by assuming that any new funding must be subordinated to existing long-term debt.

Sound banks, who still have access to entirely riskless collateral, can roll over their existing money-like debt from period 1 to period 2 at a zero net interest rate. As will become clear shortly, this is because international lenders have no alternative uses of their funds in the interim period.¹⁸ However, they also cannot raise any additional fresh funds externally in the “financial crisis” state of the world.¹⁹ This assumption helps to greatly simplify the analysis, but is starker than necessary. What is important is that sound banks cannot fully pledge their period-2 returns to international lenders, so that their period-1 activities are constrained by their own liquid resources (cf. Acharya, Shin, and Yorulmazer 2011). Sound banks stand ready to purchase distressed assets as long as their expected net return exceeds the zero net return on liquid assets, that is, as long as $k \leq 1$.

3.3. Investors

Investors outside the banking sector are endowed with W units of the consumption good in period 1.²⁰ They have access to an investment technology that, for a period-1

18. Note also that the net interest rate is zero because there is no discounting between these periods, as we interpret period 1 as an interim stage right before period 2.

19. A possible microfoundation of this friction is to assume that it takes more time (for matching borrowers and lenders, screening activities, legal consultation, etc.) to set up a new financial contract than to extend an existing contract for one period. Under this assumption, it is impossible to write new borrowing contracts in the short interim stage, whereas rolling over existing short-term debt contracts is feasible.

20. For simplicity, we treat the endowment as exogenous in the following analysis. In Online Appendix D, we discuss a model extension where investors endogenously choose W by borrowing from households in period zero and show that our results are robust to this alternative specification.

investment of size K , yields a gross output of $y(K) > K$ consumption goods in period 2, where $y(\cdot)$ is a concave function satisfying $y'(W) \geq 1$. In line with Gersbach and Rochet (2012), we think of this technology as investors lending to perfectly competitive entrepreneurs operating in the “traditional sector” of the economy, who do not need to be monitored and therefore can be directly financed.

Investors can alternatively use their resources in period 1 to purchase shares in bank projects at the price k . The gross profit of an investor who spends Z on shares in bank projects is given by

$$\Pi^I = y(W - Z) + \frac{1}{k}Z. \quad (5)$$

It is immediate that profit-maximizing investors are willing to purchase shares in bank projects only if both their investment opportunities yield the same marginal return. In particular, if investors purchase a total quantity $Z > 0$ of bank projects, the fire-sale price k has to satisfy

$$\frac{1}{k} = y'(W - Z). \quad (6)$$

The more the bank assets absorbed by investors are, the lower the fire-sale price is, and hence the higher the losses incurred by distressed banks are. Moreover, because investors have scarce resources W , their financial investment (i.e. purchases of bank assets) crowds out productive investment in the traditional sector. This depresses the total amount of goods available for consumption in the economy, because $y(W - Z) + Z < y(W)$ when $Z > 0$ due to our assumption that $y'(W) \geq 1$. Fire-sales thus do not only redistribute income from banks to investors, but also induce real costs.

For analytical convenience and to sharpen the discussion, we will assume that the production technology y is of a Cobb–Douglas type, $y(K) = AK^\alpha$, where $A > 0$ and $\alpha \in (0, 1)$. However, as we show in Online Appendix E, our results do not hinge on this specific functional form for $y(\cdot)$, but are robust to alternative specifications.

3.4. International Lenders

International lenders discount the future with the factor $\delta > \beta$. They have deep pockets and lend to the domestic economy by purchasing entirely riskless (collateralized) debt issued by domestic banks.²¹ Accordingly, international lenders have a perfectly elastic demand for riskless short-term “money-like” bonds in period 0 at the interest rate $R^m = 1/\delta$. In the interim period 1, international lenders have no alternative uses of their funds and are thus willing to roll over their bond holdings at a zero interest rate if

21. One can think of these lenders as international banks, who give secured short-term loans to domestic banks on the international interbank market.

the bank still has access to entirely riskless collateral (which is true only for sound banks).²²

3.5. The Banks' Optimization Problem

Individual banks take prices R^b , R^m , and k as given. They choose investment in risky illiquid assets, I , long-term borrowing, B , money creation, M , and liquidity holdings, L , to maximize profits, subject to the balance sheet constraint

$$I + L \leq M + B \quad (7)$$

and the collateral constraint (4). A bank's ex-ante expected profit is given by

$$\begin{aligned} \mathbb{E}\Pi^B(\theta) = & \left(1 - \frac{\pi}{q}\right) \left\{ f(I) - R^m M - \tilde{R}^b(g)B + L \right\} \\ & + \frac{\pi}{q}(1 - q) \left\{ f(I) - R^m M - \tilde{R}^b(b)B + L + \left(\frac{1}{k} - 1\right)L \right\} \\ & + \pi \left\{ \lambda I - R^m M - \tilde{R}^b(b)B + L - \left(\frac{1}{k} - 1\right)(R^m M - L) \right\}, \quad (8) \end{aligned}$$

where we have used $p = \pi/q$ to eliminate the parameter p . The first term in curly brackets gives the bank's profit in the good state of the world. The second term denotes the profit in the bad state of the world, but when the bank's own project is of a high-return type. Compared to the good state, the bank makes an additional profit $(1/k - 1)L$ by using its liquid assets to purchase distressed assets at a discount.²³ Finally, the third term denotes the profit in the bad state of the world and when the bank's own project is of a low-return type. In this scenario, the bank incurs fire-sale losses amounting to $(1/k - 1)(R^m M - L)$.

Using $B = I + L - M$, the Lagrangian function for the bank's problem is given by

$$\begin{aligned} \mathcal{L}^B = & f(I) - R^m M - R^b(I + L - M) + L \\ & + \frac{\pi}{q} \left\{ (1 - q) \left(\frac{1}{k} - 1\right)L + q \left\{ \lambda I - f(I) - \left(\frac{1}{k} - 1\right)(R^m M - L) \right\} \right\} \\ & - \eta \left\{ \frac{R^m M - L}{k} - \lambda I \right\}, \end{aligned}$$

22. That money-like debt is held by international lenders rather than domestic households is different from Stein (2012), where households are willing to hold both money-like debt and risky debt because holding money yields a *convenience yield*, which compensates for its lower return. We adopt the current formulation mainly for simplicity.

23. Note that as long as $1/k > 1$, a sound bank will always use its entire liquid assets L to purchase shares in distressed banks' projects. When $1/k = 1$ a sound bank is indifferent between purchasing project shares or keeping its liquid assets. In both cases, the profit to the bank equals $(1/k - 1)L$.

where $\eta \geq 0$ denotes a Lagrangian multiplier. The first-order condition with respect to investment, I , yields

$$R^b = f'(I)(1 - \pi) + \pi\lambda + \eta\lambda. \quad (9)$$

The right-hand side of this expression gives the expected marginal benefit of an increase in investment, whereby the term $\eta\lambda$ reflects that an increase in I relaxes the collateral constraint.²⁴ The first-order condition with respect to short-term borrowing, M , yields

$$\frac{R^b - R^m}{R^m} \leq \pi \left(\frac{1}{k} - 1 \right) + \frac{\eta}{k}, \quad (10)$$

which has to hold with equality if $M > 0$. The left-hand side gives the marginal benefit of money creation relative to long-term financing of investment, whereas the right-hand side gives the marginal cost (resulting from higher fire-sale losses when distressed and a tighter collateral constraint). The first-order condition with respect to liquid assets, L , yields

$$R^b - 1 \geq \frac{\pi}{q} \left(\frac{1}{k} - 1 \right) + \frac{\eta}{k}, \quad (11)$$

which has to hold with equality if $L > 0$. The left-hand side gives the marginal opportunity cost of holding an additional unit of liquidity, whereas the right-hand side gives the marginal benefit. Finally, the following complementary slackness condition has to hold:

$$0 = \eta \left\{ \frac{R^m M - L}{k} - \lambda I \right\}. \quad (12)$$

It is important to emphasize that an individual bank does not take into account its incremental impact on the fire-sale price k , which in equilibrium will be determined by the aggregate asset sales in the banking system and the aggregate amount of resources available to absorb fire-sold assets. This generates a pecuniary externality, which manifests itself in two ways. On one hand, each bank does not internalize that its money creation imposes a *negative externality* on others: Given L , a higher level of M increases the quantity of assets the bank must fire-sell when distressed, $R^m M - L$, which has a negative effect on the fire-sale price k . On the other hand, each bank does also not internalize that higher liquid assets L impose a *positive externality*. First, a higher level of liquidity L reduces the quantity of assets the bank must fire-sell when distressed, $R^m M - L$, which has a positive effect on the fire-sale price. And, second, independent of the bank's choice of M , a higher level of liquidity L implies that, if in a crisis the bank remains sound, it can purchase more assets from distressed banks, which has a further positive effect on the fire-sale price. This latter effect is present only in environments where liquidity risk is not purely systemic, and hence distressed

24. Note that our assumptions on f guarantee that banks will choose $I > 0$ and that the banks' optimization problem is well defined and has an interior solution.

bank assets are in part absorbed by sound banks rather than investors who require a fire-sale discount.

4. The Unregulated Competitive Equilibrium

We now examine the unregulated equilibrium where households, banks, investors, and international lenders maximize their individual objectives, while being unaware of their incremental influence on prices and aggregate outcomes.

Denote by M^* and L^* a bank's equilibrium choices for money creation and liquidity holdings, respectively. Recall that in the good state of the world, there are no sales of bank assets and investors use their entire resources for productive investment, yielding $y(W) = AW^\alpha$. In the bad state of the world, however, fire sales may occur depending on the banks' choices for M^* and L^* . If $M^* > 0$, then distressed banks together must raise an aggregate amount of $q(R^m M^* - L^*)$ resources to honor their promises in period 1. They can raise $(1 - q)L^*$ from sound banks, who will be the first to purchase distressed assets (because liquid assets have a zero net return between periods 1 and 2). If sound banks have sufficient liquid assets to absorb all assets sold by distressed banks, the equilibrium price of these assets will be equal to their fundamental value, $k^* = 1$. If, however, sound banks run out of liquidity, the remaining $qR^m M^* - L^*$ assets must be absorbed by investors outside of the banking system, whose no-arbitrage condition (6) then pins down the equilibrium fire-sale price,

$$\frac{1}{k^*} = \alpha A(W + L^* - qR^m M^*)^{\alpha-1}. \quad (13)$$

Fire sales thus occur when M^* is large relative to L^* , so that outside investors must come in as buyers of distressed assets in crisis times. Moreover, for any given amount of fire-sold assets, the equilibrium fire-sale discount is larger the smaller are the resources available to investors, W . The costs of fire sales are thus high in environments where W is low.

Inspecting the banks' optimality condition for money creation (10), it is immediate that unregulated banks always issue a strictly positive quantity of private money in equilibrium, $M^* > 0$. To understand the underlying intuition, assume that $M^* = 0$ would hold. Then the collateral constraint (4) would necessarily be nonbinding, and there would be no fire sales in the "financial crisis" state of the world (such that $k^* = 1$). Accordingly, the marginal cost of money creation relative to long-term financing of investment would be zero, whereas the marginal benefit would be strictly positive, because $R^b - R^m > 0$. Every individual bank would have an incentive to issue money, and hence $M^* = 0$ cannot hold in the unregulated equilibrium.

Regarding banks' choice of liquidity, we arrive at the following result.

