Fragile New Economy: Intangible Capital, Corporate Savings Glut, and Financial Instability*

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Abstract

Intangible-intensive firms in the U.S. hold an enormous amount of liquid assets that are in fact short-term debts issued by financial intermediaries. This paper builds a macro-finance model that captures this structure. A self-perpetuating savings glut emerges in equilibrium. As intangibles become increasingly important for production, firms hoard more liquidity to finance investments in intangibles with limited pledgeability. The resulting low interest rates induce intermediaries to increase leverage and bid up asset prices, which in turn encourages firms to invest more and hoard even more liquidity to fund expansion. Along these secular trends, endogenous risk accumulates in the financial system.

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1 Introduction

U.S. nonfinancial corporations have accumulated a substantial amount of cash, turning from net borrowers in aggregate to net lenders (Quadrini, 2017). Their liquid assets increased from 5% of GDP in the 1980s to 9.6% of GDP by 2019.[1] The cash-to-assets ratio of the average public firm more than doubled (Bates, Kahle, and Stulz, 2009; Gao, Whited, and Zhang, 2018). This paper provides the first theory of the macroeconomic causes and consequences of corporate savings gluts.

The first ingredient is firms' trade-off between investing in tangible capital, which can be externally financed, and investing in unpledgeable intangibles, which needs liquidity holdings. Empirically, intangible investment has surpassed tangible investment (Corrado and Hulten, 2010), and corporate savings are concentrated in intangible-intensive sectors.[2] In the model, intangible-investment efficiency rises exogenously, tilting investment towards intangibles. The emergence of a corporate savings glut and its macroeconomic effects depend on the general equilibrium forces.

The second ingredient is a distinguishing feature of the model. Firms hold liquidity in the form of financial intermediaries' debts. Empirically, corporate savings consist of deposits and money-market securities issued by intermediaries. In the model, firms hold intermediary debts that are in turn backed by intermediaries' claims on firms' pledgeable cash flows from tangible capital. Thus, firms' liquidity holdings and investments depend on intermediaries' balance-sheet capacity.

A unique financial accelerator generates a self-perpetuating corporate savings glut and amplifies the economy's responses to both the structural change of intangible-investment efficiency and business-cycle shocks. Firms' savings push down interest rates, so intermediaries can borrow cheaply and grow, driving up the market value of tangible capital. A higher value of pledgeable capital implies that firms' liquidity holdings can be levered up to larger investments, so firms are more eager to save and interest rates decline further, which encourages intermediaries to take on more risks and keep bidding up the value of tangible capital. In the model, firms optimally choose

[1]Liquid assets include currency, deposits, open market papers, repurchase agreements, and Treasury securities held directly or indirectly via money-market or mutual funds (source: Financial Accounts of the United States).

[2]Pinkowitz, Stulz, and Williamson (2015) find that R&D-intensive U.S. firms hold more cash than foreign firms, while other U.S. firms' cash holdings do not show a difference. Graham and Leary (2018) find within the U.S., the increase in cash is mainly in health and technology sectors. Falato, Kadyrzhanovaz, Sim, and Steri (2018) and Begenau and Palazzo (2021) conduct a structural analysis on the rise of intangible capital and corporate cash holdings.

investment composition. Investment is financially constrained and liquidity holdings are necessary due to the intangible component, while the tangible component triggers feedback effects.

This paper is the first to jointly analyze the corporate savings glut and other secular trends, such as the decline of interest rates, the rise of asset valuations, and the growth of financial intermediation. It is also the first to analyze endogenous financial risks along these trends, showing that a transition towards an intangible-intensive economy is accompanied by an increasingly fragile financial system. Following Caballero, Farhi, and Gourinchas (2008), the model highlights the role of savings glut in explaining low interest rates under asset shortages. It differs by connecting the asset supply to intermediaries' balance-sheet capacity, which is key to the endogenous origination of financial risk. It also differs by modelling corporate savings in a closed-economy instead of foreign savings in a world economy. Driven by investment needs, corporate savings comove with asset prices. The resulting feedback mechanism is key to the amplification of financial risk.

The continuous-time economy has entrepreneurs, bankers, and households. Their roles are discussed sequentially. First, I focus on entrepreneurs and, in particular, their liquidity demand.

