The Rise of Intangible Capital and Financial Fragility*

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Abstract

This paper studies financial instability in an economy where growth is driven by intangible investment. Firms' intangible investment (R&D) creates new productive capital. Once created, capital can be sold to financial intermediaries. Since intangible investment is not pledgeable, firms carry cash, which is inside money issued by intermediaries (short-term safe debt). In good times, well capitalized intermediaries push up the price of capital. This motivates firms to create more capital, but to do so, they must build up cash holdings. As firms' money demand expands, the yield on inside money (i.e. intermediaries' debt cost) declines, so intermediaries increase leverage and push up capital price even further. Thus, the model generates booms that share several features with the U.S. experience before the Great Recession: the rise of corporate cash holdings, the expansion of the financial sector through leverage, increases in asset price, and the decline of interest rate. The model generates endogenous risk accumulation: a longer period of boom and expansion of the financial sector predict a more severe crisis. In crises, the spiral flips, leading to sudden deleveraging of intermediaries and depressed intangible investment.

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1 Introduction

The U.S. economy exhibited five trends in the two decades leading up to the Great Recession:

Fact 1: The U.S. economy was transforming from a manufacturing-based economy to a more intangible-intensive economy. The production of goods and services increasingly relied on intangible capital, such as knowledge capital, organizational capital, and brand names. According to Corrado and Hulten (2010), intangible investment overtook physical investment as the largest source of economic growth in the United States in the period of 1995-2007.

Fact 2: An increasing share of non-financial corporations' assets were cash holdings (Bates, Kahle, and Stulz (2009)). "Cash" includes bank deposits and shares of money market mutual funds that are in turn portfolios of financial intermediaries' liabilities, such as repurchase agreements and asset-backed commercial papers. The rise of corporate cash holdings came from the growing R&D-intensive sectors (Falato and Sim (2014); Begenau and Palazzo (2015); Pinkowitz, Stulz, and Williamson (2015); Graham and Leary (2015)).

Fact 3: In the Untied States, the assets held by the financial sector increased dramatically (Gorton, Lewellen, and Metrick (2012)). More generally in advanced economies, Schularick and Taylor (2012) find that the bank loan-to-GDP ratio doubled in the last two decades. The growth of the financial sector was fueled by high leverage, especially through the issuance of money-like securities (or short-term safe debt) (Adrian and Shin (2010); Gorton (2010); Gorton and Metrick (2012); Pozsar (2014)).

Fact 4: Interest rate declined steadily.

Fact 5: The price of risky assets increased across asset classes.

Despite extensive debates on the forces behind these trends and their macroeconomic implications, there are relatively few theories that analyze these phenomena jointly. Motivated by Fact 1, this paper builds a model that reproduces Fact 2, 3, 4, and 5. By jointly explaining these facts, the model also reveals a new mechanism of financial instability that delivers several implications that are consistent with the findings in a surging empirical literature: a longer period of bank expansion precedes a sharper decline of bank equity (Baron and Xiong (2016)) and a more severe economic recession (Jordà, Schularick, and Taylor (2013)). At the center of the mechanism is financial intermediaries' role as inside money creators.

Before diving into the theoretical setup and mechanism, let us connect these five facts from the perspective of financial friction. The rising share of productive capital that is intangible implies a shrinkage of pledgeable assets (i.e., physical capital, such as properties, plants, and equipments). As a result, the corporate sector hoards more cash in anticipation of liquidity needs, for instance, investments in intangibles (e.g., R&D). Cash takes the form of the financial sector's short-term safe debt, such as deposits, which are directly used as means of payment, and money-like securities that are close substitutes to money.

Therefore, a rising corporate money demand feeds leverage to the financial sector, and as a result, financial intermediaries are able to acquire more assets. Moreover, because the financial sector tends to be better suited to manage risky assets than other sectors, and thus, assign a higher asset value, the expansion of their purchasing power pushes up asset prices. The rising corporate money demand also pushes down the interest rate. In fact, because of the introduction of money market mutual funds and the repeal of Regulation Q, money is interest-paying (Lucas and Nicolini (2015)). When the demand rises, the yield on money (i.e., the interest rate) declines.

I build a continuous-time model of dynamic economy that crystallizes this narrative. At the center are two key ingredients. First, the cash that firms desire is short-term safe debt issued by bankers (i.e., inside money).[1] Second, the risky asset price depends on intermediaries balance-sheet capacity, because intermediaries assign a higher value to risky assets than the rest of the economy, and thus, are the natural buyers in the sense of Shleifer and Vishny (1992). These two ingredients lead to two reinforcing mechanisms of instability, the inside money channel and the balance-sheet channel.

The economy has two sectors, bankers and entrepreneurs. Both types consume generic goods that are produced by capital. Capital is traded in a competitive market. The aggregate shock ("macro shock") arrives at Poisson times with a constant intensity. When the shock hits, a fraction of capital is destroyed. However, less capital is destroyed when held by bankers. This expertise to rescue value from failed assets echoes Bolton and Freixas (2000). Due to this

[1]The term, inside money, is borrowed from Gurley and Shaw (1960). From the private sector's perspective, gold, fiat money, or government securities are in positive supply ("outside money"), while as bank liabilities, deposits are in zero net supply ("inside money"). See Lagos (2008) for a brief review of the related literature.

expertise, bankers assign a higher value to capital than entrepreneurs. In equilibrium, bankers borrow from entrepreneurs, holding a levered position in capital.

Following a macro shock, asset price declines, because bankers lose wealth (equity) and purchasing power. I assume that bankers cannot recapitalize by issuing equity to entrepreneurs. This friction gives rise to the following balance-sheet channel of shock amplification. As capital price declines, bankers' equity is further eroded due to the downward reevaluation of their assets, and a lower level of bankers' equity leads to a further decrease in capital price. This mechanism has been well explored in the macro finance literature (e.g., Brunnermeier and Sannikov (2014)).

The theoretical contribution of this paper is the inside money channel, which is built upon the balance-sheet channel and amplifies it. Entrepreneurs have opportunities to create new capital from goods. These opportunities arrive at idiosyncratic Poisson times with constant intensity. I assume the creation of capital is immediate. Investment can be interpreted as an R&D or prototype stage that happens instantaneously. Once it is done, new capital is created (or matures), and can be readily sold in the market. Entrepreneurs can only issue up to θ fraction of the shares of investment project ($\theta < 1$), and thus, they need to invest out of their own pocket. The requirement of insiders' stake can be motivated by the fact that entrepreneurs' inalienable human capital is needed for capital creation (Hart and Moore (1994)).

Moreover, I assume that only ϕ (< 1) fraction of entrepreneurs' holdings of existing capital contributes to internal liquidity (i.e., can be readily pledged or sold), which intends to capture the limited pledgeability of intangible capital. To justify this assumption, consider a technology of creating worthless counterfeits out of thin air that comes along with the investment technology to entrepreneurs. Outsiders can only examine up to ϕ fraction of inventory. This information friction captures the difficulty to measure intangible capital, such as organizational capital, as its effectiveness tends to be better appraised by insiders. Thus, ϕ is called "tangibility". In contrast, money (i.e. bank debt) is perfectly liquid: every dollar of it can be used to purchase investment inputs. The superior liquidity of bank debt (or inside money) is a key ingredient. Because of this, entrepreneurs assign a liquidity premium to bank debt, which lowers bankers' borrowing cost. Because liquidity is used for investment, this liquidity premium depends on the endogenous capital price, leading to the following feedback mechanism.

Consider a calm period without any macro shock ("boom"). Bankers accumulate wealth through their levered position on capital. As capital price increases, the balance-sheet channel implies a feedback loop: an upward reevaluation of capital increases bankers' wealth even further, which in turn leads to an even higher capital price.

However, the story does not end here. Because capital is worth more, entrepreneurs want to create more capital, but to do so, they must build up savings, and ideally in the most liquid form (i.e., inside money). A higher marginal value of money holdings from investment translate into a higher liquidity premium assigned to bank debt, which lowers bankers borrowing cost and encourages them to expand balance sheets by taking on more debt. As the banking sector grows via both equity accumulation and debt issuance, asset price increases even further. This feedback loop is the inside money channel.

In a boom, the mutual reinforcement of the balance-sheet channel and the inside money channel leads to higher capital price, lower interest rate (bankers' debt cost), the growth of the banking sector, and the growth of entrepreneurs' money holdings. Along the process, endogenous risk accumulates. In particular, endogenous risk is measured by the difference between the current capital price and the post-shock capital price (i.e., the new equilibrium price after the macro shock hits). This wedge widens as the boom prolongs.

Endogenous risk accumulates in a boom precisely because of the increasing capital price. What differentiates bankers and entrepreneurs as capital holders are two-fold: first, the macro shock destroys a smaller fraction of bankers' holdings; second, bankers do not face the capital illiquidity problem that entrepreneurs face at the times of investment ($\phi < 1$). When capital price is higher and investment more profitable, capital illiquidity is more costly for entrepreneurs. Therefore, the second difference between bankers and entrepreneurs as capital holders widens as capital price increases. When the macro shock hits, destroying bankers' wealth and triggering capital reallocation towards entrepreneurs (the second-best capital holders), the downward reevaluation of capital is more severe if the economy has not experienced any shocks for a long period of time and capital price is at a very high level.

The positive feedback loops turn into vicious cycles when the macro shock hits. The

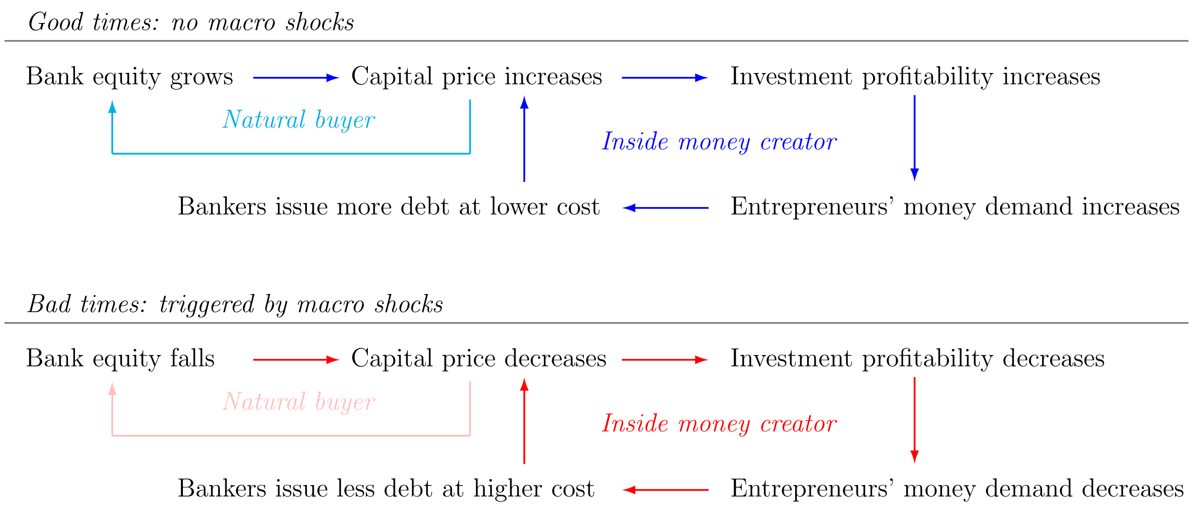

Figure 1: Money Supply and Demand.

initial destruction of capital reduces bankers' wealth, and triggered the balance-sheet channel that amplifies the negative effect on capital price. The decline of capital price discourages entrepreneurs' investment, which in turn leads to a lower money demand and a small liquidity premium assigned to bank debt. Therefore, bankers have to borrow at a relatively higher cost, so their balance sheet shrinks via both equity destruction and deleveraging. As natural buyers retreat from the market, capital price decreases even further. The downward spiral of capital price leads to lower investments by entrepreneurs. Figure 1 illustrates the mechanisms.

Literature. The structural change towards a new economy that is intangible-intensive has attracted a lot of attention (Corrado and Hulten (2010)). Several studies explore the implications of this structural change in different areas from both theoretical and empirical perspectives, such as Atkeson and Kehoe (2005) (productivity accounting), McGrattan and Prescott (2010) (current account dynamics), Eisfeldt and Papanikolaou (2014) (asset pricing), and Peters and Taylor (2016) (corporate investment). This paper looks into the financial stability issue of an intangible economy. While there is a large literature on how financial development affects industrial structure (e.g, Levine (1997); Rajan and Zingales (1998)), the reverse question, how industrial structure affects the financial system, has largely been unexplored.