PROPOSITION 1. *In the unregulated competitive equilibrium, banks hold liquid assets, $L^* > 0$, only if crises are not highly systemic,*

$$q < \frac{R^b - R^m}{(R^b - 1)R^m} \equiv \bar{q}, \quad (14)$$

and fire sales are sufficiently costly,

$$\begin{aligned} W < (\alpha A)^{\frac{1}{1-\alpha}} & \left(\frac{(1-q)\pi R^m}{(1-q)\pi R^m + qR^b(R^m - 1)} \right)^{\frac{1}{1-\alpha}} \\ & + q\lambda \left(\frac{(1-q)\pi R^m}{(1-q)\pi R^m + qR^b(R^m - 1)} \right) \\ & \times (f')^{-1} \left(\frac{R^b - \lambda \frac{(1-q)\pi R^m (R^b - 1) - \pi R^b (R^m - 1)}{(1-q)\pi R^m + qR^b (R^m - 1)} - \pi\lambda}{1 - \pi} \right) \equiv \bar{W}. \quad (15) \end{aligned}$$

To understand the conditions for $L^* > 0$, note that unregulated banks hold liquidity if and only if the expected return exceeds their opportunity cost of funds R^m . The expected return depends critically on how systemic liquidity risk is, as reflected by q . When q is small, that is, risk is not very systemic, the probability that an individual bank remains sound during a crisis is high; being able to roll over short-term debt, a sound bank can use its liquidity reserves profitably to purchase distressed assets at a fire-sale discount. Moreover, as we have outlined previously, the parameter W is a key determinant of the size of the fire-sale discount; when W is small, the discount is large. The expected return on liquid assets is thus high when both q and W are small, as reflected by the thresholds in (14) and (15).

We now explore whether liquidity holdings are ever sufficiently large to absorb all fire-sold assets within the banking system during crises, and hence to prevent fire-sale losses for distressed banks altogether. Our findings are summarized in the following proposition.

PROPOSITION 2. *In the unregulated competitive equilibrium, banks never hold sufficient liquid assets to absorb all fire-sold assets within the banking system, that is, $L^* < qR^m M^*$. In crisis times, fire-sold bank assets are thus in part absorbed by investors outside the banking system, which crowds out investment in the traditional sector and leads to output losses.*

The intuition behind this result is similar to the intuition underlying $M^* > 0$. If liquid assets were sufficient to absorb all fire-sold assets within the banking system, the equilibrium price of distressed bank projects would be equal to $k^* = 1$. Every individual bank would then have an incentive to increase money creation or reduce liquidity holdings, leading to $qR^m M^* > L^*$. In the *financial crisis* state of the world, investors outside the banking sector thus need to come in as buyers of distressed assets, but they are willing to purchase these assets only at a discount. Distressed

banks therefore incur fire-sale losses. Moreover, purchases of bank assets crowd out productive investment in the traditional sector, which depresses aggregate output.

We finally explore whether banks create a large enough amount of private money so that their collateral constraint is binding in the unregulated competitive equilibrium. To this end, note first that when the collateral constraint is nonbinding, the banks' optimality conditions (10) and (11) boil down to

$$R^b - R^m = \pi \left(\frac{1}{k^*} - 1 \right) R^m \leq q(R^b - 1)R^m. \tag{16}$$

It is immediate that these conditions cannot hold when $q < \bar{q}$, implying that the collateral constraint is always binding in equilibrium when crises are not highly systemic. When crises *are* highly systemic, $q \geq \bar{q}$, condition (16) holds only if the equilibrium fire-sale discount is very large, $1/k^* - 1 = (R^b - R^m)/(\pi R^m)$. This is consistent with equilibrium only if the investors' resources W are very scarce, as established by the following lemma:

LEMMA 1. *When $q < \bar{q}$, the banks' collateral constraint is always binding in the unregulated equilibrium. When $q \geq \bar{q}$, the banks' collateral constraint is binding in the unregulated equilibrium if*

$$W > (\alpha A)^{\frac{1}{1-\alpha}} \left(\frac{\pi R^m}{\pi R^m + R^b - R^m} \right)^{\frac{1}{1-\alpha}} + q\lambda \left(\frac{\pi R^m}{\pi R^m + R^b - R^m} \right) (f')^{-1} \left(\frac{R^b - \pi\lambda}{1 - \pi} \right) \equiv \underline{W},$$

and it is nonbinding if $W \leq \underline{W}$.

5. The Constrained-Efficient Allocation

We next examine the equilibrium allocation that would be chosen by a benevolent planner who instructs banks on their initial liability and asset choices, $\{B, M, I, L\}$, while anticipating the equilibrium response of households, investors, and international lenders. The planner maximizes social welfare, which, because all income earned by banks and investors eventually accrues to the household sector, is given by the discounted sum of expected household consumption. In period 0, households are endowed with X consumption goods and lend a total amount \tilde{B} to banks, such that $C_0 = X - \tilde{B}$. In period 2, households consume the returns generated in the banking sector and the traditional sector, less the repayment of international lenders. If the good state prevails, total consumption is hence given by

$$C_2(g) = f(I) + L - R^m M + y(W),$$

whereas, if the bad state prevails,

$$C_2(b) = (1 - q)f(I) + q\lambda I + L - R^m M + y(W + L - qR^m M) + qR^m M - L.$$

Using the market clearing condition $\tilde{B} = B$, social welfare can thus be expressed as

$$\begin{aligned}
 U = & X - B + \beta \frac{\pi}{q} \{f(I) + L + y(W) - R^m M\} \\
 & + \beta \left(1 - \frac{\pi}{q}\right) \{(1 - q)f(I) + q\lambda I + y(W + L - qR^m M) - (1 - q)R^m M\},
 \end{aligned} \tag{17}$$

which depends only on the banks' choice variables $\{B, M, I, L\}$ together with the exogenous parameters and functions $\{X, W, \beta, \pi, q, R^m, \lambda, f, y\}$.

In line with the related literature, we assume that the planner is subject to the same collateral constraint (4) that private banks face when borrowing from international lenders; unlike these banks, however, he realizes that the price k depends on the quantity of bank assets that must be absorbed by investors in the bad state. The planner must further respect the market clearing condition (7) and the technological constraint that idle liquid assets by banks cannot be invested in the technology $y(\cdot)$, which in our economy is equivalent to $qR^m M - L \geq 0$. Finally, he takes the borrowing rate charged by international lenders, R^m , as given.

The planner instructs banks on their choices for $\{B, M, I, L\}$ such as to maximize (17), subject to $qR^m M - L \geq 0$, the collateral constraint (4), the balance sheet constraint (7), and the pricing equation

$$k = \mathcal{K}(W + L - qR^m M) = \begin{cases} \frac{1}{y'(W+L-qR^m M)} & \text{if } qR^m M > L, \\ 1 & \text{if } qR^m M = L. \end{cases} \tag{18}$$

Using the balance sheet constraint $B + M = I + L$ to eliminate the choice variable B , the planner's problem boils down to instructing banks on their choices for $\{I, M, L\}$ such as to maximize the Lagrangian function

$$\begin{aligned}
 \mathcal{L}^P = & \frac{1}{\beta}(X - I - L + M) + f(I) + y(W) - R^m M + L \\
 & + \frac{\pi}{q} \{q(\lambda I - f(I)) + y(W + L - qR^m M) - y(W) + qR^m M - L\} \\
 & - \eta \left\{ \frac{R^m M - L}{\mathcal{K}(W + L - qR^m M)} - \lambda I \right\} - \gamma(L - qR^m M),
 \end{aligned} \tag{19}$$

where $\eta \geq 0$ and $\gamma \geq 0$ denote Lagrangian multipliers. The first-order conditions for $\{I, M, L\}$ are given byf

$$R^b = f'(I)(1 - \pi) + \pi\lambda + \eta\lambda, \tag{20}$$

$$\begin{aligned}
 \frac{R^b - R^m}{R^m} \leq & \pi (y'(W + L - qR^m M) - 1) \\
 & + \frac{\eta}{k} \left\{ 1 + q(R^m M - L) \frac{\mathcal{K}'(\cdot)}{k} \right\} - q\gamma,
 \end{aligned} \tag{21}$$

$$R^b - 1 \geq \frac{\pi}{q} (y'(W + L - qR^m M) - 1) + \frac{\eta}{k} \left\{ 1 + (R^m M - L) \frac{\mathcal{K}'(\cdot)}{k} \right\} - \gamma, \tag{22}$$

where we have used $\pi = p \cdot q$ and $R^b = 1/\beta$ to facilitate comparison with the unregulated equilibrium. Note further that (12), (18) and the complementary slackness condition $\gamma(L - (1 - q)R^m M) = 0$ must hold in the constrained-efficient allocation.

Equations (21) and (22) are the planner’s optimality conditions for money creation, M , and liquid assets, L . These conditions reflect that the planner anticipates the effects of his choices on the fire-sale price and the crowding out of productive investment, while ignoring the purely redistributive consequences of fire sales. Note that, when evaluated at the unregulated equilibrium allocation, the terms in curly brackets in the planner’s optimality conditions for money creation and liquidity holdings are strictly larger than one.²⁵ When the collateral constraint is binding, the social costs of money creation and the social benefits of holding liquidity are thus higher than internalized by unregulated banks.

As the constrained planner takes into account that even small amounts of outstanding “money-like” debt can lead to large drops in the fire-sale price k and thus large fire-sale losses, he may prefer banks not to issue any “money-like” debt at all despite its lower interest rate. Inspection of (21) shows that this is the case only when crises are extremely likely. In particular, we have the following.

LEMMA 2. *The constrained social planner finds it optimal to have banks create a positive amount of money if*

$$\pi < \frac{R^b - R^m}{R^m(y'(W) - 1)}. \tag{23}$$

Regarding the planner’s choice of liquidity, we arrive at the following result.

PROPOSITION 3. *Assume that the parameters π , R^b , R^m , and W satisfy (23). In the constrained-efficient allocation, the planner instructs banks to hold liquidity, $L^{**} > 0$, if crises are not highly systemic, $q < \bar{q}$, and the costs of fire sales are not too low, $W < \widehat{W}$, where $\widehat{W} > \bar{W}$. The planner thus certainly instructs banks to hold liquidity in all environments where unregulated banks hold liquidity.*

The intuition behind Proposition 3 can be best understood as follows. Relative to the unregulated competitive equilibrium, the social planner seeks to curb the amount of asset fire sales during crises, $qR^m M^{**} - L^{**}$, because he internalizes that this reduces the production loss in the traditional sector and increases the fire-sale price k^{**} ; an increase in the fire-sale price, in turn, improves social welfare by raising

25. Recall that $L^* < qR^m M^*$ (which implies $\gamma = 0$), and $\mathcal{K}'(\cdot) > 0$.

the collateral value of risky assets, $\lambda I^{**} k^{**}$, thus promoting banks' access to cheap borrowing through money creation.