A unit mass of infinitely-lived entrepreneurs manage tangible and intangible capital to produce non-durable generic goods. Capital represents efficiency units and its output is normalized to one unit of goods per unit of time. Capital depreciates stochastically, loading on an aggregate Brownian shock. A negative shock reduces capital stocks, i.e., the production capacity in the economy. In spite of these common features, tangible and intangible capital differ in liquidity.

As in Holmström and Tirole (1998), entrepreneurs face idiosyncratic Poisson shocks that entail a restart of business – their existing capital is destroyed, but they may create new capital. They choose the amount of goods to invest (scale) and their intangible share of investment (composition). To finance the investment, entrepreneurs can sell the ownership of tangible capital at a competitive-market price, and commit to dutifully managing the capital on behalf of buyers, delivering goods it produces. In other words, tangible capital is liquid (tradable and pledgeable). In contrast, intangible capital is not tradable or pledgeable, representing technological, human, and organizational capital that are inalienable or difficult for creditors to repossess.

The output of tangible capital is capitalizable, while intangible capital contributes the noncapitalizable share of output. The dichotomy follows Caballero, Farhi, and Gourinchas (2008) who study global savings gluts and the shortages of financial assets. Later, the model is extended to incorporate a third type of capital, tradable intangibles (Akcigit, Celik, and Greenwood, 2016).

The illiquidity of intangible capital gives rise to a funding constraint on entrepreneurs' investment. Even though investing in tangible capital relaxes the constraint, intangible investment creates sufficiently many units of intangible capital such that entrepreneurs optimally choose a positive intangible share. Importantly, the productivity of intangible investment increases over time. This captures exogenous technological changes. Because capital is essentially a stream of future consumption units, the fact that intangible investment creates increasingly more capital also captures the shift of consumers' preference towards products and services generated by intangibles.

The funding constraint implies that entrepreneurs want to hold liquidity and finance investment with a combination of internal funds and external funds (raised against tangible capital). A potential solution of liquidity provision, in the spirit of Holmström and Tirole (1998), is to pool all entrepreneurs' tangible capital – the source of capitalizable output – into a mutual fund whose shares are distributed to entrepreneurs. The fund diversifies away the idiosyncratic Poisson shocks, so when the shock hits an individual entrepreneur, her holdings of fund shares are still valuable and can be used to buy goods as investment inputs, even though her own capital is destroyed.

However, such diversification services require expertise. In reality, firms mainly hold money-market instruments issued by financial intermediaries in their portfolios of "cash and cash equivalents". A unit mass of infinitely-lived bankers are introduced to intermediate the liquidity supply.

Bankers buy tangible capital with their own wealth (equity) and by issuing short-term safe debts ("deposits") that entrepreneurs hold as liquidity buffers. Bankers create value not as lenders (their typical roles in macro-finance models) but instead as the issuers of liquid assets. The model highlights bankers' role in addressing asset shortages (Caballero, 2006; Caballero, Farhi, and Gourinchas, 2017b). Entrepreneurs assign a liquidity premium to deposits, which is equal to the marginal value of liquidity due to the Poisson-arriving investment needs (Holmström and Tirole, 2001). This liquidity premium lowers the deposit rate, encouraging bankers to expand their balance sheets. However, acquiring tangible capital and issuing safe deposits involve risk-taking, so bankers' capacity to intermediate the liquidity supply depends on their wealth as the risk buffer.

Finally, households are introduced, competing with entrepreneurs to hold deposits. Following the literature, households' demand is from deposit-in-utility, motivated by the roles of deposits as means of payment. Households can also trade tangible capital. This is the first model featuring both firms' and households' liquidity demand. Their relative importance in driving interest rates, asset prices, and endogenous financial risk will be analyzed via counterfactual analysis.

The Markov equilibrium has four state variables that have a hierarchical structure. The highest level is time and it triggers secular trends via the productivity of intangible investment. At the next level, the ratio of bankers' wealth to tangible capital stock measures the size of intermediation capacity relative to the amount of assets available for intermediation. Together with time, it determines all prices, such as the deposit rate and the value of tangible capital. At the third and fourth levels, respectively, are tangible and intangible capital stocks, driving the aggregate quantities. The law of motion of a state variable depends on itself and the state variables at higher levels. The problem of solving the full equilibrium dynamics is converted to solving a system of partial differential equations. Next, I discuss how the economy responds to structural changes in the investment technology and to the business-cycle shocks (Brownian shock to the capital stocks).