This paper contributes to the literature of heterogeneous-agent models of macroeconomy. A key friction in this literature is the limited risk-sharing between sectors, which in this paper, corresponds to the assumption that bankers cannot recapitalize by issuing equity to entrepreneurs. Noted by Di Tella (2014), perfect risk-sharing shuts down the balance-sheet channel (e.g., Kiyotaki and Moore (1997); Bernanke and Gertler (1989)). A large literature explores the macroeconomic and asset pricing implications of dynamic wealth distribution among heterogeneous agents (e.g., Basak and Cuoco (1998); Krusell and Smith (1998); Longstaff and Wang (2012); He and Krishnamurthy (2013); Brunnermeier and Sannikov (2014); Moll (2014)). This paper contributes to this literature by highlighting a particular dimension of heterogeneity (i.e., bankers as money suppliers and entrepreneurs as money demanders) that leads to a new feedback loop that interacts with the balance-sheet channel.

A recent literature revives the money view of financial intermediation that emphasizes the liabilities of financial intermediaries as inside money that lubricates the economy by facilitating trades (Kiyotaki and Moore (2000); Hart and Zingales (2014); Quadrini (2014); Piazzesi and Schneider (2016)). This paper takes a step further by embedding this money view in an entrepreneurial economy that suffers from capital and investment illiquidity.[2] The $\theta - \phi$ framework that leads to entrepreneurs' money demand is inspired by Kiyotaki and Moore (2012) who study the outside money (or fiat money) whose supply is intervened by the government instead of the inside money issued within the private sector by bankers.

In this paper, bankers add value to the economy by providing liquidity – securities that can be hoarded by financially constrained entrepreneurs to meet liquidity needs. Woodford (1990), Holmström and Tirole (1998), and Farhi and Tirole (2011) study the private sector's capacity to create liquidity and potential government intervention in liquidity supply. This paper highlights a particular sector, the banking sector, as liquidity providers, and thereby, links banks' balance-sheet capacity to the liquidity available for entrepreneurs to hoard for capital creation, and also links entrepreneurs' liquidity demand to the leverage of banks who are the natural buyers of risky capital created by entrepreneurs.

From the empirical side, this paper is inspired by the literature of corporate cash holdings (e.g., Opler et al. (1999); Bates, Kahle, and Stulz (2009)). Many have found a secular

[2] Safe debt serves as money, which echoes the literature that links the information insensitivity of assets' payout to assets' monetary services (Gorton and Pennacchi (1990); Holmström (2012); Dang et al. (2014)).

increase of nonfinancial firms' cash holdings in the last few decades that was driven by cash held in the R&D-intensive sectors (e.g., Falato and Sim (2014); Begenau and Palazzo (2015); Pinkowitz, Stulz, and Williamson (2015); Graham and Leary (2015)). Physical capital, such as properties, plants, and equipments, support firms' borrowing by serving as collateral (Almeida and Campello (2007)). The structural transformation towards an intangible economy implies a shrinkage of pledgeable assets in the productive sector, and thus, a stronger liquidity hoarding incentives of firms. As pointed out by Pozsar (2011), corporate treasuries have become a prominent component of "institutional cash pools" that feed leverage to the financial sector, particularly through the money markets.[3]

The theoretical literature on corporate cash holdings commonly focuses only on firms' decision to save (e.g., Bolton, Chen, and Wang (2011); Froot, Scharfstein, and Stein (1993)). This partial equilibrium approach allows modeling a rich environment of corporate decision making, but by assuming a perfectly elastic supply of storage, the models sever the link between firms' money demand dynamics and the equilibrium yield on money (i.e., the interest rate paid by money-like securities). By endogenizing money supply, my model predicts that the growth of corporate money demand leads to low interest rate and the growth of the financial sector who supplies money, and thereby, linking these three phenomena in a coherent framework that puts inside money at the center.

Finally, the model produces the endogenous risk accumulation in a boom, which has been documented by a surging literature. Schularick and Taylor (2012) find the expansion of bank asset (loans) precedes financial crises in advanced economies.[4] In the model, a longer period of bank expansion predicts more severe crises. Jordà, Schularick, and Taylor (2013)

[3] Several papers have made the point that the growth of the shadow banking sector is fueled by the demand of money-like securities (e.g., Gorton (2010); Gorton and Metrick (2012); Stein (2012); Pozsar (2014).

[4] In line with Bordo et al. (2001) and Reinhart and Rogoff (2009), Schularick and Taylor (2012) define financial crises as events during which a country's banking sector experiences bank runs, sharp increases in default rates accompanied by large losses of capital that result in public intervention, bankruptcy, or forced merger of financial institutions. Using the information from credit spreads, Krishnamurthy and Muir (2016) are able to achieve a sharper differentiation between financial and non-financial crises, and thus, provide a granular identification of financial crises. They also find that bank credit expansion precedes financial crises. Using both the information from credit spreads and the composition change of corporate bond issuance, López-Salido, Stein, and Zakrajšek (2015) find that when the issuance of high-yield ("junk") bond outpaces the total bond issuance, and when corporate bond credit spreads are narrow relative to their historical norms, the subsequent real GDP growth, investment, and employment tend to slow down.

document a close relationship between the build-up of bank credit and the severity of the subsequent recessions. Moreover, when the economy is hit by the macro shock, the decrease of bank equity is larger when the preceding boom is longer, which is consistent with the findings by Baron and Xiong (2016) that bank credit expansion predicts bank equity crashes. The key to risk accumulation is the combination of the balance-sheet channel and the inside money channel: due to the investment-driven liquidity demand of entrepreneurs, the difference between the first-best and second-best buyers of capital widens in booms, and thus, triggered by the macro shock, the reallocation from the first-best to the second-best buyers has a stronger impact on capital price.

The rest of the paper is organized as follows. Section 2 introduces the model and discusses the main mechanisms. In section 3, the performances of the fully solved model demonstrate the mechanisms. Section 4 concludes.

2 Model

2.1 Setup

Consider a continuous-time, infinite-horizon economy with two types of agents, bankers and entrepreneurs. Each type has a continuum of representative agents with measure equal to one.

Preferences. Both types of agents maximize expected logarithm utility with discount rate ρ:

$$E\left[\int_{t=0}^{\infty} e^{-\rho t} \ln\left(c_t^i\right) dt\right], i \in \{f, nf\}. \tag{1}$$

Throughout this paper, subscripts denote time, and superscripts denote types or sectors with "f" being the financial sector (bankers) and "nf" being the non-financial sector (entrepreneurs). For example, c_t^{nf} is the representative entrepreneur's consumption at time t.

Capital and aggregate shock. At time t, the economy has K_t units of capital that produces non-durable generic goods for consumption and investment. One unit of capital produces a units of goods per unit of time (a is a positive constant). Both entrepreneurs and bankers can own capital, and capital is traded in a competitive market at price q_t (denominated in goods).

At Poisson times with intensity equal to λ, a certain fraction of capital is destroyed. The random arrival of capital destruction is the only source of aggregate uncertainty in this economy (i.e., the "macro shock"). Bankers and entrepreneurs differ in their ability to deal with the capital destruction shocks. When capital is owned by bankers, a fraction $\underline{\delta}$ of capital is destroyed when the macro shock hits. When capital is owned by entrepreneurs, a fraction $\overline{\delta}$ is destroyed. I assume $\underline{\delta} < \overline{\delta}$ so that bankers are better at dealing with capital destruction.

We can interpret capital as efficiency units or production projects, so the assumption $\underline{\delta} < \overline{\delta}$ captures bankers' expertise in restructuring distressed projects (Bolton and Freixas (2000)). Since bankers assign a higher value to capital, when they are undercapitalized, and thus, less willing to hold risky capital, the equilibrium capital price declines. In other words, the market fails to reflect the full value of capital when bankers' risk-taking capacity is limited. In this paper, the term "market illiquidity" captures the constrained capacity of natural buyers in the sense of Shleifer and Vishny (1992) and Brunnermeier and Sannikov (2014) instead of transaction costs or other trading frictions (reviewed by Vayanos and Wang (2013)).[5]

Investment and inside money. Entrepreneurs have opportunities to create new capital. Investment opportunities arrive at idiosyncratic Poisson times with constant intensity λ_I, where the subscript "I" stands for both idiosyncratic and investment.[6] Thus, every instant, a constant fraction $\lambda_I dt$ of entrepreneurs make investments. They can convert one unit of goods into one unit of capital instantaneously. This investment is scalable, so when $q_t > 1$, entrepreneurs want to invest as much as possible. The scale of investment is limited by financial frictions.

To create one unit of capital that is worth q_t, entrepreneurs can issue up to θ fraction of equity to competitive investors including non-investing entrepreneurs and bankers ("outside equity"). They must invest $(1 - \theta q_t)$ out of their own pocket ("inside equity"). Once the capital is created, entrepreneurs deliver θ units of capital to outside investors and retain $(1 - \theta)$

[5]Other specifications of financial intermediaries' "specialnes" may serve the same purpose of making bankers the natural buyer of capital, such as intermediaries' lower risk aversion (Longstaff and Wang (2012)), their collateralization expertise (Rampini and Viswanathan (2015)), their unique ability to hold risky assets (He and Krishnamurthy (2013)), their unique ability to monitor projects (Diamond (1984) and Holmström and Tirole (1997)), and their advantage in diversification (Brunnermeier and Sannikov (2016)).

[6]These idiosyncratic investment shocks are not insurable; otherwise, entrepreneurs will not have liquidity needs, which is a critical ingredient of this model.

units that are worth $(1-\theta)\,q_t$. Therefore, the investment return on internal equity ("ROI") is

$$ROI_t = \frac{(1-\theta)\,q_t}{1-\theta q_t}. \tag{2}$$

It increases in the capital price q_t through the unlevered return $(1-\theta)\,q_t$ and the leverage on internal equity $\frac{1}{1-\theta q_t}$. The limited pledgeability of investment can arise because entrepreneurs' inalienable human capital is required in the R&D or prototype stage, and thus, entrepreneurs must hold a stake to credibly commit to work (Hart and Moore (1994)). Once they input their effort and the prototype becomes mature or commercialized, productive capital is created. Capital creation take place sequentially within an instant.

Internal funds come from two sources: entrepreneurs' holdings of existing capital and their holdings of money. Only a fraction ϕ of their existing capital can be readily sold in exchange for goods as investment inputs ($\phi < 1$). The illiquidity arises from an information friction. I assume that in addition to the capital creation technology, investing entrepreneurs can also create counterfeits that are indistinguishable from productive capital. Investors can verify the quality of capital up to ϕ fraction of entrepreneurs' inventory.[7]

In contrast, entrepreneurs can exchange all of their money holdings for goods. Money is short-term safe debt issued by bankers. At time t, bankers' issues debt that matures at $t+dt$ and pays a risk-free market interest rate r_t. Entrepreneurs carry bank debt ("inside money") as a perfect means of payment in anticipation of investment needs.[8] Money lubricates the economy by facilitating goods reallocation towards investing entrepreneurs. The moneyness of safe debt echoes the theories that links assets' information insensitivity to their monetary services (e.g., Gorton and Pennacchi (1990); Holmström (2012); Dang et al. (2014)).

Discussion: intangible economy. The $\theta-\phi$ framework is motivated by advanced economies' increasing reliance on intangibles in the production, such as design, brand names, firms' proprietary technology, and entrepreneurs' human capital.[9] The financial stability implications

[7]Note that non-investing entrepreneurs do not have access to the counterfeit technology, so they do not face the illiquidity of capital. Whether an entrepreneur is investing or not is public information.

[8]The term is borrowed from Gurley and Shaw (1960). From the private sector's perspective, fiat money and government securities are in positive supply ("outside money"), while deposits, as bank liabilities, are in zero net supply ("inside money"). See Lagos (2008) for a brief review of the related literature.

[9]According to Corrado and Hulten (2010), intangible investment has overtaken physical investment as the

of this structural change has largely remained unexploited. The assumption $\theta < 1$ captures the fact that firms' intangible investment is largely financed by internal liquidity.[10] The assumption $\phi < 1$ captures the fact that it is difficult to measure intangible capital.[11] Capital represents production (revenue-generating) units, which could simply be a particular design of common products. It is often difficult measure the quality of such intangible capital.

From a theoretical perspective, this paper adopts the $\theta - \phi$ framework in Kiyotaki and Moore (2012) to analyze the dynamics and stability implications of inside money creation.[12] Kiyotaki and Moore (2012) focuses on outside money (fiat money) that is supplied by government instead of private entities (banks) that engage in dynamic balance-sheet management.

2.2 Markov equilibrium

Wealth evolution. Let n_t^i denote the net worth (wealth) of a representative agent in sector i ($i \in \{f, nf\}$). I characterize a Markov equilibrium where η_t, the fraction of aggregate wealth in the banking sector is the only aggregate state variable:

$$\eta_t = \frac{n_t^f}{n_t^f + n_t^{nf}}, \tag{3}$$

which has a deterministic growth rate μ_t^η ($:= \frac{d\eta_t/dt}{\eta_t}$) before the macro shock hits. Note that because both production and investment have constant return to scale, the economy is scale-free, so the aggregate capital stock K_t is not a state variable.[13]

In a Markov equilibrium, all endogenous variables are functions of η_t. Their dynamics

largest source of economic growth in the United States in the period of 1995-2007.