Assume for simplicity that the planner seeks to increase the fire-sale price by Δk and that this requires reducing asset fire sales by x euros. To achieve this, the planner can follow one of three approaches. First, he can instruct banks to borrow x additional euros of long-term debt and hold the proceeds as liquidity; the net cost of this transaction is equal to $(R^b - 1)x$. Second, he can instruct them to borrow $x/(qR^m)$ additional euros of long-term debt and reduce money creation by the same amount; this incurs a net cost equal to $x(R^b - R^m)/(qR^m)$. And, third, if risk is not overly systemic, $q < 1/R^m$, he can instruct banks to increase money creation by $x/(1 - qR^m)$ euros and hold the proceeds as liquidity, which incurs a net cost equal to $x(R^m - 1)/(1 - qR^m)$. The ranking of these three approaches in terms of their costs depends on how systemic liquidity risk is. In particular, when risk is highly systemic, $q > \bar{q}$, the cheapest way to increase the fire-sale price by Δk is to follow the second approach, that is, to borrow additional long-term debt and reduce money creation. By contrast, when risk is not highly systemic, $q < \bar{q}$, the cheapest way is to follow the third approach, that is, to increase money creation and hold the proceeds as liquidity.²⁶

This does not imply, however, that the planner always instructs banks to hold liquidity when $q < \bar{q}$. After all, the planner's three approaches to support the fire-sale price outlined previously do not only differ in their respective costs, but also in how they impact asset sales by affected banks, $R^m M^{**} - L^{**}$, and therefore in how they impact the collateral constraint beyond the effect operating through the fire-sale price. It is readily seen that, in this specific regard, the second approach of borrowing additional long-term debt and reducing money creation always outperforms the others; for a given effect on the fire-sale price, it reduces $R^m M^{**} - L^{**}$ by more than the other two approaches, and thus contributes more to relaxing the collateral constraint. This counteracts the aforementioned cost advantage of the third approach (increasing money creation and holding the proceeds as liquidity) in environments where $q < \bar{q}$. As a consequence, even in such environments, the planner finds it optimal to hold liquidity only when his motive to manipulate the fire-sale price is sufficiently strong, which is the case when investor resources are sufficiently scarce, $W < \widehat{W}$. Moreover, it is immediate that in environments where risk is highly systemic, $q \geq \bar{q}$, the planner strictly prefers to manipulate the fire-sale price through additional long-term borrowing and reducing money creation, and accordingly he chooses not to hold liquidity. Finally, note that because the planner internalizes the social benefits of holding liquidity, he values liquidity more than unregulated banks do. He thus chooses to hold liquidity at levels of W where banks find this too costly; hence, $\widehat{W} > \overline{W}$.

We next explore whether the planner ever finds it optimal to fully insure against fire-sale risk by having banks hold sufficient liquidity to absorb all distressed assets in the banking system.

26. Note that only in the special case where $q = \bar{q}$, all three approaches are equivalent in terms of costs.

PROPOSITION 4. *Assume that the parameters π , R^b , R^m , and W satisfy (23). The constrained social planner fully insures the banking system against fire-sale risk, $L^{**} = qR^m M^{**}$, if crises are not highly systemic, $q < \bar{q}$, and the costs of fire sales are sufficiently high, $W < \widehat{W}^{fi}$, where $\widehat{W}^{fi} < \widehat{W}$.*

The intuition behind this result is best understood as follows. Recall from Proposition 3 that the social planner instructs banks to hold a positive amount of liquidity when $q < \bar{q}$ and $W < \widehat{W}$, that is, the first-order condition (22) holds as an equality. The optimal choice of L^{**} thus equates the marginal opportunity cost $R^b - 1$ of holding more liquidity to the marginal benefit resulting from reduced asset fire sales, $qR^m M - L$. Lower asset fire sales are beneficial because they reduce the output loss in the traditional sector in the bad state of the world, and because a higher fire-sale price raises the collateral value of illiquid assets, which, in turn, improves banks' access to cheap short-term borrowing in the initial period and thus stimulates productive investment. Inspecting (22) it is immediate that, for any quantity of asset fire sales $x = qR^m M - L > 0$, the marginal benefit of an increase in L is larger the smaller are the resources available to outside investors, W .²⁷ The marginal cost of reducing asset fire sales, in turn, is independent of W . Accordingly, there exists a critical threshold level for investor resources, which we denote by \widehat{W}^{fi} , such that, if $W < \widehat{W}^{fi}$, the marginal gain of reducing asset fire sales dominates the marginal cost for all $x > 0$. The planner then finds it optimal to prevent fire sales altogether, as established by Proposition 4.

Finally, note that in the model developed by Kara and Ozsoy (2019) it is also in principle possible that the constrained social planner finds it optimal to fully prevent fire sales. However, under their assumptions on the technology operated by outside investors and the convex operational cost faced by banks, the (social) costs associated with a moderate amount of asset fire sales are very low, whereas holding liquidity to reduce fire sales becomes increasingly costly. As a consequence, full insurance against fire-sale risk is never optimal for the constrained social planner.

6. Social Inefficiencies and the Role of Risk

The results presented thus far indicate that private decisions of unregulated banks in our model may lead to socially inefficient aggregate outcomes. In this section, we further elaborate on this feature. Throughout the analysis, we assume that the model parameters π , R^b , R^m , and W satisfy (23), such that money creation is positive in

27. Under our maintained assumptions on the investors' technology $y(\cdot)$, and given that $q < \bar{q}$, $W < \widehat{W}$, and $x = qR^m M - L > 0$, the first-order condition (22) boils down to

$$R^b - 1 = \frac{\pi}{q} \left(\frac{\alpha A}{(W-x)^{1-\alpha}} - 1 \right) + \frac{\eta}{k} \left\{ 1 + (1-\alpha) \frac{R^m M - L}{W-x} \right\},$$

where $\eta/k > 0$. The marginal benefit of an increase in L thus is monotonically decreasing in W and approaches infinity as W approaches zero.

both the unregulated equilibrium and the constrained-efficient allocation. Our first observation is the following.

PROPOSITION 5. *The unregulated competitive equilibrium is socially efficient if and only if crises are highly systemic, $q \geq \bar{q}$, and fire sales are overly costly, $W \leq \underline{W}$.*

The underlying intuition, which is already familiar from Stein's (2012) analysis, can be best understood as follows. Recall that individual banks do not take into account the incremental effect of their decisions on the fire-sale price, which creates a pecuniary externality. Recall further that when $q \geq \bar{q}$ and $W \leq \underline{W}$, the collateral constraint is nonbinding in the unregulated competitive equilibrium (cf. Lemma 1). The pecuniary externality then operates only through prices in budget constraints, and thus does not lead to social inefficiencies in line with the first welfare theorem (cf. Stein 2012, p. 74).²⁸

If crises are not highly systemic, $q < \bar{q}$, or fire sales are not overly costly, $W \geq \underline{W}$, banks' money creation is sufficiently high to make the collateral constraint binding in equilibrium. The pecuniary externality then operates not only through prices in budget constraints, but also through the collateral constraint, which does lead to social inefficiencies. The following proposition characterizes these inefficiencies for the case where risk is still highly systemic, but fire sales are *not* overly costly.

PROPOSITION 6. *When crises are highly systemic, $q \geq \bar{q}$, and fire sales are not overly costly, $W \geq \underline{W}$, unregulated banks create an excessive amount of private money, $M^* > M^{**}$, overinvest in risky assets, $I^* > I^{**}$, and hold the socially efficient amount of liquidity, $L^* = L^{**} = 0$.*

Proposition 6 (together with Proposition 5) shows that the results in Stein (2012) carry over to environments where crises are *highly*, but not necessarily *fully*, systemic. To see the underlying intuition, consider a situation where all banks create M units of money, invest I units, hold no liquidity, $L = 0$, and the collateral constraint is binding, $R^m M = \lambda I k$. When an individual bank now increases its money creation and investment, it incrementally reduces the fire-sale price to $k' < k$, and thereby reduces the collateral value of all other banks' assets to $\lambda I k'$. For a given level of I , these other banks can thus no longer create M units of money, but must instead rely to a larger extent on long-term borrowing. This raises their overall borrowing costs as $R^b > R^m$. Each bank's borrowing through money creation thus imposes a negative externality on all other banks. Unregulated banks that do not internalize this *borrowing externality*

28. In the current setting, this can easily be verified by comparing the banks' optimality conditions (10) and (11) to the planner's optimality conditions (21) and (22) when the collateral constraint is nonbinding. It is immediate that the respective conditions are equivalent when $\eta = 0$ (and hence also $\gamma = 0$), and that the planner thus chooses the same allocation that unregulated banks choose in equilibrium.

create a socially excessive amount of money in equilibrium, $M^* > M^{**}$, and overinvest in risky assets, $I^* > I^{**}$, which serve as collateral for money creation.²⁹

We next examine environments where crises are not highly systemic, $q < \bar{q}$, and show that the social inefficiencies arising in such environments can be qualitatively very different from the social inefficiencies arising in environments where risk is highly systemic.

PROPOSITION 7. *When crises are not highly systemic, $q < \bar{q}$, and fire sales are sufficiently costly, $W < \bar{W}$, unregulated banks hold a positive but inefficiently low amount of liquidity, $L^* < L^{**}$, create an inefficiently low amount of private money, $M^* < M^{**}$, and underinvest in risky assets, $I^* < I^{**}$.*

Proposition 7 contrasts sharply with the case where crisis risk is highly systemic, in which the unregulated competitive equilibrium is either socially efficient or characterized by excessive money creation and overinvestment. To understand the underlying intuition, recall first that when $q < \bar{q}$ and $W < \bar{W}$, both unregulated banks and the social planner find it optimal to hold liquidity. Banks do, however, not internalize the full social benefits of their liquidity holdings. By increasing its stock of liquid assets, each bank incrementally reduces the amount of aggregate asset fire sales during crises, $qR^m M - L$, which raises the fire-sale price. The increase in the fire-sale price, in turn, raises the collateral value of the risky assets held by all other banks, who can now create more money and hence finance investment more cheaply. By holding liquidity, each bank thus imposes a positive externality on others. Individual banks do not internalize this *liquidity externality* and hence hold less liquidity than the planner, which leads to *inefficiently low* aggregate liquidity in the banking system in the unregulated competitive equilibrium.

When aggregate liquidity is low, the equilibrium fire-sale price is low, and thus the collateral value of banks' assets is low, too. This impairs banks' ability to create money, that is, the *liquidity externality* counteracts the *borrowing externality* in equilibrium. This effect is so strong when $W < \bar{W}$ that banks end up creating an *inefficiently low* amount of private money, $M^* < M^{**}$. Moreover, the banks' impaired ability to borrow cheaply through money creation raises their overall financing costs, because they must rely increasingly on expensive long-term borrowing. The higher financing cost eventually induces *underinvestment* in risky assets relative to the constrained-efficient allocation, $I^* < I^{**}$.

The finding that aggregate liquidity shortages can give rise to *underinvestment* in risky assets by banks further contrasts with Kara and Ozsoy (2019), where banks always overinvest in risky assets. To understand this difference, recall that the banks

29. Note also that the privately and socially optimal choice of liquidity in Proposition 6 is a corner solution, $L^* = L^{**} = 0$. This feature is, however, not driving our results. In Online Appendix G, we extend the current model by adding a state of the world in which banks need liquidity to cover investment restructuring costs. In this extended model, it is privately and socially optimal for banks to hold liquid assets even when asset return risk in the bad state of the world is fully systemic, and we show that the results in Proposition 6 are robust to this alternative specification.

in their model finance investment through a fixed stock of equity capital and riskless deposits, for which they pay a zero interest rate. Borrowing is costly only because banks face a nonpecuniary convex operational cost, which depends solely on the size of their balance sheet. Accordingly, the banks' cost of financing a given portfolio of illiquid and liquid assets is independent of the fire-sale discount during a crisis, such that aggregate liquidity shortages in Kara and Ozsoy (2019) have only a moderate effect on banks' incentive to invest in risky assets.³⁰ By contrast, in our setting, the fire-sale discount is key to the banks' liability choice between short-term and long-term debt. When the fire-sale discount is large, the collateral value of banks' illiquid investments is low, and banks must rely more on expensive long-term borrowing to finance their asset portfolio. Accordingly, the overall financing cost of a given portfolio of illiquid and liquid assets increases when the fire-sale discount increases, which strongly discourages banks' investment in illiquid assets.