The first year in the model is calibrated to represent the U.S. economy in the years around 1990, matching the intangible share of investment, the level and composition (firms' holdings vs. households' holdings) of intermediary debts, deposit rates, and (tangible) capital valuation. Then I input a linear trend of intangible-investment productivity and examine the model's performances.

The model generates a trend in the intangible share of investment that matches data with an error below 0.5% (average in 1990–2010). A larger intangible share tightens the funding constraint on investment, so entrepreneurs hold more deposits and assign a larger liquidity premium, pushing down the deposit rate. A lower debt cost encourages bankers to expand their balance sheets, bidding up the market value of tangible capital. The resulting trend in capital valuation matches data with an error below 1.4% (average in 1990–2010). The rise of firms' holdings of intermediary debts also replicates data, increasing from 9.8% of households' holdings in 1990 to 14% in 2010.

Tangible capital plays two roles, production and liquidity provision (via the bankers' balance sheet). The deposit liquidity premium from entrepreneurs is transmitted by bankers to tangible capital, so the equilibrium value of tangible capital is beyond the present value of goods it produces. Therefore, the rise of entrepreneurs' liquidity demand translates into the rising capital valuation.

A feedback mechanism reinforces the trends through a self-perpetuating savings glut. As the deposit rate declines and bankers bid up the value of tangible capital, the financing capacity of entrepreneurs' investments becomes larger, allowing deposit holdings to be levered up to larger investments. Moreover, investments are more profitable as the tangible capital is more valuable. Despite a greater financing capacity, the cornerstone holdings of internal funds are still necessary due to the intangible part of investment. Therefore, the marginal value of liquidity increases, resulting in an even stronger deposit demand of entrepreneurs and an even lower deposit rate.

The feedback mechanism also amplifies the economy's response to the aggregate shock that hits capital stocks. Endogenous financial risk accumulates after positive shocks, and materializes into a downward spiral when negative shocks trigger the decline of intermediated liquidity supply.

Consider a positive shock. Given bankers' levered positions in tangible capital, the ratio of bankers' wealth to tangible capital stock, a key state variable, increases. The liquidity premium on deposits makes bankers' marginal costs of financing (and discount rates) lower than those of the rest of the economy. Therefore, when they become richer relative to the supply of tangible capital, their demand drives up the market value of tangible capital, which in turn leads to a higher leverage on entrepreneurs' deposits and higher investment profits. So, entrepreneurs assign a larger liquidity premium on deposits, driving down the bankers' discount rate. A sequence of positive shocks widen the discount-rate gap between bankers and the rest of the economy, making the value of tangible capital increasingly sensitive to shocks that trigger reallocation between the two groups.

The accumulation of endogenous financial risk is biased towards the downside. Positive shocks trigger the reallocation of tangible capital to bankers with low discount rates but eventually cause bankers to consume their wealth. However, negative shocks cause a continuing reallocation of tangible capital to the rest of the economy with high discount rates. Such asymmetry sheds light on the recent findings that longer booms precede more severe crises.[3]

[3] Please refer to Baron and Xiong (2017), Jordà, Schularick, and Taylor (2013), Krishnamurthy and Muir (2016), and López-Salido, Stein, and Zakrajšek (2017) among others. The mechanism is consistent with banks' procyclical

The accumulation of financial risk in the form of asset-price volatility affects the real economy. Given a high volatility, the value of tangible capital falls significantly after negative shocks, reducing entrepreneurs' leverage on deposit holdings and investments. By reducing bankers' wealth, the decline of tangible capital value also causes bankers to shrink balance sheets, so entrepreneurs hold fewer deposits and investments decline further. The composition of capital stock, which determines the fraction of output that is capitalizable, is also affected as a result. Depending on entrepreneurs' choices of their intangible share of investment and the investment technology, the decline of investments affect the two types of capital stocks disproportionately.