[10] In particular, R&D heavily relies on internal financing, which has been well documented since Hall (1992) and Himmelberg and Petersen (1994). Hall and Lerner (2009) review the literature on innovation financing.

[11] Corrado, Hulten, and Sichel (2005) and McGrattan and Prescott (2010) discuss the measurement of technology capital. Atkeson and Kehoe (2005) and Eisfeldt and Papanikolaou (2014) measure organization capital.

[12] The money or liquidity demand is investment-driven, in line with Holmström and Tirole (1998, 2001) and Eisfeldt and Rampini (2009). Eisfeldt (2007) show that the liquidity premium of securities such Treasury bills cannot be explained by a liquidity demand driven by consumption smoothing under standard preferences.

[13] Wealth or consumption share is a common state variable in the literature of heterogeneous-agent models, such Basak and Cuoco (1998), Longstaff and Wang (2012), and Brunnermeier and Sannikov (2014).

are linked to the dynamics of the state variable η_t, for example, before the macro shock hits,

$$\mu_t^q := \frac{dq_t/dt}{q_t} = \frac{q'(\eta_t)}{q(\eta_t)}\mu_t^\eta \eta_t,$$

As will be explained in detail later, in equilibrium, capital price increases in η_t (i.e., $q'(\eta_t) > 0$). Moreover, $q_t > 1$, because investing entrepreneurs cannot invest unlimited resources to close the wedge between q_t, the value of capital, and 1, the cost of creating capital.

Bankers and entrepreneurs allocate wealth between safe debt and risky capital. A short position in safe debt means borrowing.[14] Let x_t^i denote the fraction of wealth invested in capital ($i \in \{f, nf\}$). Before the macro shock hits, the flow of funds constraint (i.e. the evolution of wealth) is represented by a deterministic growth rate of wealth

$$\mu_t^{n^i} := \frac{dn_t^i/dt}{n_t^i} = \left(1 - x_t^i\right) r_t + x_t^i \left(\frac{a}{q_t} + \mu_t^q\right) - \frac{c_t^i}{n_t^i}, i \in \{f, nf\}. \tag{4}$$

The pre-shock return of capital holdings includes a dividend gain $\frac{a}{q_t}$ and a capital gain μ_t^q. In equilibrium, bankers borrows from entrepreneurs, so we have $x_t^f > 1$ and $x_t^{nf} < 1$.

A constant fraction $\lambda_I dt$ of entrepreneurs can make investments and experience a jump in their wealth. Because when $q_t > 1$, each dollar of inside equity will be worth ROI_t (> 1) after investment, investing entrepreneurs want to use all of these resources to maximize the scale of investment. Given their internal funds $\left[\phi x_t^{nf} + \left(1 - x_t^{nf}\right)\right] n_t^{nf}$, which is the sum of entrepreneurs' holdings of bank debt and their resalable or pledgeable capital holdings, their investment is given by the following Proposition.

Proposition 1 *At time t, if investment opportunities arrive, entrepreneurs will convert*

$$i_t = \left(\frac{1}{1 - \theta q_t}\right) \left[1 - (1 - \phi) x_t^{nf}\right] n_t^{nf}, \tag{5}$$

units of goods into new capital. The investment depends on internal liquidity, and through the leverage on internal equity $\frac{1}{1-\theta q_t}$, depends on capital price (Tobin's q). After investment, the

[14] Under log-utility, optimal consumption is proportional to wealth, and the Inada condition implies infinite marginal utility when wealth equals to zero. As a result, the agents always try to avoid bankruptcy and keep a positive net worth, and agents never default on debt.

investing entrepreneur's wealth jumps up to

$$\widehat{n}_t^{nf} = \left\{ROI_t\left[1-(1-\phi)\,x_t^{nf}\right]+(1-\phi)\,x_t^{nf}\right\}n_t^{nf}. \tag{6}$$

The liquid part of wealth (fraction $\left[1-(1-\phi)\,x_t^{nf}\right]$) is multiplied by the investment return on internal equity (i.e., ROI_t), and the value of the illiquid part of wealth (fraction $(1-\phi)\,x_t^{nf}$) stays the same. By holding more money instead of capital (i.e., decreasing x_t^{nf}), entrepreneurs can increase the positive jump in wealth when investment opportunities arrive. This is the benefit of holding inside money.

From bankers' and entrepreneurs' pre-shock wealth evolution, we can derive the dynamics of η_t. Before the macro shock hits, η_t follows a deterministic path with the following growth rate:

$$\begin{aligned}\mu_t^{\eta} &= \frac{d\eta_t/dt}{\eta_t}=\frac{n_t^{nf}}{\left(n_t^f+n_t^{nf}\right)}\left(\frac{dn_t^f/dt}{n_t^f}-\frac{dn_t^{nf}/dt}{n_t^{nf}}\right) \\ &= (1-\eta_t)\left\{\left(\frac{a}{q_t}+\mu_t^q-r_t\right)\left(x_t^f-x_t^{nf}\right)-\right. \\ &\quad \left.\lambda_I\left\{ROI_t\left[1-(1-\phi)\,x_t^{nf}\right]+(1-\phi)\,x_t^{nf}-1\right\}\right\},\end{aligned} \tag{7}$$

where the last line represents the wealth jump of the $\lambda_I dt$ measure of investing entrepreneurs. As will be confirmed by the model solution, the Markov equilibrium has a steady state η^* at which $\mu_t^{\eta}=0$. In equilibrium, bankers' wealth has a higher loading on the pre-shock excess return of capital ($x_t^f > x_t^{nf}$), but entrepreneurs' wealth grows via the creation of new capital. When the two forces balance each other ($\mu_t^{\eta}=0$), the economy reaches its steady state, and stays there until the macro shock hits.

When the shock hits, both sectors lose wealth. Denote the post-shock net worth as $\widetilde{n}_t^i$ ($i\in\{f,nf\}$). Let "$\sim$" denote the post-shock value. Bankers' wealth changes from n_t^f to $\widetilde{n}_t^f$:

$$\widetilde{n}_t^f=\left[\frac{\widetilde{q}_t}{q_t}\left(1-\underline{\delta}\right)x_t^f+\left(1-x_t^f\right)\right]n_t^f.$$

A fraction $1-\underline{\delta}$ of risky capital holdings remain and get re-evaluated at the post-shock price

$\widetilde{q}_t$. Entrepreneurs' wealth changes from n_t^{nf} to $\widetilde{n}_t^{nf}$:

$$\widetilde{n}_t^{nf} = \left[\frac{\widetilde{q}_t}{q_t}\left(1-\overline{\delta}\right)x_{t,k}^{nf} + \left(1 - x_t^{nf}\right)\right] n_t^{nf}.$$

Therefore, when the macro shock hits, η_t jumps to $\widetilde{\eta}_t$:

$$\widetilde{\eta}_t = \frac{\widetilde{n}_t^f}{\widetilde{n}_t^f + \widetilde{n}_t^{nf}} = \frac{\left[\frac{\widetilde{q}_t}{q_t}\left(1-\underline{\delta}\right)x_t^f + \left(1-x_t^f\right)\right]\eta_t}{\left[\frac{\widetilde{q}_t}{q_t}\left(1-\underline{\delta}\right)x_t^f + \left(1-x_t^f\right)\right]\eta_t + \left[\frac{\widetilde{q}_t}{q_t}\left(1-\overline{\delta}\right)x_t^{nf} + \left(1-x_t^{nf}\right)\right]\left(1-\eta_t\right)}. \tag{8}$$

Since all endogenous variables are functions of η_t, when η_t jumps to the new value $\widetilde{\eta}_t$, all the other variables also jump. For example, the capital price jumps from q_t to $\widetilde{q}_t$.

Proposition 2 *The Markov equilibrium has a single state variable η_t, whose dynamics are summarized in Equations (7) and (8).*

Optimization. Next, I will solve agents' optimal decisions. Let $V^f\left(n_t^f, \eta_t\right)$ denote a banker's value function, which depends on the individual's wealth and the aggregate state. The Hamilton–Jacobi–Bellman equation (HJB) is:

$$\rho V^f\left(n_t^f,\eta_t\right) = \max_{c_t^f\geq 0, x_t^f \geq 0} \ln\left(c_t^f\right) + \frac{\partial V^f}{\partial n_t^f}\mu_t^{n^f} n_t^f + \frac{\partial V^f}{\partial \eta_t}\mu_t^{\eta}\eta_t + \lambda\left[V^f\left(\widetilde{n}_t^f, \widetilde{\eta}_t\right) - V^f\left(n_t^f, \eta_t\right)\right].$$

The last term reflects the jump in value function when the net worth of jumps from n_t^f to $\widetilde{n}_t^f$ after the macro shock. The log utility implies the functional form of $V^f\left(n_t^f,\eta_t\right)$ is

$$V^f\left(n_t^f,\eta_t\right) = \frac{1}{\rho}\ln\left(n_t^f\right) + U^f\left(\eta_t\right).$$

After substituting this function into the HJB equation, we have the following proposition.

Proposition 3 *Bankers' optimal consumption (c_t^f) and leverage (i.e., capital-to-wealth ratio x_t^f) satisfy the following first-order conditions (F.O.C.) respectively:*

$$c_t^f = \rho n_t^f,$$

and

$$\frac{a}{q_t} + \mu_t^q - r_t \leq \lambda \left(\frac{1 - \frac{\widetilde{q}_t}{q_t}\left(1 - \underline{\delta}\right)}{1 - \left[1 - \frac{\widetilde{q}_t}{q_t}\left(1 - \underline{\delta}\right)\right] x_t^f} \right), \tag{9}$$

which hold in equality if $x_t^f > 0$.

In equilibrium, the F.O.C. condition for x_t^f holds in equality, because bankers always hold some risky capital (i.e., $x_t^f > 0$). Risk is measured by $1 - \frac{\widetilde{q}_t}{q_t}\left(1 - \underline{\delta}\right)$, the total loss per dollar of risky capital holdings (i.e., the different before the pre-shock value, 1, and the post-shock value, $\frac{\widetilde{q}_t}{q_t}\left(1 - \underline{\delta}\right)$). Risk has two components, the exogenous risk $\underline{\delta}$ and the endogenous risk $\frac{\widetilde{q}_t}{q_t}$ from capital reevaluation. Increasing one dollar investment in capital brings a potential loss of wealth equal to $1 - \frac{\widetilde{q}_t}{q_t}\left(1 - \underline{\delta}\right)$. Due to log utility, the marginal value of wealth is the reciprocal of wealth level, so the right-hand side of Equation (9) is the expected marginal loss of value by increasing leverage x_t^f. The left-hand side is the expected marginal gain, the excess return (i.e. the difference between the return on capital and the debt cost r_t). Holding constant the pre-shock excess return (i.e., the left-hand side of Equation (9)), the fraction of bankers' wealth invested in capital (or leverage), x_t^f, decreases in risk.

Let $V^{nf}\left(n_t^{nf}, \eta_t\right)$ denote an entrepreneur's value function. The HJB equation is:

$$\begin{aligned}
\rho V^{nf}\left(n_t^{nf}, \eta_t\right) = & \max_{c_t^{nf} \geq 0, x_t^{nf} \geq 0} \ln\left(c_t^{nf}\right) + \frac{\partial V^{nf}}{\partial n_t^{nf}} \mu_t^{n^{nf}} n_t^{nf} + \frac{\partial V^{nf}}{\partial \eta_t} \mu_t^{\eta} \eta_t \\
& + \lambda \left[V^{nf}\left(\widetilde{n}_t^{nf}, \widetilde{\eta}_t\right) - V^{nf}\left(n_t^{nf}, \eta_t\right) \right] \\
& + \lambda_I \left[V^{nf}\left(\widehat{n}_t^{nf}, \eta_t\right) - V^{nf}\left(n_t^{nf}, \eta_t\right) \right].
\end{aligned}$$

The last line reflects the jump in value function when the net worth jumps from n_t^{nf} to $\widehat{n}_t^{nf}$. The log utility implies the functional form of $V^{nf}\left(n_t^{nf}, \eta_t\right)$ is

$$V^{nf}\left(n_t^{nf}, \eta_t\right) = \frac{1}{\rho} \ln\left(n_t^{nf}\right) + U^{nf}\left(\eta_t\right).$$

Substituting this conjecture into the HJB equation, we have the following proposition.