Finally, let us also briefly discuss the scenario where crises are not very systemic, $q < \bar{q}$, and fire sales are not very costly, $W \geq \bar{W}$. Unregulated banks then do not hold liquidity, whereas the planner does hold liquidity as long as $W < \hat{W}$. Accordingly, liquidity holdings by unregulated banks are inefficiently low when $W \in [\bar{W}, \hat{W})$ and socially efficient when $W \geq \hat{W}$. The results for money creation and investment are less clear cut because, as outlined previously, these depend on the interaction of the *borrowing externality* and the *liquidity externality*. It is intuitive, however, that as the investors' endowment W increases, the cost of fire sales declines, and hence the less incentive the planner has to support the fire-sale price. The planner's liquidity holdings thus decrease as W increases, and the *liquidity externality* thus becomes less and less important. At some point, the effect of the *borrowing externality* dominates the effect of the *liquidity externality*, which then leads to excessive money creation and overinvestment in equilibrium. This is clearly the case as soon as $W \geq \hat{W}$, in which case the planner does no longer hold liquidity, and hence the liquidity externality no longer distorts the unregulated competitive equilibrium allocation. In what follows, we further discuss these findings in the context of a numerical example.

7. A Numerical Illustration

In this section we illustrate the main results of our analysis by means of a numerical example. Following Stein (2012), we let $f = 3.5 \log(I) + I$, $\lambda = 1$ and $\pi = 0.02$. We further set the parameters of the investment technology in the traditional sector to $\alpha = 0.4$ and $A = 48.48$.³¹ The interest rate parameters are set to $R^m = 1.0025$, reflecting a low interest rate environment, and to $R^b = 1.0325$; the spread between R^b and R^m is thus equal to 3% as in the numerical examples provided by Stein (2012). Finally, we do

30. In particular, this effect is not strong enough to overturn that banks overinvest in illiquid assets in their model economy.

31. A justification for these parameter choices is provided in what follows.

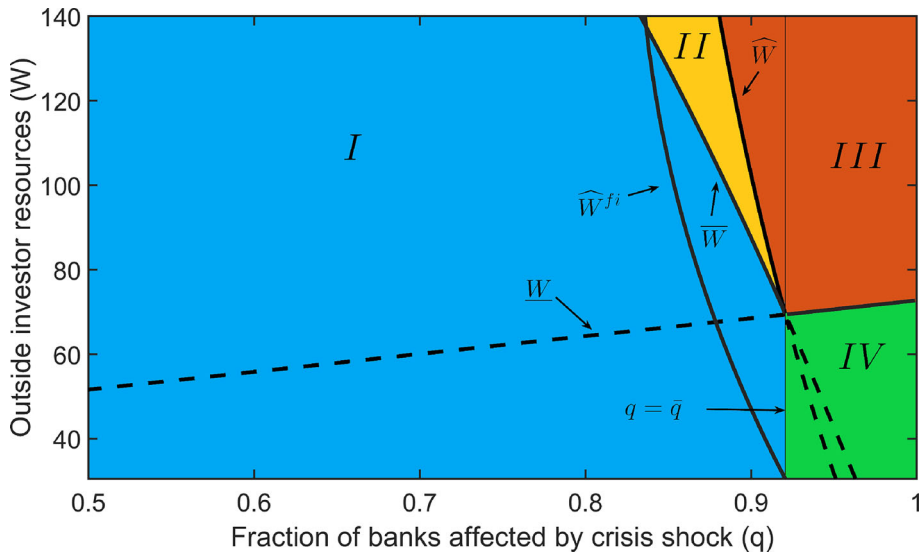


FIGURE 2. Equilibrium regimes on (q, W) space. Functional forms and parameters are given by $f = 3.5 \log(I) + I$, $\lambda = 1$, $\pi = 0.02$, $\alpha = 0.4$, $A = 48.48$, $R^b = 1.035$, and $R^m = 1.0025$.

not pick a single numerical value for the parameter q , but instead vary this parameter between $q = \pi$ and $q = 1$. When $q = \pi$, the bad state is revealed with certainty in period 1, $p = 1$, but affects only a random fraction π of banks; risk is thus purely idiosyncratic. When $q = 1$, the bad state is realized only with probability $p = \pi$, but affects all banks simultaneously; risk is thus fully systemic.

Given our choices of functional forms and parameters, the threshold \bar{q} is given by $\bar{q} = 0.92$ and the thresholds \underline{W} , \bar{W} , \widehat{W}^{fi} , and \widehat{W} are functions of q only. Figure 2 plots these functions for $q \in [0.5, 1]$ in the range where W satisfies (23) and $y'(W) \geq 1$.³² Moreover, it shows that the (q, W) -parameter space can be decomposed into four regions. In the blue region I, both $q < \bar{q}$ and $W < \bar{W}$ are satisfied, and thus there is insufficient money creation in the unregulated competitive equilibrium (cf. Proposition 7). In the red region III, $W \geq \widehat{W} > \underline{W}$, and hence there is excessive money creation; in the green region IV, $q > \bar{q}$ and $W < \underline{W}$, and hence the unregulated competitive equilibrium is socially efficient (cf. Proposition 5). In the yellow region II, $q < \bar{q}$ and $W \in [\bar{W}, \widehat{W})$. In this region, the unregulated competitive equilibrium is socially inefficient as banks hold insufficient liquidity; whether money creation and investment are excessive or insufficient is, however, not clear a priori.³³

Figure 3 takes a closer look at the unregulated competitive equilibrium and the constrained-efficient allocation when $W = 140$, as in Stein (2012). Note that for this

32. We restrict attention to $q \geq 0.5$ to better visualize our results and because no qualitative changes happen when $q < 0.5$.

33. See the discussion at the end of Section 6.

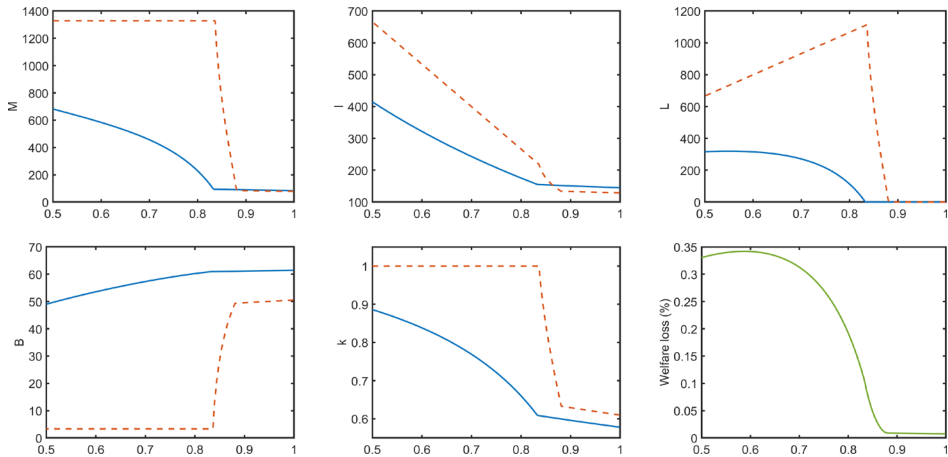


FIGURE 3. Comparing the unregulated equilibrium and the constrained-efficient allocation. In all panels, q is varied between 0.5 and 1 along the horizontal axis. The blue solid line corresponds to the unregulated competitive equilibrium, and the red dashed line to the constrained-efficient allocation. Functional forms and parameters are given by $f = 3.5 \log(I) + I$, $W = 140$, $\lambda = 1$, $\pi = 0.02$, $\alpha = 0.4$, $A = 48.48$, $R^b = 1.0325$, and $R^m = 1.0025$.

parameter choice, given our choices for α and A , the fire-sale price reacts only gradually to small amounts of fire sales, that is, $y'(W) = 1$. The first five panels of Figure 3 display the equilibrium allocations $\{M^*, L^*, I^*, B^*, k^*\}$ and $\{M^{**}, L^{**}, I^{**}, B^{**}, k^{**}\}$, whereas the bottom right-hand panel illustrates the welfare loss in the unregulated competitive equilibrium relative to the constrained-efficient allocation.

With regard to the unregulated competitive equilibrium, the following observations are particularly noteworthy. First, M^* and I^* are both decreasing in q ; unregulated banks create less money and invest less in risky assets the more systemic crises are, even though each individual bank's risk of experiencing a low return is kept constant at $\pi = 0.02$. This is because, as q increases, more banks need to fire-sell distressed assets in the financial crisis state of the world, which depresses the equilibrium fire-sale price k^* . A lower fire-sale price, in turn, reduces the collateral value of banks' assets already in period 0, and thus limits banks' ability to create money for any given level of investment I . Banks must rely more on long-term borrowing to finance investment, and thus B^* increases. As this raises their overall financing costs, banks invest less in risky assets when risk is more systemic.

With regard to the constrained-efficient allocation, it is worth highlighting that, as long as the planner fully insures against fire-sale risk (which is the case in our example when $q < 0.84$), both money creation and long-term borrowing, M^{**} and B^{**} , hardly vary with changes in q . The same is true for total assets, $L^{**} + I^{**}$, but not for the asset composition. In particular, liquidity holdings L^{**} increase in q as long as $q < 0.84$, because the planner needs more liquid assets to fully insure against fire-sale risk the more systemic crises are; investment in risky assets, I^{**} , decreases in q . Once crises are sufficiently systemic, $q \geq 0.84$, the planner takes fire-sale risk and reduces his liquidity

holdings; M^{**} and I^{**} are then both decreasing in q , whereas B^{**} is increasing in q . The underlying intuition is the same as in the unregulated competitive equilibrium.

Comparing the unregulated competitive equilibrium allocation to the constrained-efficient allocation confirms the general findings discussed in Section 6. In our example, unregulated banks create an excessive amount of money and overinvest in risky illiquid assets when $q > 0.88$; they create an inefficiently low amount of money, hold too little liquidity, and *overinvest* in risky assets when $q \in (0.86, 0.88]$; and they create an inefficiently low amount of money, hold too little liquidity, and *underinvest* in risky assets when $q \leq 0.86$ (i.e. when at least 14% of banks are not directly affected by the crisis shock). Against this background, it would be interesting to further explore the nature of social inefficiencies in a dynamic and carefully calibrated version of the current model economy; however, this goes beyond the scope of the present paper and is left for future research.

8. Macroprudential Regulation

We next examine whether and how a macroprudential regulator can implement the constrained-efficient allocation as a competitive equilibrium. For environments with excessive money creation (or short-term overborrowing) and overinvestment, it is well known from the existing literature that this can be achieved using instruments such as outright caps on borrowing, Pigouvian taxes on debt issuance, or bank capital requirements. We therefore restrict our attention to environments that give rise to *inefficiently low* money creation and investment by private banks, which are less well understood. To keep the analysis concise, we focus on the case where both $W < \bar{W}$ and $W < \widehat{W}^{fi}$ are jointly satisfied.

We first present our main findings and then discuss the underlying intuition.