Proposition 4 *Entrepreneurs' optimal consumption (c_t^{nf}) and capital-to-wealth ratio (x_t^{nf})*

satisfy the following first-order conditions (F.O.C.) respectively:

$$c_t^{nf} = \rho n_t^{nf},$$

and

$$\begin{aligned}\frac{a}{q_t} + \mu_t^q - r_t \leq &\lambda \left(\frac{1 - \frac{\widetilde{q}_t}{q_t}\left(1-\overline{\delta}\right)}{1 - \left[1 - \frac{\widetilde{q}_t}{q_t}\left(1-\overline{\delta}\right)\right] x_t^{nf}} \right) \\ &+ \lambda_I \left\{ \frac{\left(ROI_t - 1\right)\left(1-\phi\right)}{ROI_t\left[1 - \left(1-\phi\right) x_t^{nf}\right] + \left(1-\phi\right) x_t^{nf}} \right\},\end{aligned} \tag{10}$$

which holds in equality if $x_t^{nf} > 0$.

In comparison with bankers' F.O.C. condition (Equation (9)), the right-hand side of Equation (10) has a similar risk compensation term and a new illiquidity compensation term. The last line of Equation (10) reflects the illiquidity of capital. Switching one dollar from money to capital, entrepreneurs lose $(1-\phi)$ dollars of internal liquidity for investments, which in turn reduces the positive jump in wealth by $(ROI_t - 1)(1-\phi)$ as shown in Equation (6). Due to log utility, the marginal value of wealth is the reciprocal of wealth level, so the last line of Equation (10) is the expected marginal loss of value by switching one dollar of wealth from money to capital. For entrepreneurs to hold capital (i.e. $x_t^{nf} > 0$ and the F.O.C. condition holds in equality), the excess return of risky capital holdings must be sufficient to compensate entrepreneurs for both the risk exposure and the illiquidity.

Aggregation. In aggregate, investing entrepreneurs converts $i_t \lambda_I dt$ units of goods into new capital, where individual entrepreneur's investment, i_t, is given by Equation (5). Thus, the aggregate amount of goods invested is

$$\left(\frac{1}{1-\theta q_t}\right)\left[1 - (1-\phi)\, x_t^{nf}\right] N_t^{nf} \lambda_I dt,$$

where N_t^{nf} is the aggregate wealth of entrepreneurs. Similarly, let N_t^f denote the aggregate wealth of bankers. The aggregate consumption is given by $\rho N_t^f dt + \rho N_t^{nf} dt$. Note that because debt is in zero net supply, the aggregate wealth of the economy is $q_t K_t$ (i.e., the total value of productive capital). Therefore, the aggregate consumption is $\rho q_t K_t dt$. In equilibrium, the aggregate production, $aK_t dt$, is equal to the sum of consumption and investment:

$$aK_t dt = \rho N_t^f dt + \rho N_t^{nf} dt + \left[\frac{1-(1-\phi)\,x_t^{nf}}{1-\theta q_t}\right] N_t^{nf} \lambda_I dt.$$

Dividing both sides by $K_t dt$, we have the goods market clearing condition:

$$a = \rho q_t + \left[\frac{1-(1-\phi)\,x_t^{nf}}{1-\theta q_t}\right](1-\eta_t)\, q_t \lambda_I. \tag{11}$$

The capital market clearing conditions is

$$x_t^f N_t^f + x_t^{nf} N_t^{nf} = q_t K_t,$$

which, after dividing both sides by the aggregate wealth (i.e., $q_t K_t$), can be simplified to

$$x_t^f \eta_t + x_t^{nf}(1-\eta_t) = 1. \tag{12}$$

The debt market clears automatically by Walras' law. Given any initial capital stock K_0, the Markov equilibrium is formally defined as follows.

Proposition 5 *For any initial capital endowments of bankers and entrepreneurs, there is a Markov equilibrium that is described by the stochastic processes of bankers' consumption (c_t^f) and portfolio choice (x_t^f), entrepreneurs' consumption (c_t^{nf}), portfolio choice (x_t^{nf}), and investment (i_t), and the price variables (i.e., capital price q_t and interest rate r_t) on the filtered probability space generated by the Poisson process of macro shock, such that*

(1) agents know and take as given the processes of price variables;

(2) agents make optimal choices as stated in Proposition 1, 3, and 4;

(3) price variables adjust to clear the markets;

(4) all the choice and price variables are functions of η_t, so Proposition 2 gives an autonomous law of motion that maps any path of macro shocks to the current state η_t.

2.3 Mechanism and empirical implications

The model has two mechanisms that amplify each other and lead to financial instability. Bankers add value to the economy in two ways. First, the macro shock destroys a smaller fraction of capital, when capital is held by bankers instead of entrepreneurs ($\underline{\delta} < \overline{\delta}$). This is the specialness of the asset side of bankers' balance-sheet.[15] Second, bankers are money creators. By issuing short-term safe debt that serves as inside money, they provide the most liquid securities that entrepreneurs can hold against liquidity shocks. Inside money allows investing entrepreneurs to purchase goods that are used to create new capital, and thus, directly affects economic growth. To what extend bankers can provide these two services depends on their wealth (i.e., equity).

Consider a calm period without any macro shocks. As shown in the wealth evolution equation (Equation (4)), bankers accumulate equity by earning the spread between return on capital and debt cost. As bankers get richer, they hold more capital, and as capital gets reallocated towards its natural buyers, the market price of capital increases. An upward reevaluation of capital increases the value of assets on bankers' balance-sheet, and through leverage, it increases bankers' equity even further. This positive feedback loop, or a balance-sheet channel, echoes the one considered by Brunnermeier and Sannikov (2014). In good times, the increases in asset price and in natural buyers' risk-taking capacity reinforce each other. However, the story does not end here.

When asset price increases, return on internal liquidity increases ($dROI_t/dq_t > 0$), so entrepreneurs require a higher compensation for capital illiquidity (equivalently, assign a larger liquidity premium on money) as shown by Proposition 4. As a result, the entrepreneurs' portfolio is more biased towards bank debt. Intuitively, when capital becomes more valuable, entrepreneurs want to create more capital, but to do so, they need to build up savings, ideally

[15] If we interpret capital as efficiency units or productive projects, bankers' superiority in maintaining existing capital is related to the credit view on banking that emphasizes bankers' expertise in extending credit and collect repayments.

in the most liquid form (i.e., money). The increasing money demand pushes down the market interest rate r_t, which is banks' debt cost, and pushes up the equilibrium quantity of bank debt, which allows bankers to expand their balance-sheet even faster that what is induced by the increases in bank equity. As a result, bankers have more ammunition to push up the asset price even further, which in turn feeds into the aforementioned balance-sheet channel.

The mutually reinforcing mechanisms are illustrated by Figure 1 in Introduction. During a calm period without macro shocks, the economy exhibits the following features:

1 *Asset (capital) price increases;*

2 *Capital is reallocated towards the financial sector (banks);*

3 *The financial sector grows, fueled by increasing amount of debt;*

4 *Firms (entrepreneurs) hold more cash (inside money issued by banks);*

5 *Interest rate declines.*

The model's calm period reproduces several key features of the two decades before the 2007-09 financial crisis in the United States. During that time, asset prices rose across different asset classes. The financial sector grows dramatically (Schularick and Taylor (2012); Greenwood and Scharfstein (2013)). The growth is funded by the issuance of short-term safe assets (Adrian and Shin (2010); Gorton and Metrick (2012); Pozsar (2014); Carlson et al. (2016)).

There is a large empirical literature that documents the increases of cash holdings in the non-financial corporate sector (e.g., Opler et al. (1999); Bates, Kahle, and Stulz (2009)), and many have attributed the increase to the firms in the new-economy industries that are R&D intensive (Falato and Sim (2014); Begenau and Palazzo (2015); Pinkowitz, Stulz, and Williamson (2015); Graham and Leary (2015)).

Another salient feature during this period is the secular decline of interest rate. A prominent explanation is the global imbalance (Caballero, Farhi, and Gourinchas (2008)). This paper turns the attention to domestic money demand, and in particular, the corporate liquidity hoarding for investment needs.[16] The repeal of Regulation Q essentially introduces interest-paying money (Lucas and Nicolini (2015)). Therefore, when the money demand is strong, the yield on money (i.e., the interest rate) tends to decline. The low interest rate allows banks to borrow at a low cost, and thus, to take on more risks.

Many have argued that the development of shadow banking sector is driven by the strong demand for money-like securities.[17] The financial intermediaries' privilege to create money is a double-edged sword: on the one hand, inside money facilitates transaction and resources reallocation; on the other hand, it fuels the financial sector's risk-taking. When the macro shock hits, the feedback loops in Figure 1 turn into vicious cycles.

Consider the economy hit by the macro shock. As a fraction of capital holdings are destroyed, bankers lose their equity. As the natural buyers retreat from the market, capital price declines, which erodes bankers' equity even further. Moreover, as capital price decreases, entrepreneurs find investments less profitable (i.e., the investment return on internal liquidity, ROI_t, is lower), which decreases entrepreneurs' incentive to hoard money. Their money demand contracts, leading to higher debt cost for the bankers and a smaller equilibrium quantity of bank debt, which precipitate the balance-sheet contraction in the banking sector and result in even lower capital price.

A key assumption is that bankers cannot raise equity from entrepreneurs. Otherwise, the effect of macro shock will be dissipated across the whole economy instead of concentrated on the bankers. In fact, if bankers can raise equity from entrepreneurs, they will hold all the capital, so capital price will be a constant at the first-best level and the amplification mechanisms are muted.[18] The model imposes the restriction that the only financial contract between bankers and entrepreneurs is risk-free debt. Allowing banks to issue equity can improve the model's quantitative performance and may introduce new mechanisms like He and Krishna-

[16] Investment need is a key determinant of the cross-sectional variation in corporate cash holdings (e.g., Denis and Sibilkov (2010); Duchin (2010)), especially for firms with less collateral (e.g., Almeida and Campello (2007); Li, Whited, and Wu (2016)) and more intensive R&D activities (Falato and Sim (2014)).

[17] As pointed out by Gorton (2010), Gorton and Metrick (2012), and Stein (2012), circumventing regulations on leverage to capture the money premium is one of driving forces behind the growth of shadow banking.

[18] Equity issuance is mathematically equivalent to perfect risk-sharing (i.e., bankers and entrepreneurs can freely bet on the macro shock). Di Tella (2014) show that perfect risk-sharing shuts down the balance-sheet channel of asset price variation.

murthy (2013), but as long as there are some frictions on bankers' equity issuance, the model's qualitative implications carry through.

When the macro shock hits, the state variable η_t will jump downward to $\widetilde{\eta}_t$, because in equilibrium, bankers have a larger exposure to macro shocks (i.e., $x_t^f > x_t^{nf}$). As a result, the capital price decreases, jumping from q_t to $\widetilde{q}_t$. In contrast to the exogenous capital destruction, capital reevaluation is an endogenous risk. The strength of the model's shock amplification mechanism is measured by the following ratio,

$$\textit{Endogenous amplification strength:} \quad \frac{1 - \frac{\widetilde{q}_t}{q_t}\left(1 - \underline{\delta}\right)}{\underline{\delta}}. \tag{13}$$

From bankers' perspective, it is the ratio of total loss to exogenous loss per dollar of risky capital holdings. A large value indicates the model's shock amplification mechanisms are strong. Next, I will calibrate the parameters and fully solve the model. The amplified impact can be three times larger.

3 Solution

Based on the numeric solution (details in the Appendix), this section shows the model's properties graphically, and in particular, how the model generates the stylized facts in booms and how the feedback mechanisms lead to endogenous risk that materializes in crises.

3.1 Calibration

One unit of time corresponds to a month. I set λ_I equal to 0.0125, which implies 5% arrival rate at quarterly frequency in line with the calibration of Kiyotaki and Moore (2012). λ is $\frac{1}{60}$, so the macro shock arrives every five years, which is roughly consistent with the NBER business cycle frequency in the post-war period. I set $\underline{\delta} = 0.025$ and $\overline{\delta} = 0.05$, which is broadly consistent with the estimates of default loss in Andrade and Kaplan (1998) and Chen (2010). ρ is set to 0.0025 (annualized to 3%). a set to 0.0167, which implies a capital price-to-production ratio around 8 over the cycle. θ, the external financing capacity of investment projects, is set to 10%.

ϕ is set to 0.9 in the baseline calibration. It is the key parameter in this model, as it measures the fraction of existing capital that can be pledged or readily sold when an investment opportunity arrives. Lower value of ϕ corresponds higher illiquidity of capital, which I interpret as a higher level of intangibility. Fixing other parameters, we can think of the economy as indexed by ϕ. Decreasing ϕ corresponds to an unexpected and permanent increase in the intangibility of productive capital in this economy.

If $\phi = 1$, the inside money channel is shut down. An increase in the capital price and the profitability of investment does not increase entrepreneurs' preference for bank debt, because the holdings of bank debt and existing capital are equally liquid when investment opportunities arrive. The inside money channel is shut down. As will be shown at the end of this section, a lower value of ϕ strengthens the model's shock amplification mechanism, making the economy more unstable.

3.2 Equilibrium properties

Asset price. Panel A of Figure 2 shows the equilibrium asset price as a function of bankers' wealth share η_t. Capital price increases in bankers' wealth and risk-taking capacity for two reasons. First, when hit by the macro shock, it suffers less loss than entrepreneurs ($\underline{\delta} < \overline{\delta}$). Second, bankers' marginal cost of financing (i.e. their debt cost) is lower than entrepreneurs', because of the liquidity premium assigned to bank debt.

State variable dynamics. The drift of state variable η_t is shown in Panel B of Figure 2. A steady state exists around $\eta_t = 0.34$, which is marked by the dotted vertical lines in the four panels of Figure 2 and the upcoming figures. When the financial sector's wealth share reaches 34%, the drift of state variable is equal to zero, so the economy will stay there until hit by a macro shock. This steady state is stable, because to the left, the growth rate of η_t is positive (i.e., $\mu_t^\eta > 0$), and to the right, $\mu_t^\eta < 0$. The growth rate is large where η_t is small. This is because the bankers are earning a higher spread between the return on capital and their debt cost, and the return of capital is large because capital price is low when η_t is low.

According to simulation results, if the economy starts at $\eta_t = 5\%$, it takes an average of

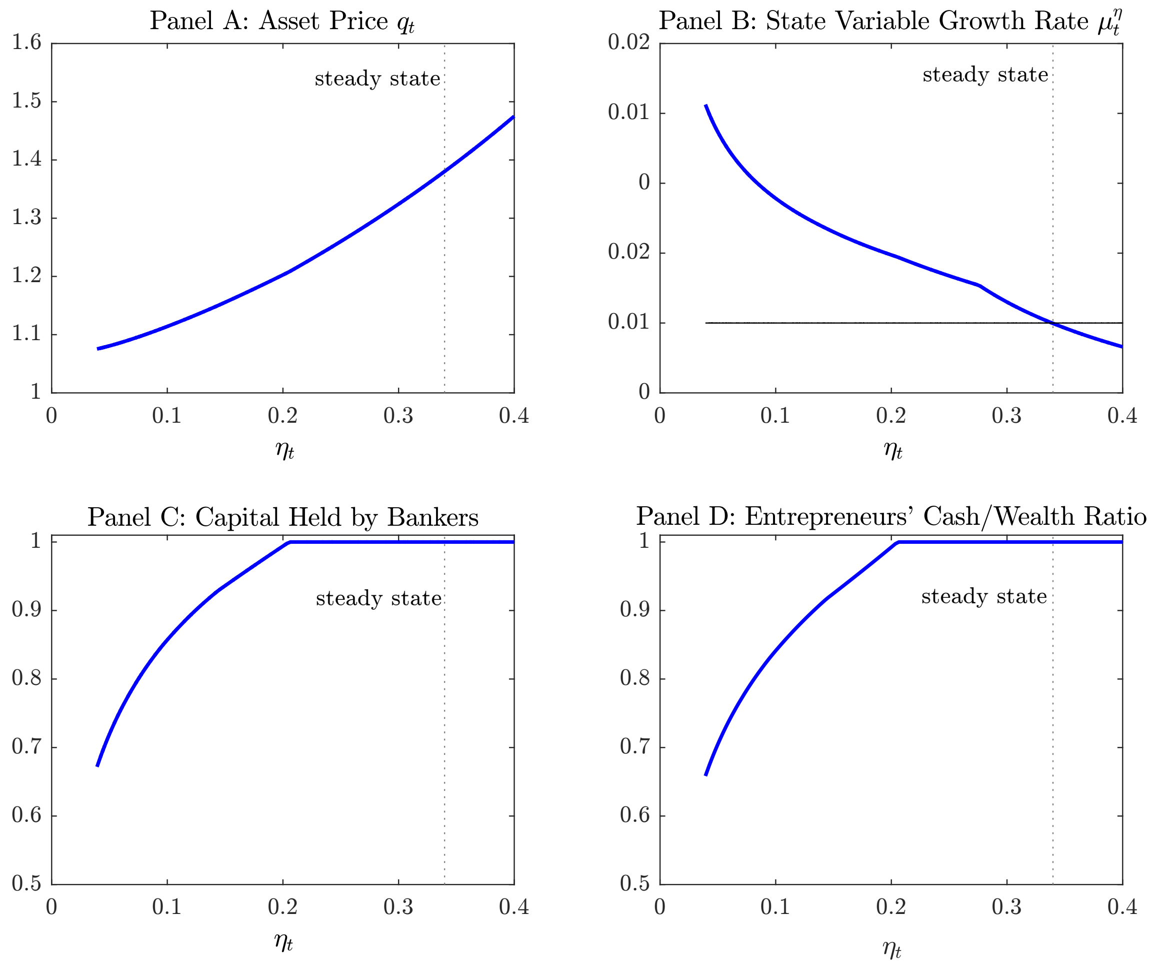

Figure 2: Equilibrium Capital Price and Allocation.

125 years to reach the steady state $\eta = 34\%$. During the process, we observe the expansion of the financial sector (i.e., increases in η_t), increasing asset price (q_t), and an increasing share of capital being held by the financial sector ($x_k^f \eta_t$). Therefore, the calibrated model speaks to the relatively long-run dynamics of the economy, for instance, the last two decades of the U.S. economy, instead of business-cycle variations.

Capital allocation. Panel C of Figure 2 shows the fraction of capital held by bankers. When the banking sector is still small, entrepreneurs have to hold capital, which happens when $\eta_t < 0.2$. Entrepreneurs' first-order condition for x_t^{nf} holds in equality (Equation (10)). The expected return on capital must compensate for both the exposure to macro shock and the illiquidity. Because of $\underline{\delta} < \overline{\delta}$, it is inefficient for the entrepreneurs to hold existing capital, but it has to when the natural buyer's risk-taking capacity is limited. Close to the steady state, all the existing capital is held by bankers, so entrepreneurs focus on creating new capital and invests all of its wealth in inside money issued by bankers. In other words, when η_t is high, the economy achieves an efficient specialization: bankers hold capital, and entrepreneurs hold money and create capital (Panel D of Figure 2). The subsequent figures mark the inefficiency point, below which entrepreneurs hold capital.

Endogenous risk and risk pricing. Panel A of Figure 3 shows the pre-shock excess return of capital

$$\frac{a}{q_t} + \mu_t^q - r_t.$$

Panel B shows bankers' total loss faced per dollar of risky capital holdings when the macro shock hits

$$1 - \frac{\widetilde{q}}{q}\left(1 - \underline{\delta}\right).$$

I use bankers' total loss as a measure of risk, become bankers are always the marginal investor, while entrepreneurs exit the market when η_t is large enough. As the banking sector grows and the economy moves towards the steady state, endogenous risk accumulates. The bankers' total loss per dollar increases from around 2.5% (i.e. without any endogenous risk) to around 9%. As a consequence, bankers require a higher pre-shock excess return as compensation.

When entrepreneurs hold risky asset, Equation (10) holds in equality and it decomposes the pre-shock excess return into two components: the macro risk compensation

$$\lambda\left(\frac{1 - \frac{\widetilde{q}_t}{q_t}\left(1 - \overline{\delta}\right)}{1 - \left[1 - \frac{\widetilde{q}_t}{q_t}\left(1 - \overline{\delta}\right)\right] x_t^{nf}}\right),$$

and the illiquidity compensation

$$\lambda_I\left(\frac{ROI_t\left(1 - \phi\right) - \left(1 - \phi\right)}{ROI_t\left(1 - \left(1 - \phi\right) x_t^{nf}\right) + \left(1 - \phi\right) x_t^{nf}}\right). \tag{14}$$

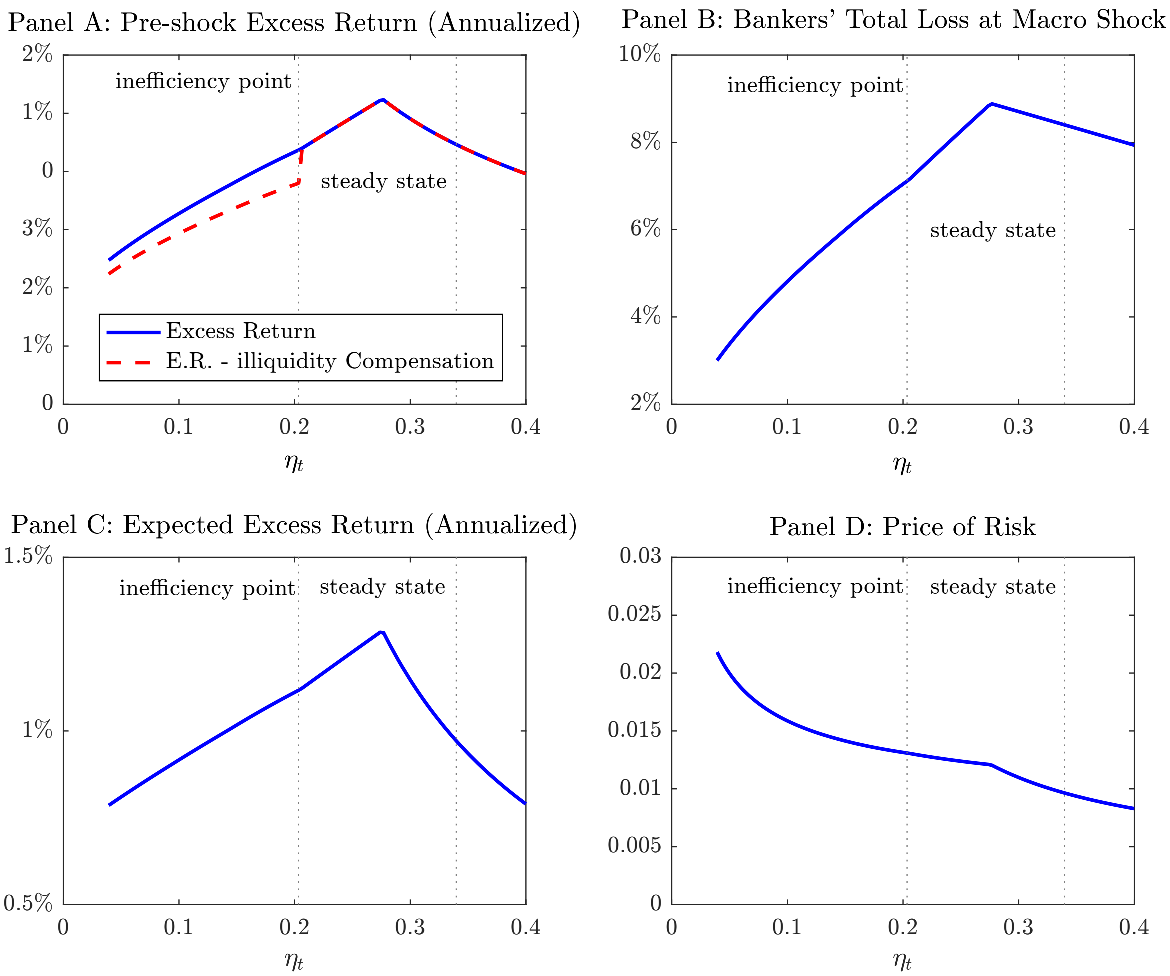

Figure 3: Endogenous Risk and Risk Pricing.

Because entrepreneurs can only invest in two assets, the risky and illiquid capital and the safe debt, the illiquidity compensation also reflects the liquidity premium that assigned to the safe debt issued by bankers. The red dotted line in Panel A of Figure 3 shows the macro risk compensation required by entrepreneurs. The gap between this line and the pre-shock excess return is the illiquidity compensation. It grows as η_t increases and capital price increases, because capital asset price leads to a higher return on internal liquidity.