PROPOSITION 8. *Assume that $q < \bar{q}$, $W < \bar{W}$, and $W < \widehat{W}^{fi}$ are satisfied. A macroprudential regulator can implement the constrained-efficient allocation as a competitive equilibrium by collecting a Pigouvian tax τ on short-term “money-like” debt and paying a subsidy r on liquid assets, where $\tau = q(R^m - 1)/(1 - q) > 0$ and $r = \tau R^b / (R^m(q - \pi)) > 0$. Alternatively, the regulator can implement the constrained-efficient allocation by imposing a liquidity requirement of $\mu = q$ units for each unit of short-term liabilities $R^m M$ in period 0.*

Proposition 8 shows that the regulator can use both price-based and quantity-based measures to achieve constrained efficiency. The price-based approach involves a liquidity subsidy together with a strictly positive tax on money creation. This latter finding may appear counterintuitive, given that banks create an *inefficiently low* amount of private money in the unregulated equilibrium. To understand the underlying intuition, it is important to realize that insufficient money creation arises from the interaction of the borrowing externality and the liquidity externality in our environment. In particular, money creation is too low in the unregulated equilibrium

only because aggregate liquidity holdings are too low (and hence the collateral value of liquid assets is too low, which impairs banks' ability to create "enough" money). If liquidity holdings were not too low, for example, because the regulator pays a liquidity subsidy to banks, banks would actually create an excessive amount of money due to the borrowing externality. Hence, the tax on money creation must be positive to correct for this *partial equilibrium* effect. Moreover, it is evident that the regulator must use both τ and r jointly to implement the constrained-efficient allocation; the optimal liquidity subsidy r implements the efficient level of aggregate liquidity, whereas the optimal tax τ implements the efficient amount of short-term borrowing conditional on the (socially efficient) level of liquidity.³⁴

Proposition 8 further argues that the regulator can implement constrained efficiency by only imposing appropriate minimum liquidity requirements on banks. This is because such requirements play a dual role in our environment. First, they ensure that the ratio of liquidity relative to private money is aligned with the corresponding ratio in the constrained-efficient allocation. Second, requiring banks to hold nonremunerated liquid assets increases the effective cost of money creation relative to long-term borrowing, and hence resembles a Pigouvian tax. It is important to emphasize that, although the regulator needs only one quantity-based instrument (the minimum liquidity requirement), this instrument must be employed actively. Only by reducing the liquidity requirement in the bad state for *all* banks, the regulator eventually prevents fire sales, by allowing sound banks to purchase assets from distressed banks. A *static* liquidity requirement cannot restore constrained efficiency. An important takeaway is therefore that liquidity requirements such as the LCR introduced in Basel III need to be managed actively and changed in response to macroeconomic and financial shocks to show their full potential.

Note that an important drawback of the price-based regulation relative to the quantity-based regulation is that the former implies an overall financial cost for the regulator. Specifically, as shown in the proof of Proposition 8, to implement the constrained-efficient allocation as a competitive equilibrium, the subsidies paid on liquid assets under price regulation necessarily exceed the Pigouvian tax revenues, $\tau M^{**} < rL^{**}$. By contrast, the quantity-based regulation is budget neutral. A further drawback is that price-based regulation is more information-intensive than quantity-based regulation. In particular, to set the correct subsidy for liquidity, the planner must not only know how systemic crises are, q , but also how likely they are, as reflected by π . This further strengthens the case for using minimum liquidity requirements as a macroprudential policy tool in environments with imperfect information.

Finally, note that bank capital adequacy ratios, or other macroprudential tools that seek to curb excessive short-term borrowing and risky investment by banks, are not suitable instruments in our environment. This is simply because, as the competitive

34. This reasoning also makes clear that, as long as the collateral constraint is binding, the borrowing externality and the liquidity externality cannot perfectly offset each other, and hence the unregulated equilibrium is then always socially inefficient.

equilibrium is characterized by short-term underborrowing and underinvestment rather than overborrowing and overinvestment, any restrictions on borrowing and investment would not bind in the competitive equilibrium.

9. Conclusion

We have provided a joint analysis of banks' liability choice between private money creation and long-term borrowing together with their asset choice between safe liquid and risky illiquid investments in a simple three-period banking model. The model environment features pecuniary externalities and liquidity risk, whereby the latter is not necessarily fully systemic. We have shown that, in general, privately optimal decisions by banks lead to socially inefficient outcomes. The nature of inefficiency depends critically on the degree to which risk is systemic: When risk is highly systemic, banks create an excessive amount of money and overinvest in risky assets; when risk is not highly systemic, banks hold insufficient liquidity, create insufficient private money, and underinvest in illiquid assets. A macroprudential regulator can then best restore constrained efficiency by imposing quantity-based liquidity requirements on banks. Price-based regulatory measures are less well suited for achieving this objective, because they are more information intensive and involve a financial cost for the regulator.

Appendix A: Empirical Evidence on Asset Return Risk

A key assumption in our model is that risk is not fully systemic. This deviation from the existing literature can easily be justified on empirical grounds; real-world banks are highly heterogeneous in many dimensions, including, for example, their asset choices, liability choices, geographical location, monitoring technologies, or second-best use values of assets (cf. Lucas, Schaumburg, and Schwaab 2019; Geerolf 2019). Figure A.1 provides empirical evidence on the high degree of asset heterogeneity across the 50 largest banks in the European Union. It shows each of these banks' exposure to households, nonfinancial corporations, financial corporations, general governments, and central banks, respectively, as a share of the bank's total exposures.³⁵ Evidently, exposures of different banks to different sectors vary greatly. For example, banks' exposures to the household sector range from 0% to 80% of total exposures, indicating that shocks originating in the household sector have very different effects on the asset performance of different banks.

35. We restrict attention to the 50 largest banks to emphasize that heterogeneity is not a matter driven by bank size.

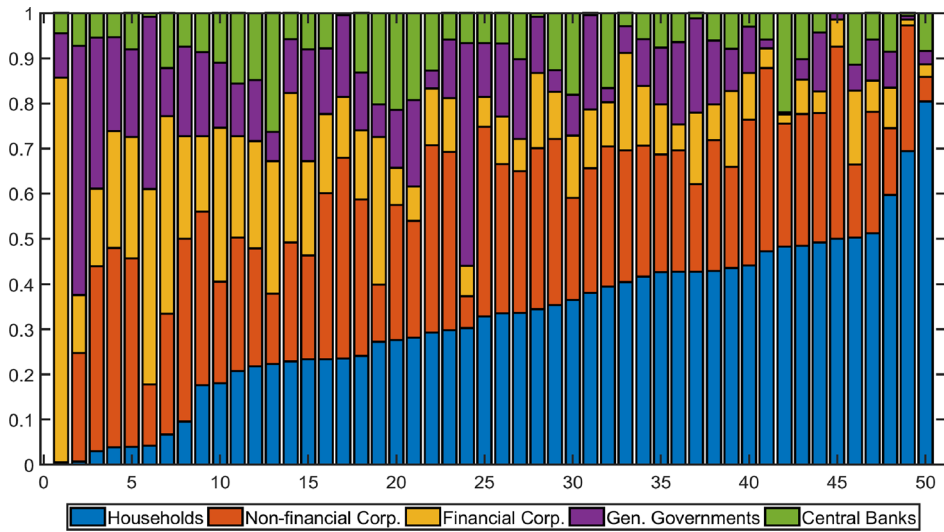


FIGURE A.1. European banks’ exposure to different sectors in the economy. Each bar represents one of the 50 largest banks participating in the 2017 E.U.-wide transparency exercise. It shows the share of the bank’s exposure vis-a-vis five different sectors in the economy (households, nonfinancial corporations, financial corporations, general governments, and central banks) in total exposures. Banks are ordered according to their exposure to the household sector. Reference date: 30 June 2017. Data source: European Banking Authority (EBA). Data are available at <https://www.eba.europa.eu/risk-analysis-and-data/eu-wide-transparency-exercise/2017/results>.

Appendix B: Definitions

The Unregulated Competitive Equilibrium

DEFINITION B.1. An unregulated competitive equilibrium is a collection of prices $\{R^m, \tilde{R}^b(g), \tilde{R}^b(b), R^b, k^*, \eta^*\}$ and allocations

$$\{C_0^*, C_2^*(g), C_2^*(b), M^*, \tilde{B}^*, B^*, I^*, L^*, Z^*\}$$

satisfying the following conditions:

1. Given $\{R^m, \tilde{R}^b(g), \tilde{R}^b(b)\}$ and $\{M^*, B^*, I^*, L^*\}$, the households’ choices $\{\tilde{B}^*, C_0^*, C_2^*(g), C_2^*(b)\}$ maximize utility (1) subject to the budget constraints

$$C_0^* \leq X - \tilde{B}^*, \tag{B.1}$$

$$C_2^*(g) \leq f(I^*) + L^* - R^m M^* + y(W), \tag{B.2}$$

$$C_2^*(b) \leq (1 - q)f(I^*) + q\lambda I^* - R^m M^* + y(W + L^* - qR^m M^*) + qR^m M^*. \tag{B.3}$$

2. Given $\{R^m, R^b, k^*\}$, the banks' choices $\{M^*, B^*, I^*, L^*\}$ maximize profits (8) subject to the budget constraint (7) and the collateral constraint (4).
3. Given k^* , the outside investors' choice Z^* maximizes investor profits (5).
4. International lenders maximize profits: $R^m = 1/\delta$.
5. Goods markets clear: (B.1)–(B.3) hold with strict equality.
6. Financial markets clear:

$$\tilde{B}^* = B^*,$$

$$Z^* = \begin{cases} 0 & \text{if } \theta = g, \\ qR^m M^* - L^* & \text{if } \theta = b. \end{cases}$$

7. The budget constraint (7), the collateral constraint (4), and the complementary slackness condition (12) are satisfied, and $\eta^* \geq 0$.

The Constrained-Efficient Allocation

DEFINITION B.2. A constrained-efficient allocation is a collection of prices $\{R^b, R^m, k^{**}, \eta^{**}, \gamma^{**}\}$ and allocations

$$\{C_0^{**}, C_2^{**}(g), C_2^{**}(b), M^{**}, B^{**}, I^{**}, L^{**}\}$$

satisfying the following conditions:

1. Given R^m , the planner's choices $\{M^{**}, B^{**}, I^{**}, L^{**}\}$ maximize social welfare (17) subject to the collateral constraint (4), the pricing equation (18), and $L^{**} \leq qR^m M^{**}$.
2. Households choose $\{C_0^{**}, C_2^{**}(g), C_2^{**}(b)\}$ to maximize utility and goods markets clear: $R^b = 1/\beta$ and

$$C_0^{**} = X - B^{**},$$

$$C_2^{**}(g) = f(I^{**}) + L^{**} - R^m M^{**} + y(W^{**}),$$

$$C_2^{**}(b) = (1 - q)f(I^{**}) + q\lambda I^{**} - R^m M^{**} + y(W + L^{**} - qR^m M^{**}) + qR^m M^{**}.$$

3. International lenders maximize profits: $R^m = 1/\delta$.
4. The fire-sale price satisfies

$$k^{**} = \begin{cases} \frac{1}{y'(W + L^{**} - qR^m M^{**})} & \text{if } qR^m M^{**} > L^{**}, \\ 1 & \text{if } qR^m M^{**} = L^{**}. \end{cases}$$

5. The collateral constraint (4) and the complementary slackness condition (12) hold, and $\eta^{**} \geq 0$.
6. The complementary slackness condition $\gamma^{**}(L^{**} - qR^m M^{**}) = 0$ holds, $\gamma^{**} \geq 0$ and $L^{**} \leq qR^m M^{**}$.

Appendix C: Proofs

Proof of Proposition 1

Consider a candidate equilibrium allocation with positive liquidity holdings, $L^* > 0$. When $L^* > 0$ is optimal, equation (11) must hold with strict equality. The equilibrium conditions can then be solved for the allocation

$$\begin{aligned} k^* &= \frac{(1-q)\pi R^m}{(1-q)\pi R^m + qR^b(R^m - 1)}, \\ \eta^* &= \left(R^b - 1 - \frac{R^b(R^m - 1)}{(1-q)R^m} \right) k^*, \\ I^* &= (f')^{-1} \left(\frac{R^b - \eta^* \lambda - \pi \lambda}{1 - \pi} \right), \\ M^* &= \frac{(\alpha A k^*)^{\frac{1}{1-\alpha}} + \lambda I^* k^* - W}{(1-q)R^m}, \\ L^* &= R^m M^* - \lambda I^* k^*. \end{aligned}$$

This allocation is a competitive equilibrium if and only if the implied value for both L^* and η^* are nonnegative. It is straightforward to show that this is equivalent to the conditions

$$q \leq \frac{R^b - R^m}{(R^b - 1)R^m} \equiv \bar{q}$$

and

$$\begin{aligned} W &\leq (\alpha A)^{\frac{1}{1-\alpha}} \left(\frac{(1-q)\pi R^m}{(1-q)\pi R^m + qR^b(R^m - 1)} \right)^{\frac{1}{1-\alpha}} \\ &\quad + q\lambda \left(\frac{(1-q)\pi R^m}{(1-q)\pi R^m + qR^b(R^m - 1)} \right) \\ &\quad \times (f')^{-1} \left(\frac{R^b - \lambda \frac{(1-q)\pi R^m (R^b - 1) - \pi R^b (R^m - 1)}{(1-q)\pi R^m + qR^b (R^m - 1)} - \pi \lambda}{1 - \pi} \right) \equiv \bar{W}. \end{aligned}$$

Conversely, a competitive equilibrium with positive liquidity holdings does not exist when either of these conditions is violated.