The expected excess return is the pre-shock excess return adjusted by the expected loss

$$\frac{a}{q_t} + \mu_t^q - r_t + \lambda\left(1-\underline{\delta}\right)\left(\frac{\widetilde{q}_t}{q_t}-1\right) + \lambda\underline{\delta}\left(-1\right).$$

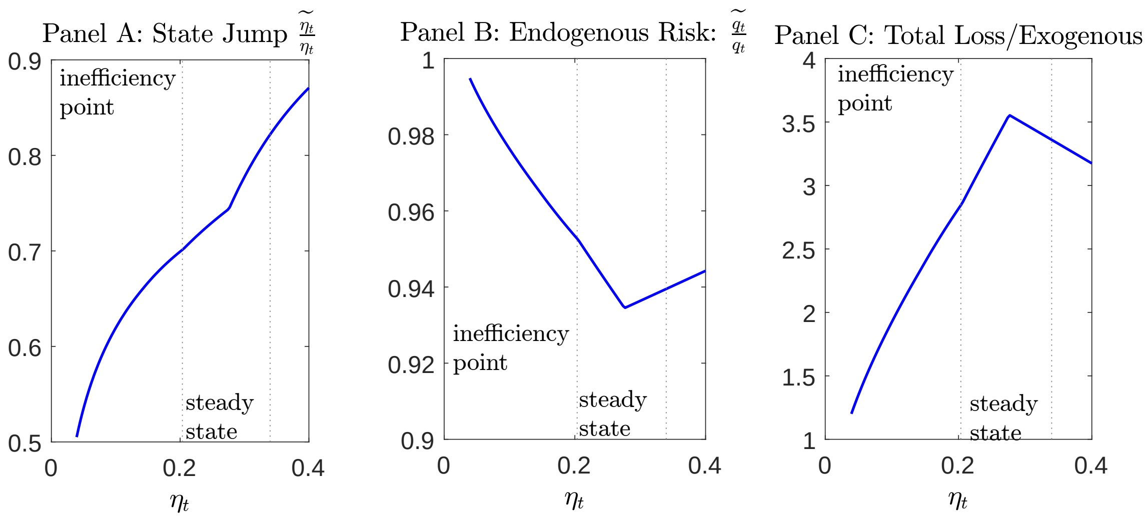

Figure 4: Risk Accumulation and Amplification.

It follows the same pattern as the pre-shock excess return (Panel C of Figure 3).

Panel D shows the "price of risk", which is the ratio of expected excess return divided by total loss per dollar of investment. It decreases as the bankers' wealth share increases. Thus, the model economy generates counter-cyclical price of risk, which is well documented by the empirical asset pricing literature (e.g., Lettau and Ludvigson (2010)). The dynamics of risk price is dominated by the dynamics of quantity of risk (Panel B). As a result, the dynamics of expected excess return (Panel C) follows the quantity of risk instead of risk price.

Financial instability. Panel A of Figure 4 shows the ratio of post-shock state to the pre-shock state (i.e., $\frac{\widetilde{\eta}_t}{\eta_t}$). It shows the impact of macro shock on the state variable. This ratio increases as η_t increases. Therefore, as the banking sector grows, it becomes more stable (or less sensitive to shocks). However, this does not necessarily lead to smaller endogenous risk.

Panel B of Figure 4 shows the ratio of post-shock capital price to pre-shock asset price (i.e., $\frac{\widetilde{q}_t}{q_t}$). When η_t is relatively small, this ratio decreases as η_t increases, which means endogenous risk accumulates as the banking sector grows. Going through a long calm period, bankers accumulate equity, which has two effects: first, it makes the banking sector more robust to shocks (direct effect); second, it increases asset price (equilibrium effect).

A higher asset price increases endogenous risk through the inside money channel. When capital price q_t increases, entrepreneurs' return on internal liquidity ROI_t increases, which makes them want to bias their wealth portfolio more towards the inside money (i.e. bank debt). This reduces bankers' debt cost, giving bankers a larger advantage over entrepreneurs in holding capital. In other words, through entrepreneurs' investment-driven money demand, an increase in asset price amplifies the difference between the first-best buyers of capital (i.e., bankers) and the second-best buyers of capital (i.e., entrepreneurs). As a result, when the macro shock hits and the reallocation towards second-best buyers takes place, capital price decreases more. When the banking sector is sufficiently well-capitalized, this mechanism (i.e., the equilibrium effect) is overwhelmed by the direct effect.

Panel C of Figure 3 shows the strength of shock amplification in the model economy. The ratio of total loss (i.e., $1 - \frac{\widetilde{q}_t}{q_t}(1-\underline{\delta})$) to exogenous loss (i.e., $\underline{\delta}$) increases to above 3.5, and then decreases as the direct effect of bank equity accumulation dominates the equilibrium effect that amplifies the shock through the inside money channel. This amplification effect is quantitatively large in comparison with the existing macro finance literature (e.g., Brunnermeier and Sannikov (2014)).

Inside money channel. Panel A of Figure 5 shows an entrepreneur's return on internal liquidity. As η_t grows, capital price grows, which leads to higher ROI_t, and thus, a higher illiquidity compensation required by entrepreneurs to hold capital (Panel B). Note that after the inefficiency point, entrepreneurs no longer hold capital, so the plot stops. This confirms the previous explanation of endogenous risk accumulation through the widening difference between the first-best (bankers) and second-best holders (entrepreneurs) of capital that is due to entrepreneurs' aversion to capital illiquidity at investment times.

As shown in Panel C of Figure 5, a stronger money demand of entrepreneurs pushes down the interest rate (i.e. the risk-free rate), which reduces the leverage cost for bankers. Panel D plots $(1-\eta_t)\left(1-x_t^{nf}\right)$(i.e., the inside money to total wealth ratio). $(1-\eta_t)$ share of wealth held by entrepreneurs, of which $\left(1-x_t^{nf}\right)$ fraction is invested in risk-free debt issued by bankers. When the banking sector is small, its money creation capacity is restricted, because it does not have enough net worth to buffer the macro shock. The liquidity supply increases as the banking sector grows and its leverage cost decreases due to a rising liquidity

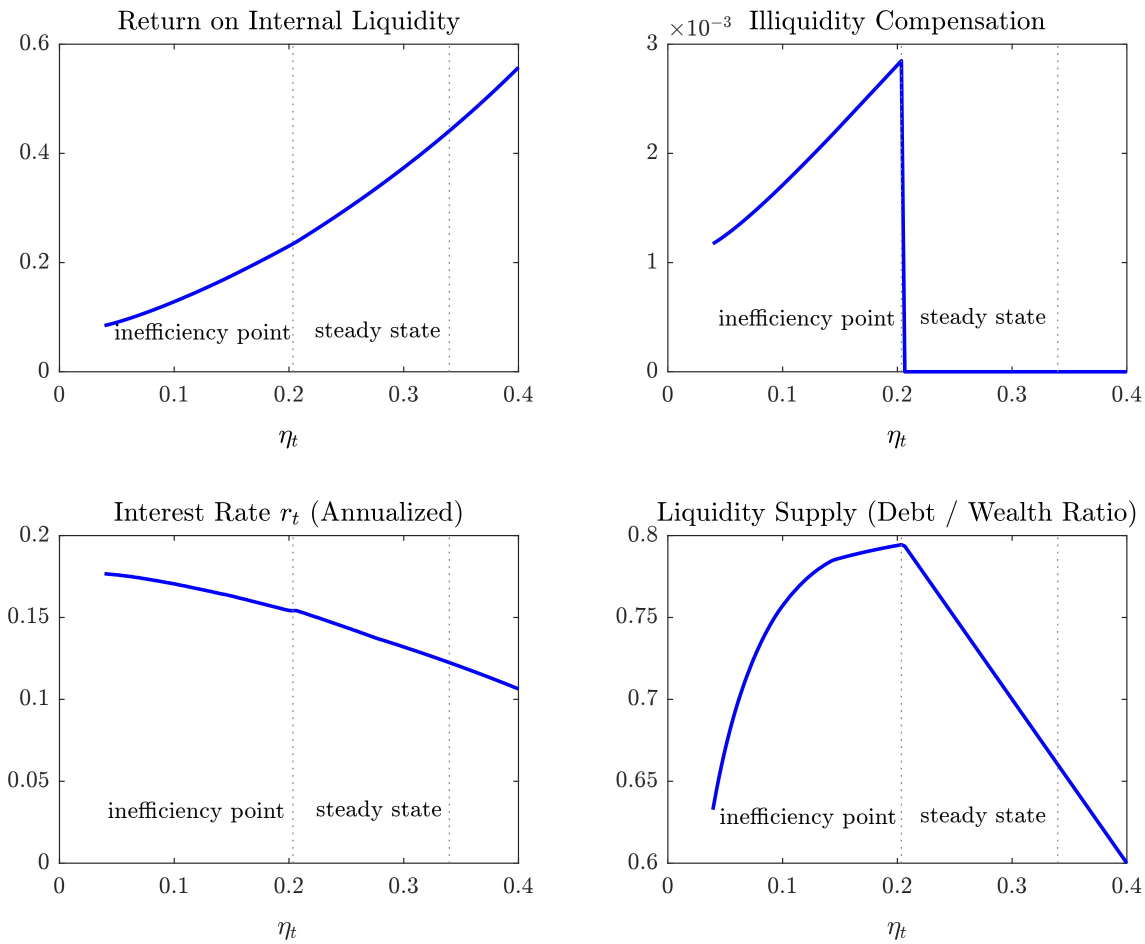

Figure 5: Inside Money Channel.

premium assigned to bank debt. After the inefficiency point, bankers already hold all the capital, so asset side of their balance-sheet can only grow through the upward reevaluation of capital instead of reevaluation and reallocation from entrepreneurs to bankers. As a result, a further increase of bank equity crowds out bank debt.

Panel C and D of Figure 5 reproduce the experience of the United States and other advanced economies in the last three decades. Through the inside money channel, the interest rate declines, and at the same time, the indebtedness of the financial sector increases (Schularick and Taylor (2012)). As shown in Figure 4, endogenous risk accumulates along with the increasing capital price, setting the stage of severe crises when the macro shock hits.

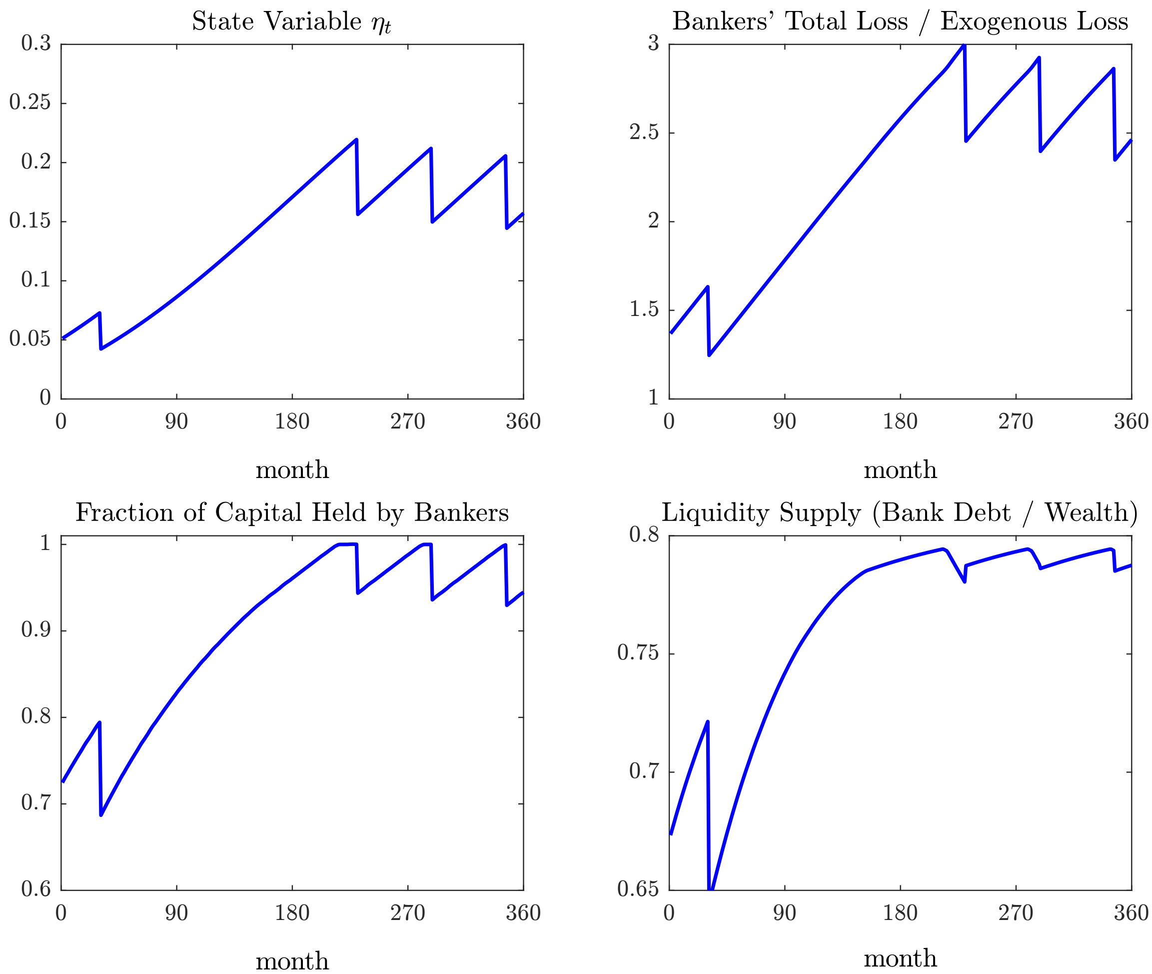

Figure 6: Simulation.

Simulation. Figure 6 shows a simulated path of the economy for 30 years (360 months). The economy starts from $\eta_t = 5\%$. After being hit by the macro shock at the 40th month, the economy experiences a prolonged period of boom. Panel A shows the trajectory of the state variable η_t. The banking sector's wealth share grows to more than 20%. Bankers increase risk-taking, holding a larger share of capital (Panel C). By issuing more inside money, bankers provide liquidity to entrepreneurs (Panel D). Along the process, the economy accumulates endogenous risk (Panel B). The boom is followed by three recessions. Each recession lasts for three to four years, during which the banking sector cannot hold all the capital, so entrepreneurs have to hold capital and the economy deviates from the efficient specialization.

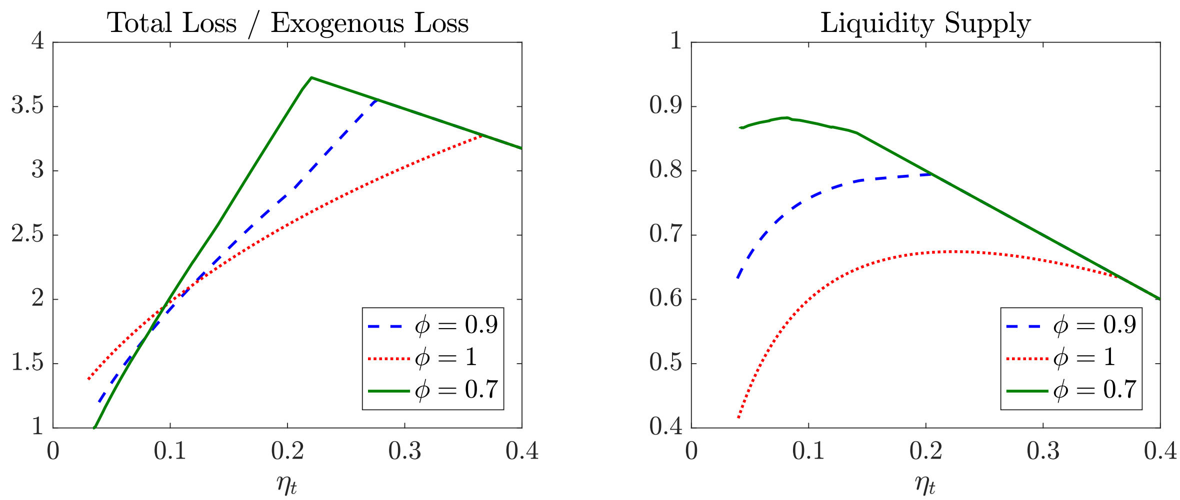

Figure 7: Financial Instability in an Intangible Economy.

Intangibility and instability. When $\phi = 1$, the inside money channel is shut down, because investment opportunities arrive, bank debt and capital are equally liquid and both can be freely exchanged for investment inputs. The investing entrepreneurs can invest all of their wealth in creating new capital.[19] When $\phi < 1$, bank debt is more liquid than capital, and thus, entrepreneurs bias their wealth allocation towards bank debt, giving rise to the inside money channel. A lower value of ϕ means capital is more illiquid at the investment times. Note that investing entrepreneurs can either sell existing capital for investment inputs, or equivalently, pledging existing capital to borrow investments inputs. The latter form of capital liquidity emphasizes collateralizability, which is closely related to the capital tangibility. Thus, I interpret a decrease in ϕ as a structural transformation towards a more intangible economy.

Figure 7 compares the model's performances, and in particular, the strength of the shock amplification mechanism across different values of ϕ ($= 0.7$, 0.9, and 1). Moving from $\phi = 1$ to $\phi = 0.9$ and 0.7, the shock amplification mechanism is strengthened (Panel A). When capital becomes more intangible, entrepreneurs assign a higher liquidity premium to bank debt, leading to a stronger inside money channel of financial instability. In the case of $\phi = 1$, the only shock amplification mechanism is the standard balance-sheet channel (Brunnermeier

[19] They are still financially constrained, in the sense that the creation of new capital cannot fully rely on external funding (i.e., $\theta < 1$).

and Sannikov (2014)). Therefore, by comparing it with the cases of $\phi < 1$, we see how much the inside money channel contributes to the endogenous risk.

The economy's indebtedness decreases in ϕ. When the economy becomes more intangible, bankers cater to entrepreneurs' money demand by issuing more safe debt. Panel B of Figure 7 shows the bank debt to total wealth ratio. As the economy becomes more intangible-intensive, the capital illiquidity problem becomes more severe. This drives up the production sector's demand for inside money in anticipation of investment needs, and thereby, pushes down the leverage cost for banks and leads to a more indebted banking sector.

4 Conclusion

This paper aims to provide a unified and coherent explanation of several trends in the U.S. economy in the two decades leading up to the Great Recession, such as the rising corporate money demand, the expansion of the financial sector, the declining interest rate, and the increases in risky asset prices. At the center of my model is the endogenous dynamics of money supply (bankers create inside money) and money demand (entrepreneurs hoard liquidity for investments). Inspired by the U.S. experience of structural transformation towards an intangible economy, this paper proposes an inside money channel of financial instability that reinforces the standard balance-sheet channel and leads to the endogenous risk accumulation in booms. This new channel helps explain the recent empirical findings that a long period of bank expansion precedes severe crises.

The model leaves out the active provision of outside money for future research. By expanding money supply in booms, the government can crowd out bank leverage, and thereby, weaken the upward spiral in asset price that leads to endogenous risk accumulation. However, since entrepreneurs' incentive to invest is tied to asset prices, the government faces the tradeoff between growth and stability. In contrast to the current practice of monetary expansion in recessions, an optimal strategy of outside money supply tends to be procyclical in this setting.

The model also leaves out banks' default. The empirical literature on financial crises commonly use banks' default or a high possibility of default as a crisis indicator. A theoretical model of crisis should ideally accommodate default, and by doing so, it opens up the question of optimal government intervention, for instance, through equity injection into the banking sector, in order to prevent a sudden evaporation of inside money. To finance the intervention in bad times, the government may increase the issuance of outside money (e.g., short-term, money-like government debt), which suggests countercyclical outside money supply.

Appendix - Solving the Equilibrium

The fully solved Markov equilibrium is a set of functions that map η_t to the values of endogenous variables, such as capital price, interest rate, and bank leverage. Time subscripts are suppressed to save notations. First, we need to solve the capital price $q(\eta)$ as the fixed point of a contraction mapping in the space of $\mathbb{C}^1$. Once we know $q(\eta)$, the other endogenous variables can be solved easily.

We pick any starting candidate capital price function $q^1(\eta) \in \mathbb{C}^1$, and give it an index equal to "1" (in the superscript). Constructed from individual optimality and market clearing conditions, the following contraction functional maps $q^1(\eta)$ to $q^2(\eta)$ in $\mathbb{C}^1$. Then, we apply the functional to $q^2(\eta)$ to get $q^3(\eta)$, and repeat until convergence. The fixed point $q^\infty(\eta)$ is the equilibrium capital price function $q(\eta)$ that satisfies all the equilibrium conditions.

The contraction mapping can be constructed in five steps. First, from the goods market clearing condition,

$$a - \rho q^1 = \lambda_I \left(\frac{1 - (1-\phi)\, x^{nf,1}}{1 - \theta q^1} \right) (1-\eta)\, q^1,$$

we can solve the implied $x^{nf,1} = x^{nf,1}(\eta)$, i.e. the entrepreneurs' capital-to-wealth ratio as a function of η.[20] Second, using the capital market clearing condition,

$$x^{f,1}\eta + x^{nf,1}(1-\eta) = 1,$$

we can solve the implied $x^{f,1} = x^{f,1}(\eta)$, i.e. the bankers' capital-to-wealth ratio as a function of η. Third, we can solve $\widetilde{\eta}^1 = \widetilde{\eta}^1(\eta)$, which is the state to which the economy jumps from η when the macro shock hits, using the equation

$$\widetilde{\eta}^1 = \frac{\widetilde{n}^f}{\widetilde{n}^f + \widetilde{n}^{nf}} = \frac{\left[\frac{\widetilde{q}^1}{q^1}(1-\underline{\delta})\, x^{f,1} + \left(1 - x^{f,1}\right)\right]\eta}{\left[\frac{\widetilde{q}^1}{q^1}(1-\underline{\delta})\, x^{f,1} + (1-x^{f,1})\right]\eta + \left[\frac{\widetilde{q}^1}{q^1}\left(1-\overline{\delta}\right) x^{nf,1} + (1-x^{nf,1})\right](1-\eta)},$$

where $\widetilde{q}^1 = q^1\left(\widetilde{\eta}^1\right)$. Since the function $q^1(\eta)$ is known, the equation above solves $\widetilde{\eta}^1$ as a

[20]The starting candidate $q^1(\eta)$ should be chosen such that the implied $x^{nf,1}(\eta) \geq 0$.

function of η. Fourth, we can solve the *pre-shock excess return* of capital using bankers' F.O.C. condition for x^f (which holds in equality),

$$\lambda\left(\frac{1-\frac{\widetilde{q}^1}{q^1}\left(1-\underline{\delta}\right)}{1-\left[1-\frac{\widetilde{q}^1}{q^1}\left(1-\underline{\delta}\right)\right]x^{f,1}}\right).$$

The final step is to check entrepreneurs' F.O.C. condition for x^{nf} at every value of η (i.e. the inequality (10)). If it is violated, we update q^1 to q^2; if it is not violated, the value of q^2 at η is set to equal q^1. We have already solved the *pre-shock excess return* of capital, which is the left-hand side of the inequality (10). The right-hand side can be solved by substituting in q^1, $\widetilde{q}^1$ and $x^{nf,1}$,

$$\lambda\left(\frac{1-\frac{\widetilde{q}^1}{q^1}\left(1-\overline{\delta}\right)}{1-\left[1-\frac{\widetilde{q}^1}{q^1}\left(1-\overline{\delta}\right)\right]x^{nf,1}}\right)+\lambda_I\left(\frac{\left(ROI^1-1\right)\left(1-\phi\right)}{ROI^1\left[1-\left(1-\phi\right)x^{nf,1}\right]+\left(1-\phi\right)x^{nf,1}}\right),$$

where $ROI^1=\frac{(1-\theta)q^1}{1-\theta q^1}$, the return on internal liquidity given q^1.

To construct $q^2(\eta)$, consider the following four scenarios for every value of η. First, the left-hand side of the inequality (10) is larger than the right-hand side. In this case, entrepreneurs prefer to hold more capital at the current price $q^1(\eta)$. We solve a new (and higher) $x^{nf,2}$ by setting entrepreneurs' F.O.C. to equality, and then update the value of q^1 at η to $q^2(\eta)$ that is solved by substituting $x^{nf,2}$ into the goods market clearing condition.[21] Second, the left-hand side of the inequality (10) is smaller than the right-hand side. If $x^{nf,1}=0$, we do not need to update q^1, so $q^2(\eta)=q^1(\eta)$. If $x^{nf,1}>0$, we solve a new $x^{nf,2}$ by setting entrepreneurs' F.O.C. to equality, and then update the value of q^1 at η to $q^2(\eta)$ that is solved by substituting $x^{nf,2}$ into the goods market clearing condition. Finally, if the left-hand side of the inequality (10) is equal to the right-hand side, we do not need to update q^1, so $q^2(\eta)=q^1(\eta)$.

Therefore, we have constructed a functional that maps $q^1(\eta)$ to $q^2(\eta)$. The proof of

[21] This means to adjust q^1 upward. In particular, the root in $\left(1,\frac{1}{\theta}\right)$ is selected. When $q<1$, aggregate investment is zero. Goods market clearing implies $q=\frac{a}{\rho}$, which is larger than one under the calibrated parameter values, a contradiction. Therefore, $q\geq 1$. q has to be small than $\frac{1}{\theta}$. Otherwise, the investment project becomes self-financing, in which case the scale of investment is positive infinite.

this mapping being a contraction mapping in $\mathbb{C}^1$ is beyond the scope of the paper, but under the calibrated parameter values, the recursive algorithm converges, starting from $q^1(\eta)$ that is given by the goods market clearing condition with $x^{nf} = 0$ for all η in $(0, 1)$.

After $q(\eta)$ is solved, we can solve x^{nf}, x^f, $\widetilde{\eta}$, $\widetilde{q}$, and the pre-shock excess return of capital as previously discussed. Since $q(\eta)$ is known, we can solve $\mu^q(\eta)$ using Itô's lemma as follows,

$$\mu^q(\eta) = \frac{dq(\eta)/q(\eta)}{d\eta/\eta} \mu^\eta(\eta),$$

where $\mu^\eta(\eta)$ is given by Equation (7). The interest rate $r(\eta)$ is solved as the difference between the pre-shock return on capital (i.e. $\frac{a}{q(\eta)} + \mu^q(\eta)$) and pre-shock excess return.