Proof of Proposition 2

Assume that $L^* = qR^m M^*$. Because $M^* > 0$, this implies $L^* > 0$. From Proposition 1 it then follows that $k^* < 1$. By the investors' no-arbitrage condition, this implies $qR^m M^* - L^* > 0$, which contradicts the initial assumption that $L^* = qR^m M^*$.

Accordingly, $L^* = qR^m M^*$ cannot hold in the unregulated competitive equilibrium. This implies that fire-sold illiquid assets are in part absorbed by outside investors, $Z^* = qR^m M^* - L^* > 0$. Investment in the traditional sector is then given by $W - Z^* < W$ and aggregate output losses are incurred because $y(W - Z^*) + Z^* < y(W)$, which follows from our assumptions that y is concave and that $y'(W) \geq 1$.

Proof of Lemma 1

We first show that $\eta^* > 0$ when $q < \bar{q}$. To see this assume that $\eta^* = 0$. In this case, the optimality conditions (10) and (11) imply $q \geq (R^b - R^b)/(R^m(R^b - 1)) \equiv \bar{q}$, which contradicts the assumption $q < \bar{q}$.

We next show that $\eta^* > 0$ when $q \geq \bar{q}$ and $W > \underline{W}$. Assume again that this was not true. When $\eta^* = 0$, the optimality conditions (9) and (10) pin down the equilibrium investment and the fire-sale price, respectively:

$$I^* = (f')^{-1} \left(\frac{R^b - \pi\lambda}{1 - \pi} \right), \tag{C.1}$$

$$k^* = \frac{\pi R^m}{\pi R^m + R^b - R^m}. \tag{C.2}$$

Because $q \geq \bar{q}$, $M^* > 0$ and $L^* = 0$ (cf. Proposition 1). The fire-sale price must therefore satisfy

$$\frac{1}{k^*} = \alpha A (W - qR^m M^*)^{\alpha-1}, \tag{C.3}$$

which can be rearranged as

$$qR^m M^* = W - (\alpha A k^*)^{\frac{1}{1-\alpha}}.$$

Because the collateral constraint is by assumption nonbinding, $qR^m M^* \leq q\lambda I^* k^*$. Hence,

$$W - (\alpha A k^*)^{\frac{1}{1-\alpha}} \leq q\lambda I^* k^* \tag{C.4}$$

must hold when $\eta^* = 0$. Using (C.1) and (C.2), it is immediate that this cannot be the case when $W > \underline{W}$. This shows that the collateral constraint is binding when $q \geq \bar{q}$ and $W > \underline{W}$.

It remains to show that the collateral constraint is nonbinding when $q \geq \bar{q}$ and $W \leq \underline{W}$. Assume this was not true, but instead $\eta^* > 0$. Then conditions (9) and (10) imply that

$$I^* > (f')^{-1} \left(\frac{R^b - \pi\lambda}{1 - \pi} \right), \tag{C.5}$$

$$k^* > \frac{\pi R^m}{\pi R^m + R^b - R^m}, \tag{C.6}$$

where the first result obtains because $(f')^{-1}$ is a decreasing function under our assumption that f is monotonically increasing. Moreover, note that the fire-sale price must again satisfy (C.3), and, because the collateral constraint is binding by assumption, (C.4) must hold as an equality, yielding

$$W = (\alpha A k^*)^{\frac{1}{1-\alpha}} + q \lambda I^* k^*.$$

Clearly, this condition cannot hold when $W \leq \underline{W}$. Hence, the collateral constraint is necessarily nonbinding, $\eta^* = 0$, when $q \geq \bar{q}$ and $W \leq \underline{W}$.

Proof of Lemma 2

When $M^{**} = 0$ the collateral constraint is nonbinding and the optimality condition of the social planner with respect to M boils down to

$$\frac{R^b - R^m}{R^m} \leq \pi(y'(W) - 1).$$

This condition cannot hold, and hence money creation is thus necessarily positive, if $\pi < (R^b - R^m)/(R^m(y'(W) - 1))$.

Proof of Proposition 3

Let $q < \bar{q}$ and consider a constrained-efficient allocation with $L^{**} \in [0, qR^m M^{**})$. Note first that this allocation must satisfy the planner’s optimality conditions for money creation and liquidity holdings,

$$\frac{R^b - R^m}{R^m} = \pi \left(\frac{1}{k^{**}} - 1 \right) + \frac{\eta^{**}}{k^{**}} \left\{ 1 + (1 - \alpha) \frac{q(R^m M^{**} - L^{**})}{W + L^{**} - qR^m M^{**}} \right\}, \tag{C.7}$$

$$R^b - 1 \geq \frac{\pi}{q} \left(\frac{1}{k^{**}} - 1 \right) + \frac{\eta^{**}}{k^{**}} \left\{ 1 + (1 - \alpha) \frac{R^m M^{**} - L^{**}}{W + L^{**} - qR^m M^{**}} \right\}, \tag{C.8}$$

and therefore

$$\frac{\eta^{**}}{k^{**}} \geq R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} > 0, \tag{C.9}$$

whereby the last inequality follows from $q < \bar{q}$. Combining (C.8) and (C.9), it follows that

$$\begin{aligned} \frac{R^b(R^m - 1)}{(1 - q)R^m} &\geq \frac{\pi}{q} \left(\frac{1}{k^{**}} - 1 \right) + (1 - \alpha) \left[R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} \right] \\ &\quad \times \left\{ \frac{R^m M^{**} - L^{**}}{W + L^{**} - qR^m M^{**}} \right\} \end{aligned} \tag{C.10}$$

must hold in equilibrium. Recall further that the equilibrium allocation must satisfy the collateral constraint (4) and the pricing equation (18). Because $L^{**} \in [0, qR^m M^{**})$ and $\eta^{**} > 0$, these conditions can be written as

$$R^m M^{**} - L^{**} = \lambda I^{**} k^{**}, \tag{C.11}$$

$$\frac{1}{k^{**}} = \alpha A (W + L^{**} - qR^m M^{**})^{\alpha-1}, \tag{C.12}$$

so that equation (C.10) can be reformulated as

$$\begin{aligned} \frac{R^b (R^m - 1)}{(1 - q)R^m} &\geq \frac{\pi}{q} \left(\frac{1}{k^{**}} - 1 \right) \\ &+ (1 - \alpha) \left[R^b - 1 - \frac{R^b (R^m - 1)}{(1 - q)R^m} \right] \frac{\lambda I^{**}}{(\alpha A)^{\frac{1}{1-\alpha}}} (k^{**})^{\frac{\alpha}{\alpha-1}}, \end{aligned} \tag{C.13}$$

and the condition

$$W = (\alpha A k^{**})^{\frac{1}{1-\alpha}} + q \lambda I^{**} k^{**} - (1 - q)L^{**} \tag{C.14}$$

must hold in equilibrium. Next, define the function

$$\mathcal{I}(k) = (f')^{-1} \left(\frac{R^b - \lambda \left[R^b - 1 - \frac{R^b (R^m - 1)}{(1 - q)R^m} \right] k - \pi \lambda}{1 - \pi} \right), \tag{C.15}$$

and note that, because f is monotonically increasing, $(f')^{-1}$ is monotonically decreasing. Moreover, because f is concave, $\mathcal{I}(k)$ is increasing in k , with its derivative being equal to

$$\mathcal{I}'(k) = -\frac{1}{f''(\mathcal{I}(k))} \lambda \left[R^b - 1 - \frac{R^b (R^m - 1)}{(1 - q)R^m} \right] > 0. \tag{C.16}$$

From (C.9) it follows that

$$I^{**} = (f')^{-1} \left(\frac{R^b - \lambda \eta^{**} - \pi \lambda}{1 - \pi} \right) \geq \mathcal{I}(k^{**}).$$

Using this result in (C.13), it is immediate that the equilibrium fire-sale price k^{**} must satisfy

$$\frac{R^b (R^m - 1)}{(1 - q)R^m} \geq \frac{\pi}{q} \left(\frac{1}{k^{**}} - 1 \right) \tag{C.17}$$

$$+ \lambda (1 - \alpha) \left[R^b - 1 - \frac{R^b (R^m - 1)}{(1 - q)R^m} \right] \frac{\mathcal{I}(k^{**})}{(\alpha A)^{\frac{1}{1-\alpha}}} (k^{**})^{\frac{\alpha}{\alpha-1}}. \tag{C.18}$$

Note that our assumptions on f guarantee that the right-hand side of (C.17) is monotonically decreasing in k^{**} .³⁶ Moreover, for small values of k^{**} , the right-hand side is clearly larger than the left-hand side. Hence, there exists a unique threshold value \hat{k} such that (C.17) holds with equality if and only if $k^{**} = \hat{k}$. For all $k^{**} > \hat{k}$, condition (C.17) holds as a strict inequality; for all $k^{**} < \hat{k}$, this condition is necessarily violated.

Now define the threshold $\widehat{W} = (\alpha A \hat{k})^{\frac{1}{1-\alpha}} + q\lambda \mathcal{I}(\hat{k})\hat{k}$ and assume that $W < \widehat{W}$. When $W < \widehat{W}$ and $L^{**} = 0$, condition (C.14) requires that $k^{**} < \hat{k}$. As we have argued previously, however, this implies that (C.17) is necessarily violated. Accordingly, a constrained-efficient allocation with $L^{**} = 0$ does not exist when $W < \widehat{W}$. This proves that, when $q < \bar{q}$ and $W < \widehat{W}$, the planner holds a positive amount of liquidity.