References

Adrian, T. and H. S. Shin (2010). Liquidity and leverage. *Journal of Financial Intermediation 19*(3), 418 – 437. Risk Transfer Mechanisms and Financial Stability.

Almeida, H. and M. Campello (2007). Financial constraints, asset tangibility, and corporate investment. *Review of Financial Studies 20*(5), 1429–1460.

Andrade, G. and S. N. Kaplan (1998). How costly is financial (not economic) distress? evidence from highly leveraged transactions that became distressed. *The Journal of Finance 53*(5), 1443–1493.

Atkeson, A. and P. J. Kehoe (2005). Modeling and measuring organization capital. *Journal of Political Economy 113*(5), 1026–1053.

Azar, J., J.-F. Kagy, and M. C. Schmalz (2016). Can changes in the cost of carry explain the dynamics of corporate cash holdings? *Review of Financial Studies*, forthcoming.

Baron, M. and W. Xiong (2016). Credit expansion and neglected crash risk. *Quarterly Journal of Economics*, forthcoming.

Basak, S. and D. Cuoco (1998). An equilibrium model with restricted stock market participation. *Review of Financial Studies 11*(2), 309–341.

Bates, T. W., K. M. Kahle, and R. M. Stulz (2009). Why do U.S. firms hold so much more cash than they used to? *The Journal of Finance 64*(5), 1985–2021.

Begenau, J. and B. Palazzo (2015). Firm selection and corporate cash holdings. 2015 Meeting Papers 1047, Society for Economic Dynamics.

Bernanke, B. S. and M. Gertler (1989). Agency costs, net worth, and business fluctuations. *The American Economic Review 79*(1), 14–31.

Bolton, P., H. Chen, and N. Wang (2011). A unified theory of Tobin's q, corporate investment, financing, and risk management. *The Journal of Finance 66*(5), 1545–1578.

Bolton, P. and X. Freixas (2000). Equity, bonds, and bank debt: Capital structure and financial market equilibrium under asymmetric information. *Journal of Political Economy 108*(2), 324–351.

Bordo, M., B. Eichengreen, D. Klingebiel, M. S. Martinez-Peria, and A. K. Rose (2001). Is the crisis problem growing more severe? *Economic Policy: A European Forum 16*(32), 53–82.

Brunnermeier, M. K. and Y. Sannikov (2014, February). A macroeconomic model with a financial sector. *American Economic Review 104*(2), 379–421.

Brunnermeier, M. K. and Y. Sannikov (2016). The I theory of money. Working paper, Princeton University.

Caballero, R. J., E. Farhi, and P.-O. Gourinchas (2008). An equilibrium model of "global imbalances" and low interest rates. *American Economic Review 98*(1), 358–93.

Carlson, M., B. Duygan-Bump, F. Natalucci, B. Nelson, M. Ochoa, J. Stein, and S. Van den Heuvel (2016). The demand for short-term, safe assets and financial stability: Some evidence and implications for central bank policies. *International Journal of Central Banking*, forthcoming.

Chen, H. (2010). Macroeconomic conditions and the puzzles of credit spreads and capital structure. *The Journal of Finance 65*(6), 2171–2212.

Corrado, C., C. Hulten, and D. Sichel (2005). Measuring capital and technology: An expanded framework. In C. Corrado, J. Haltiwanger, and D. Sichel (Eds.), *Measuring Capital in the New Economy*, pp. 11–46. San Diego: University of Chicago Press.

Corrado, C. A. and C. R. Hulten (2010, May). How do you measure a "technological revolution"? *American Economic Review 100*(2), 99–104.

Dang, T. V., G. Gorton, B. Holmström, and G. Ordonez (2014, June). Banks as secret keepers. Working Paper 20255, National Bureau of Economic Research.

DeMarzo, P. M. and D. Duffie (1999). A liquidity-based model of security design. *Econometrica 67*(1), 65–99.

Denis, D. J. and V. Sibilkov (2010). Financial constraints, investment, and the value of cash holdings. *Review of Financial Studies 23*(1), 247–269.

Di Tella, S. (2014). Uncertainty shocks and balance sheet recessions. Working paper, Stanford University Graduate School of Business.

Diamond, D. W. (1984). Financial intermediation and delegated monitoring. *The Review of Economic Studies 51*(3), 393–414.

Duchin, R. (2010). Cash holdings and corporate diversification. *The Journal of Finance 65*(3), 955–992.

Eisfeldt, A. and A. Rampini (2009). Financing shortfalls and the value of aggregate liquidity. Working paper, Duke University.

Eisfeldt, A. L. (2007). Smoothing with liquid and illiquid assets. *Journal of Monetary Economics 54*(6), 1572 – 1586.

Eisfeldt, A. L. and D. Papanikolaou (2014). The value and ownership of intangible capital. *American Economic Review 104*(5), 189–94.

Falato, A. and J. W. Sim (2014). Why Do Innovative Firms Hold So Much Cash? Evidence from Changes in State R&D Tax Credits. Finance and Economics Discussion Series 2014-72, Board of Governors of the Federal Reserve System (U.S.).

Farhi, E. and J. Tirole (2011). Bubbly liquidity. *The Review of Economic Studies*.

Froot, K. A., D. S. Scharfstein, and J. C. Stein (1993). Risk management: Coordinating corporate investment and financing policies. *The Journal of Finance 48*(5), 1629–1658.

Gorton, G. (2010). *Slapped by the Invisible Hand: The Panic of 2007*. New York, N.Y.: OxfordUniversity Press.

Gorton, G., S. Lewellen, and A. Metrick (2012, May). The safe-asset share. *American Economic Review 102*(3), 101–06.

Gorton, G. and A. Metrick (2012). Securitized banking and the run on repo. *Journal of Financial Economics 104*(3), 425 – 451. Market Institutions, Financial Market Risks and Financial Crisis.

Gorton, G. and G. Pennacchi (1990). Financial intermediaries and liquidity creation. *The Journal of Finance 45*(1), 49–71.

Graham, J. R. and M. T. Leary (2015). The evolution of corporate cash. Working paper, Duke University.

Greenwood, R. and D. Scharfstein (2013, May). The growth of finance. *Journal of Economic Perspectives 27*(2), 3–28.

Gurley, J. G. and E. S. Shaw (1960). *Money in a Theory of Finance*. Washington, D.C.: Brookings Institution.

Hall, B. H. (1992). Investment and research and development at the firm level: Does the source of financing matter? Working Paper 4096, National Bureau of Economic Research.

Hall, B. H. and J. Lerner (2009). The financing of R&D and innovation. Working Paper 15325, National Bureau of Economic Research.

Hart, O. and J. Moore (1994). A theory of debt based on the inalienability of human capital. *The Quarterly Journal of Economics 109*(4), 841–879.

Hart, O. and L. Zingales (2014). Banks are where the liquidity is. Working paper, Harvard University.

He, Z. and A. Krishnamurthy (2013). Intermediary asset pricing. *American Economic Review 103*(2), 732–70.

Himmelberg, C. P. and B. C. Petersen (1994). R&D and internal finance: A panel study of small firms in high-tech industries. *The Review of Economics and Statistics 76*(1), 38–51.

Holmström, B. (2012). The nature of liquidity provision: When ignorance is bliss. In *Presidential Address, Econometric Society, ASSA meetings, Chicago*.

Holmström, B. and J. Tirole (1997). Financial intermediation, loanable funds, and the real sector. *The Quarterly Journal of Economics 112*(3), 663–691.

Holmström, B. and J. Tirole (1998). Private and public supply of liquidity. *Journal of Political Economy 106*(1), 1–40.

Holmström, B. and J. Tirole (2001). LAPM: A liquidity-based asset pricing model. *The Journal of Finance 56*(5), 1837–1867.

Jordà, O., M. Schularick, and A. M. Taylor (2013). When credit bites back. *Journal of Money, Credit and Banking 45*(s2), 3–28.

Kiyotaki, N. and J. Moore (1997). Credit cycles. *Journal of Political Economy 105*(2), 211–248.

Kiyotaki, N. and J. Moore (2000). Inside money and liquidity. Working paper, London School of Economics.

Kiyotaki, N. and J. Moore (2005). Lawrence R. Klein Lecture: Liquidity and asset prices. *International Economic Review 46*(2), 317–349.

Kiyotaki, N. and J. Moore (2012). Liquidity, business cycles, and monetary policy. Working paper, Princeton University.

Krishnamurthy, A. and T. Muir (2016). How credit cycles across a financial crisis. Working paper, Stanford University Graduate School of Business.

Krishnamurthy, A. and A. Vissing-Jorgensen (2015). The impact of treasury supply on financial sector lending and stability. *Journal of Financial Economics 118*(3), 571 – 600.

Krusell, P. and A. A. Smith (1998). Income and wealth heterogeneity in the macroeconomy. *Journal of Political Economy 106*(5), 867–896.

Lagos, R. (2008). inside and outside money. In S. N. Durlauf and L. E. Blume (Eds.), *The New Palgrave Dictionary of Economics*. Basingstoke: Palgrave Macmillan.

Lettau, M. and S. C. Ludvigson (2010). Chapter 11 - Measuring and modeling variation in the risk-return trade-off. In Y. Aït-Sahalia and L. P. Hansen (Eds.), *Handbook of Financial Econometrics: Tools and Techniques*, Volume 1 of *Handbooks in Finance*, pp. 617 – 690. San Diego: North-Holland.

Levine, R. (1997). Financial development and economic growth: Views and agenda. *Journal of Economic Literature 35*(2), 688–726.

Li, S., T. M. Whited, and Y. Wu (2016). Collateral, taxes, and leverage. *Review of Financial Studies 29*(6), 1453–1500.

Longstaff, F. A. and J. Wang (2012). Asset pricing and the credit market. *Review of Financial Studies 25*(11), 3169–3215.

López-Salido, D., J. C. Stein, and E. Zakrajšek (2015). Credit-market sentiment and the business cycle. Working paper, Harvard University.

Lucas, R. E. J. and J. P. Nicolini (2015). On the stability of money demand. *Journal of Monetary Economics 73*, 48 – 65.

McGrattan, E. R. (2016). Intangible capital and measured productivity. Working paper, University of Minnesota.

McGrattan, E. R. and E. C. Prescott (2010, September). Technology capital and the us current account. *American Economic Review 100*(4), 1493–1522.

Moll, B. (2014, October). Productivity losses from financial frictions: Can self-financing undo capital misallocation? *American Economic Review 104*(10), 3186–3221.

Opler, T., L. Pinkowitz, R. Stulz, and R. Williamson (1999). The determinants and implications of corporate cash holdings. *Journal of Financial Economics 52*(1), 3 – 46.

Peters, R. H. and L. A. Taylor (2016). Intangible capital and the investment-q relation. *Journal of Financial Economics*, forthcoming.

Piazzesi, M. and M. Schneider (2016). Payments, credit and asset prices. Working paper, Stanford University.

Pinkowitz, L., R. M. Stulz, and R. Williamson (2015). Do u.s. firms hold more cash than foreign firms do? *Review of Financial Studies*.

Pozsar, Z. (2011). Institutional cash pools and the Triffin dilemma of the u.s. banking system. Working paper WP/11/190, International Monetary Fund.

Pozsar, Z. (2014). Shadow banking: The money view. Working paper 14-04, Office of Financial Research.

Quadrini, V. (2014). Bank liabilities channel. CEPR Discussion Papers 10265.

Rajan, R. G. and L. Zingales (1998). Financial dependence and growth. *The American Economic Review 88*(3), 559–586.

Rampini, A. A. and S. Viswanathan (2015). Financial intermediary capital. Working paper, Duke University.

Reinhart, C. M. and K. S. Rogoff (2009). *This Time Is Different: Eight Centuries of Financial Folly*. Princeton, NJ: Princeton University Press.

Schularick, M. and A. M. Taylor (2012, April). Credit booms gone bust: Monetary policy, leverage cycles, and financial crises, 1870-2008. *American Economic Review 102*(2), 1029–61.

Shleifer, A. and R. W. Vishny (1992). Liquidation values and debt capacity: A market equilibrium approach. *The Journal of Finance 47*(4), 1343–1366.

Stein, J. C. (2012). Monetary policy as financial stability regulation. *The Quarterly Journal of Economics 127*(1), 57–95.

Vayanos, D. and J. Wang (2013). Chapter 19 - Market liquidity – theory and empirical evidence. Volume 2, Part B of *Handbook of the Economics of Finance*, pp. 1289 – 1361. Elsevier.

Woodford, M. (1990). Public debt as private liquidity. *The American Economic Review 80*(2), 382–388.