To see that $\bar{W} < \widehat{W}$, note that when $q < \bar{q}$, the conditions (C.7) and (C.9) imply

$$\pi \left(\frac{1}{k^{**}} - 1 \right) < \frac{R^b - R^m}{R^m} - \left[R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} \right],$$

must hold in any equilibrium with $L^{**} \in [0, qR^m M^{**})$, and, hence, the fire-sale price in such an equilibrium must satisfy

$$k^{**} > \frac{(1 - q)\pi R^m}{(1 - q)\pi R^m + qR^b(R^m - 1)} \equiv \underline{k}.$$

Equation (C.14) then establishes that

$$\begin{aligned} \widehat{W} &> (\alpha A)^{\frac{1}{1-\alpha}} \left(\frac{(1 - q)\pi R^m}{(1 - q)\pi R^m + qR^b(R^m - 1)} \right)^{\frac{1}{1-\alpha}} \\ &+ q\lambda \left(\frac{(1 - q)\pi R^m}{(1 - q)\pi R^m + qR^b(R^m - 1)} \right) \\ &\times (f')^{-1} \left(\frac{R^b - \lambda \frac{(1-q)\pi R^m(R^b-1) - \pi R^b(R^m-1)}{(1-q)\pi R^m + qR^b(R^m-1)} - \pi\lambda}{1 - \pi} \right) = \bar{W}. \end{aligned}$$

36. To see this, note that the derivate of the right-hand side of (C.17) with respect to k^{**} is equal to

$$\begin{aligned} (k^{**})^{\frac{\alpha}{\alpha-1}} \left\{ -\frac{\pi}{q} (k^{**})^{\frac{\alpha}{1-\alpha}-2} - \left[R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} \right] \frac{\lambda \alpha \mathcal{I}(k^{**})}{(\alpha A)^{\frac{1}{1-\alpha}} k^{**}} \right. \\ \left. + \left[R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} \right]^2 \frac{\lambda(1 - \alpha)}{(\alpha A)^{\frac{1}{1-\alpha}} |f''(\mathcal{I}(k^{**}))|} \right\}. \end{aligned}$$

This derivative is positive only if

$$\begin{aligned} \frac{1}{|f''(\mathcal{I}(k^{**}))|} > \frac{\pi(\alpha A)^{\frac{1}{1-\alpha}} (k^{**})^{\frac{3\alpha-2}{1-\alpha}}}{\lambda(1 - \alpha)q} \left[R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} \right]^{-2} \\ + \left[R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} \right]^{-1} \frac{\alpha \mathcal{I}(k^{**})}{(1 - \alpha)k^{**}}. \end{aligned}$$

The right-hand side of this expression is very large under plausible parameters, and hence $f''(\mathcal{I}(k^{**}))$ must be very close to zero for the aforementioned condition to hold. Our assumptions on f rule out this scenario.

Proof of Proposition 4

Note first that from the proof of Proposition (3) it follows that a constrained-efficient allocation with $L^{**} \in [0, qR^m M^{**})$ exists only if $k^{**} > \hat{k}$ and at the same time

$$k^{**} \leq \frac{W}{(\alpha A)^{\frac{1}{1-\alpha}}} \leq 1,$$

where the last inequality is due to our assumption that $y'(W) \geq 1$. Hence, such an equilibrium does not exist when $W < (\alpha A)^{1/(1-\alpha)} \hat{k} \equiv \hat{W}^{fi}$. The planner then finds it optimal to fully insure against fire-sale risk by holding a large amount of liquidity, $L^{**} = qR^m M^{**}$.

Proof of Proposition 5

As established in Lemma 1, the banks' collateral constraint is nonbinding in the unregulated competitive equilibrium, $\eta^* = 0$, when $q \geq \bar{q}$ and $W \leq \underline{W}$. Following the exact same reasoning as employed in the proof of this lemma, it is straightforward to show that under these parametric assumptions the same is true in the constrained-efficient allocation, $\eta^{**} = 0$. Comparing the relevant equilibrium conditions, it is immediate that the unregulated competitive equilibrium then coincides with the constrained-efficient allocation and is therefore socially efficient. Moreover, Lemma 1 establishes that the collateral constraint is binding when either $q < \bar{q}$ or $W > \underline{W}$. When the collateral constraint is binding, it is straightforward to verify from the first-order conditions that the unregulated equilibrium differs from the constrained-efficient allocation.

Proof of Proposition 6

When $q \geq \bar{q}$ and $W \geq \underline{W}$, Lemma 1 establishes that $\eta^* > 0$, and it is again straightforward to show that $\eta^{**} > 0$, too. Propositions 1 and 3 directly establish that $L^* = L^{**} = 0$. To show $M^* > M^{**}$, we follow a proof-by-contradiction strategy. Assume that $M^* \leq M^{**}$ would hold. Because $L^* = L^{**} = 0$, the pricing equation (18) would then imply $k^* \geq k^{**}$, and from the first-order conditions for money creation, it would follow that $\eta^* > \eta^{**}$. The first-order condition for I would further imply that $I^* > I^{**}$. Because the collateral constraint is binding, this would imply $R^m M^* = \lambda I^* k^* > \lambda I^{**} k^{**} = R^m M^{**}$, contradicting the assumption that $M^* \leq M^{**}$. It thus follows that $M^* > M^{**}$ when $q \geq \bar{q}$ and $W > \underline{W}$. Finally, note that $M^* > M^{**}$ implies via (18) that $k^* < k^{**}$, and thus via the collateral constraint that $I^* > I^{**}$.

Proof of Proposition 7

Under the maintained assumptions, liquidity holdings are positive in both the unregulated competitive equilibrium and the constrained-efficient allocation, $L^* > 0$ and $L^{**} > 0$, and the same is true for money creation, $M^* > 0$ and $M^{**} > 0$.

Assume first that the social planner fully insures against fire sales. It then follows trivially that $k^{**} = 1$, whereas Proposition 2 establishes that $k^* < 1$, implying that $k^* < k^{**}$. From the equilibrium conditions (10), (11), (21), and (22) holding with equality, it follows that

$$\frac{\eta^{**}}{k^{**}} = \frac{\eta^*}{k^*} = R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} \tag{C.19}$$

and hence $\eta^* < \eta^{**}$. The first-order conditions for investment in the banking sector then yield $I^* < I^{**}$. The binding collateral constraint further implies $(1 - q)R^m M^{**} = \lambda I^{**} k^{**}$ and $R^m M^* - L^* = \lambda I^* k^*$, respectively. The latter condition can be written as $(1 - q)R^m M^* + qR^m M^* - L^* = \lambda I^* k^*$, which implies $(1 - q)R^m M^* < \lambda I^* k^*$ because $L^* < qR^m M^*$. Because $\lambda I^* k^* < \lambda I^{**} k^{**}$, it is immediate that $M^* < M^{**}$ and $L^* < L^{**}$.

Assume next that the social planner does *not* fully prevent fire sales. Conditions (10), (11), (21), and (22) then establish

$$\frac{1}{k^{**}} = \frac{1}{k^*} + \frac{q}{\pi} \left[R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} \right] (R^m M^{**} - L^{**}) \frac{\mathcal{K}'(\cdot)}{k^{**}},$$

which, again, yields $k^* < k^{**}$ because $\mathcal{K}'(\cdot) < 0$. From (C.19) it further follows that $\eta^{**} > \eta^*$, and from the first-order conditions for investment in the banking sector, $I^* < I^{**}$. Because $k^* < k^{**}$, the pricing equation (18) implies

$$L^{**} - qR^m M^{**} > L^* - qR^m M^*. \tag{C.20}$$

Using the binding collateral constraint, this expression can be written as $(1 - q)R^m M^{**} - \lambda I^{**} k^{**} > (1 - q)R^m M^* - \lambda I^* k^*$, which, in turn, yields

$$\lambda(I^* k^* - I^{**} k^{**}) > (1 - q)R^m(M^* - M^{**}).$$

The left-hand side of this expression is negative, establishing that $M^* < M^{**}$. From (C.20) it finally follows that $L^* < L^{**}$.

Proof of Proposition 8

We first consider the case where the regulator uses price-based regulatory measures. Assume that the regulator collects a Pigouvian tax τ on short-term “money-like” debt issuance and pays a subsidy r on liquid assets. The banks’ Lagrangian function is then given by

$$\begin{aligned} \mathcal{L}_{\tau,r}^B &= f(I) - R^m M - R^b(I + L + \tau M - M) + L(1 + r) \\ &+ \frac{\pi}{q}(1 - q) \left\{ \left(\frac{1}{k} - 1 \right) L - rL \right\} + \pi \left\{ \lambda I - f(I) - rL - \left(\frac{1}{k} - 1 \right) (R^m M - L) \right\} \\ &- \eta \left\{ \frac{R^m M - L}{k} - \lambda I \right\}. \end{aligned}$$

Differentiating the Lagrangian yields the following optimality conditions for M and L :

$$\frac{R^b - R^m}{R^m} \leq \pi \left(\frac{1}{k} - 1 \right) + \frac{\eta}{k} + \tau R^b,$$

$$R^b - 1 \geq \frac{\pi}{q} \left(\frac{1}{k} - 1 \right) + \frac{\eta}{k} + \left(1 - \frac{\pi}{q} \right) r.$$

To implement the constrained-efficient allocation as a competitive equilibrium under our maintained assumptions, the regulator must set τ and r such that $k^* = k^{**} = 1$ and $\eta^* = \eta^{**} = [R^b - 1 - (R^b(R^m - 1))/((1 - q)R^m)]$ are optimal for banks in the competitive equilibrium. It is immediate that this is the case when

$$\frac{R^b - R^m}{R^m} = \left[R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} \right] + \tau \frac{R^b}{R^m},$$

$$R^b - 1 = \left[R^b - 1 - \frac{R^b(R^m - 1)}{(1 - q)R^m} \right] + \left(1 - \frac{\pi}{q} \right) r,$$

yielding $\tau = (q(R^m - 1))/((1 - q))$ and

$$r = \frac{R^b}{R^m(q - \pi)} \cdot \frac{q(R^m - 1)}{(1 - q)R^m} = \frac{R^b}{R^m(q - \pi)} \tau.$$

Note that both τ and r are always positive.

We now consider the case where, rather than taxing money creation and subsidizing liquid assets, the regulator imposes a quantity-based regulation in the form of a liquidity requirement. In particular, we assume that banks are required by regulation to hold at least $\mu > 0$ units of liquid assets for each unit of their short-term liabilities,

$$L \geq \mu R^m M.$$

The banks' Lagrangian under such a regulation is given by

$$\begin{aligned} \mathcal{L}_\mu^B &= f(I) - R^m M - R^b(I + L - M) + L \\ &+ \frac{\pi}{q}(1 - q) \left(\frac{1}{k} - 1 \right) L + \pi \{ \lambda I - f(I) - \left(\frac{1}{k} - 1 \right) (R^m M - L) \} \\ &- \eta \left\{ \frac{R^m M - L}{k} - \lambda I \right\} - \xi \{ \mu R^m M - L \}, \end{aligned}$$

where $\xi \geq 0$ is the multiplier on the regulatory constraint. The first-order conditions with respect to M and L are given by

$$\frac{R^b - R^m}{R^m} = \pi \left(\frac{1}{k} - 1 \right) + \frac{\eta}{k} + \xi \mu,$$

$$q(R^b - 1) = \pi \left(\frac{1}{k} - 1 \right) + q \frac{\eta}{k} + \xi q,$$

which can be combined to yield

$$\frac{R^b - R^m}{R^m} - q(R^b - 1) - (1 - q)\frac{\eta}{k} = \xi(\mu - q).$$

It is easily verified that, when evaluated at the constrained-efficient allocation k^{**} and η^{**} , the left-hand side of this expression is equal to zero. Hence, the regulator can implement the constrained-efficient allocation as a competitive equilibrium by setting $\mu = q$, in which case the Lagrangian multiplier is equal to

$$\xi = \frac{R^b(R^m - 1)}{(1 - q)R^m}.$$

References

- Acharya, Viral V., Hyun Song Shin, and Tanju Yorulmazer (2011). "Crisis Resolution and Bank Liquidity." *Review of Financial Studies*, 24, 2166–2205.
- Ahnert, Toni and Enrico C. Perotti (2015). "Cheap but Flighty: How Global Imbalances Create Financial Fragility." CEPR Discussion Papers 10502, Centre for Economic Policy and Research, London. <https://ideas.repec.org/p/cpr/ceprdp/10502.html>, Accessed March 27, 2019.
- Allen, Franklin and Douglas Gale (1998). "Optimal Financial Crises." *Journal of Finance*, 53, 1245–1284.
- Allen, Franklin and Douglas Gale (2004a). "Financial Fragility, Liquidity and Asset Prices." *Journal of the European Association*, 2, 1015–1048.
- Allen, Franklin and Douglas Gale (2004b). "Financial Intermediaries and Markets." *Econometrica*, 72, 1023–1061.
- Allen, Franklin and Douglas Gale (2017). "How Should Bank Liquidity be Regulated"? In *Achieving Financial Stability Challenges to Prudential Regulation*. World Scientific, pp. 135–157. https://ideas.repec.org/h/wsi/wsichap/9789813223400_0011.html, Accessed March 27, 2019.
- Almazan, Andres (2002). "A Model of Competition in Banking: Bank Capital vs Expertise." *Journal of Financial Intermediation*, 11, 87–121.
- Benigno, Gianluca, Huigang Chen, Christopher Otrok, Alessandro Rebucci, and Eric Young (2010). "Revisiting Overborrowing and Its Policy Implications." CEPR Discussion Papers 7872, Centre for Economic Policy and Research, London, Accessed on March 27, 2019.
- Benigno, Gianluca, Huigang Chen, Christopher Otrok, Alessandro Rebucci, and Eric Young (2013). "Financial Crises and Macro-Prudential Policies." *Journal of International Economics*, 89, 453–470.
- Bernanke, Ben and Mark Gertler (1989). "Agency Costs, Net Worth, and Business Fluctuations." *American Economic Review*, 79, 14–31.
- Bhattacharya, Sidipto and Douglas Gale (1987). "Preference Shocks, Liquidity and Central Bank Policy." In *New Approaches to Monetary Economics*, edited by William Barnett and Kenneth Singleton. Cambridge University Press, pp. 69–88.
- Bianchi, Javier (2011). "Overborrowing and Systemic Externalities in the Business Cycle." *American Economic Review*, 101, 3400–3426.
- Bianchi, Javier, Juan Carlos Hatchondo, and Leonardo Martinez (2013). "International Reserves and Rollover Risk." IMF Working Papers 13/33, International Monetary Fund.
- BIS (2017). "High-Level Summary of Basel III Reforms." *Basel Committee on Banking Supervision*, Bank for International Settlements.
- Bologna, Pierluigi, Arianna Miglietta, and Anatoli Segura (2018). "Contagion in the CoCos market? A Case Study of Two Stress Events." Temi di discussione (economic working papers) 1201, Bank of Italy, Economic Research and International Relations Area. https://ideas.repec.org/p/bdi/wptemi/td_1201_18.html, Accessed March 27, 2019.

- Brunnermeier, Markus K. and Lasse Heje Pedersen (2009). "Market Liquidity and Funding Liquidity." *Review of Financial Studies*, 22, 2201–2238.
- Caballero, Ricardo J. and Arvind Krishnamurthy (2001). "International and Domestic Collateral Constraints in a Model of Emerging Market Crises." *Journal of Monetary Economics*, 48, 513–548.
- Caballero, Ricardo J. and Arvind Krishnamurthy (2003). "Excessive Dollar Debt: Financial Development and Underinsurance." *Journal of Finance*, 58, 867–894.
- Caballero, Ricardo J. and Arvind Krishnamurthy (2004). "Smoothing Sudden Stops." *Journal of Economic Theory*, 119, 104–127.
- Calomiris, Charles, Florian Heider, and Marie Hoerova (2015). "A Theory of Bank Liquidity Requirements." Columbia Business School research paper.
- Cerutti, Eugenio, Ricardo Correa, Elisabetta Fiorentino, and Esther Segalla (2016). "Changes in Prudential Policy Instruments—A New Cross-Country Database." International Finance Discussion Papers 1169, Board of Governors of the Federal Reserve System (United States).
- Cordella, Tito, Pablo Federico, Carlos Vegh, and Guillermo Vuletin (2014). "Reserve Requirements in the Brave New Macprudential World." Policy Research Working Paper Series 6793, The World Bank. <https://ideas.repec.org/p/wbk/wbrwps/6793.html>, Accessed March 27, 2019.
- Covas, Francisco and John C. Driscoll (2014). "Bank Liquidity and Capital Regulation in General Equilibrium." Finance and Economics Discussion Series 2014-85, Board of Governors of the Federal Reserve System (United States). <https://ideas.repec.org/p/fip/fedgfe/2014-85.html>, Accessed March 27, 2019.
- Davila, Eduardo and Anton Korinek (2018). "Pecuniary Externalities in Economies with Financial Frictions." *Review of Economic Studies*, 85, 352–395.
- De Nicolo, Gianni, Andrea Gamba, and Marcella Lucchetta (2012). "Capital Regulation, Liquidity Requirements and Taxation in a Dynamic Model of Banking." IMF Working Papers 12/72, International Monetary Fund. <https://ideas.repec.org/p/imf/imfwpa/12-72.html>, Accessed March 27, 2019.
- Dell'Ariccia, Giovanni and Robert Marquez (2006). "Competition Among Regulators and Credit Market Integration." *Journal of Financial Economics*, 79, 401–430.
- Diamond, Douglas W. and Raghuram G. Rajan (2011). "Fear of Fire Sales, Illiquidity Seeking, and Credit Freezes." *Quarterly Journal of Economics*, 126, 557–591.
- Diamond, D. W. and A. K. Kashyap (2016). *Liquidity Requirements, Liquidity Choice, and Financial Stability, Handbook of Macroeconomics*, Vol. 2. Elsevier, pp. 2263–2303. <https://ideas.repec.org/h/eee/macchp/v2-2263.html>, Accessed March 27, 2019.
- Draghi, Mario (2017). "Building on the Achievements of Post-Crisis Reforms." <https://www.ecb.europa.eu/press/key/date/2017/html/ecb.sp170921.en.html>, retrieved 29 January 2019.
- Farhi, Emmanuel, Mikhail Golosov, and Aleh Tsyvinski (2009). "A Theory of Liquidity and Regulation of Financial Intermediation." *Review of Economic Studies*, 76, 973–992.
- Farhi, Emmanuel and Ivan Werning (2012). "Dealing With the Trilemma: Optimal Capital Controls With Fixed Exchange Rates." NBER Working Papers 18199, NBER.
- Federico, Pablo, Carlos A. Vegh, and Guillermo Vuletin (2014). "Reserve Requirement Policy over the Business Cycle." IMES Discussion Paper Series 14-E-06, Institute for Monetary and Economic Studies, Bank of Japan. <https://ideas.repec.org/p/ime/imedps/14-e-06.html>, Accessed March 27, 2019.
- Fisher, Irving (1933). "The Debt-Deflation Theory of Great Depressions." *Econometrica*, 1, 337–357.
- Fuentes, Ignacio and Juan Carlos Casado (2017). "Contingent Convertible Bonds and Subordinated Debt of Euro Area Credit Institutions." *Economic bulletin*, Banco de España (DIC), pp. 1–9.
- Gale, Douglas and Piero Gottardi (2015). "Capital Structure, Investment, and Fire Sales." *Review of Financial Studies*, 28, 2502–2533.
- Gale, Douglas and Tanju Yorulmazer (2013). "Liquidity Hoarding." *Theoretical Economics*, 8, 291–324.
- Gale, Douglas and Tanju Yorulmazer (2017). "Bank Capital Structure, Fire Sales, and the Social Value of Deposits." SSRN: <https://ssrn.com/abstract=2946332>, Accessed March 27, 2019.

- Geerolf, Francois (2019). "Asset Pricing with Heterogeneous Intermediaries." Technical report, UCLA, Los Angeles. <https://fgeerolf.com/asset-pricing.pdf>, Accessed April 17, 2019.
- Gersbach, Hans and Jean-Charles, (2012). "Aggregate Investment Externalities and Macroprudential Regulation." *Journal of Money, Credit and Banking*, 44, 73–109.
- Gorton, Gary and Lixin Huang (2004). "Liquidity, Efficiency, and Bank Bailouts." *American Economic Review*, 94, 455–483.
- He, Zhiguo and Péter Kondor (2016). "Inefficient Investment Waves." *Econometrica*, 84, 735–780.
- (2013). "Key Aspects of Macroprudential Policy." Technical report, International Monetary Fund.
- Jeanne, Olivier (2016). "The Macroprudential Role of International Reserves." *American Economic Review*, 106, 570–573.
- Jeanne, Olivier and Anton Korinek (2010). "Managing Credit Booms and Busts: A Pigouvian Taxation Approach." NBER Working Papers 16377, NBER.
- Jeanne, Olivier and Anton Korinek (2013). "Macroprudential Regulation Versus Mopping up After the Crash." NBER Working Papers 18675, NBER.
- Jeanne, Olivier and Damiano Sandri (2016). "Optimal Reserves in Financially Closed Economies." NBER Working Papers 22139, NBER.
- Kara, Gazi and S. Mehmet Ozsoy (2019). "Bank Regulation Under Fire Sale Externalities." *The Review of Financial Studies*, <https://doi.org/10.1093/rfs/hhz117>.
- Kiyotaki, Nobuhiro and John Moore (1997). "Credit Cycles." *Journal of Political Economy*, 105, 211–248.
- Korinek, Anton (2018). "Regulating Capital Flows to Emerging Markets: An Externality View." *Journal of International Economics*, 111, 61–80.
- Korinek, Anton and Alp Simsek (2016). "Liquidity Trap and Excessive Leverage." *American Economic Review*, 106, 699–738.
- Lorenzoni, Guido (2008). "Inefficient Credit Booms." *Review of Economic Studies*, 75, 809–833.
- Lucas, André, Julia Schaumburg, and Bernd Schwaab (2019). "Bank Business Models at Zero Interest Rates." *Journal of Business & Economic Statistics*, 37, 542–555.
- Malherbe, Frederic (2014). "Self-Fulfilling Liquidity Dry-ups." *Journal of Finance*, 69, 947–970.
- Malherbe, Frederic (2015). "Optimal Capital Requirements Over the Business and Financial Cycles." Working Paper Series 1830, European Central Bank. <https://ideas.repec.org/p/ecb/ecbwps/20151830.html>, Accessed March 27, 2019.
- Mendoza, Enrique G. (2010). "Sudden Stops, Financial Crises, and Leverage." *American Economic Review*, 100, 1941–1966.
- Perotti, Enrico and Javier Suarez (2011). "A Pigovian Approach to Liquidity Regulation." *International Journal of Central Banking*, 7, 3–41.
- Piacentino, Giorgia, Anjan Thakor, and Jason Donaldson (2018). "Warehouse Banking." *Journal of Financial Economics*, 129, 250–267.
- Repullo, Rafael (2005). "Liquidity, Risk Taking, and the Lender of Last Resort." *International Journal of Central Banking*, 1, 47–80.
- Schmitt-Grohe, Stephanie and Martín Uribe (2016). "Downward Nominal Wage Rigidity, Currency Pegs, and Involuntary Unemployment." *Journal of Political Economy*, 124, 1466–1514.
- Segura, Anatoli and Javier Suarez (2017). "How Excessive Is Banks' Maturity Transformation?" *Review of Financial Studies*, 30, 3538–3580.
- Shleifer, Andrei and Robert W. Vishny (1992). "Liquidation Values and Debt Capacity: A Market Equilibrium Approach." *Journal of Finance*, 47, 1343–1366.
- Stein, Jeremy (2012). "Monetary Policy as Financial Stability Regulation." *Quarterly Journal of Economics*, 127, 57–95.
- Trichet, Jean-Claude (2011). "The ECB's Response to the Crisis." European Central Bank, <https://www.ecb.europa.eu/press/key/date/2011/html/sp110526.en.html>, retrieved 29 January 2019.
- Walther, Ansgar (2016). "Jointly Optimal Regulation of Bank Capital and Liquidity." *Journal of Money, Credit and Banking*, 48, 415–448.

Supplementary Data

Supplementary data are available at [JEEA](#) online.