As the economy becomes more intangible-intensive, new markets emerge for the exchange of intangibles. Akcigit, Celik, and Greenwood (2016) document that 16% of the U.S. registered patents between 1976 and 2006 are traded. For this reason, the model departs from the dichotomy of liquid tangible capital and illiquid intangible capital by incorporating a third type, tradable intangibles, which are traded among entrepreneurs and households. Note that as long as some intangibles are illiquid, the cornerstone liquidity holdings are still necessary for entrepreneurs' investments. Therefore, by enlarging entrepreneurs' external financing capacity, tradable intangibles increase the leverage on deposit holdings and lead to a larger liquidity premium. The mechanism is amplified. The linear trend of intangible-investment productivity triggers an increasing and convex trend in the intangible share of investment, in contrast to the linear trend in the baseline model. As a result, corporate savings rise sharply, resulting in a lower deposit rate and a higher tangible capital value. The endogenous volatility of tangible capital value is 50% higher.

Finally, I conduct a counterfactual analysis to evaluate the quantitative importance of entrepreneurs' deposit demand, relative to households', in driving interest rates, asset prices, and endogenous financial risk. Despite being less than 15% of households' holdings (both in the model and data), entrepreneurs' deposit holdings have a significant impact due to the unique feedback mechanism that links the endogenous deposit rate to the value of tangible capital, and then, to the leverage on entrepreneurs' deposit holdings.

Literature. The model makes two contributions to the literature on savings gluts, asset shortages,

payout in data (Baron, 2014; Adrian, Boyarchenko, and Shin, 2016).

and low interest rates: (1) asset demand arises from endogenous corporate savings; (2) asset supply depends on financial intermediaries' balance-sheet capacity. These two ingredients generate a feedback mechanism that amplifies both secular trends and cycles. On asset demand, the literature focuses on foreign savings (Bernanke, 2005; Caballero and Krishnamurthy, 2006; Caballero, Farhi, and Gourinchas, 2008; Caballero and Krishnamurthy, 2009; Gourinchas and Rey, 2016; Maggiori, 2017; Bolton, Santos, and Scheinkman, 2018).[4] On asset supply, the model is related to Giglio and Severo (2012) and Miao and Wang (2018) who emphasize the shortage of collateral capital, but financial intermediation is absent in their models and absent in the broad literature on asset shortages due to limited pledgeability (Holmström and Tirole, 2001; Kiyotaki and Moore, 2001; Farhi and Tirole, 2012; Martin and Ventura, 2012; Hirano and Yanagawa, 2017).

The disconnect between the macro-finance literature and the literature on corporate liquidity management is quite surprising given that corporate savings have become a major component of national savings (Pozsar, 2011; Carlson et al., 2016; Greenwood et al., 2016; Chen et al., 2017).[5] The downward trend in interest rates has drawn enormous attention and has been studied jointly with other secular trends (Caballero, Farhi, and Gourinchas, 2017a; Eggertsson, Robbins, and Wold, 2018; Farhi and Gourio, 2018; Marx, Mojon, and Velde, 2018; Corhay, Kung, and Schmid, 2019). Liquidity demand has been proposed as a key contributing factor (Del Negro, Giannone, Giannoni, and Tambalotti, 2017). However, corporate savings have been ignored. Moreover, the financial instability implications of such trends have not been studied. This paper bridges the gap.

The disconnect between the two literatures is also apparent in the partial-equilibrium approach taken by models of corporate liquidity management.(e.g., Froot, Scharfstein, and Stein, 1993; Riddick and Whited, 2009; Bolton, Chen, and Wang, 2011; Décamps, Mariotti, Rochet, and Villeneuve, 2011; He and Kondor, 2016). Except Holmström and Tirole (1998), the models assume perfect storage technology, leaving out the question of who issues the liquid securities.

Recent studies in the macro-finance literature highlight the value of bank liabilities in in-

[4]U.S. nonfinancial corporations' holdings of liquid intermediary debts are comparable in magnitude to foreigners' holdings. The ratio of the former to the later is stable since the 1990s, around 75%. Liquid intermediary debts include currency and deposits, open market papers, and repurchase agreements held directly or indirectly via money-market or mutual funds (source: Financial Accounts of the United States).

[5]The first money market fund was set up to meet the demand of nonfinancial corporations (Hershey, 1973).

complete markets (Brunnermeier and Sannikov, 2016; Quadrini, 2017) and as liquid assets for households (Kiyotaki and Moore, 2000; Moreira and Savov, 2017; Krishnamurthy and Vissing-Jørgensen, 2015; Piazzesi and Schneider, 2016; Egan, Lewellen, and Sunderam, 2018; Van den Heuvel, 2018; Begenau, 2019; Begenau and Landvoigt, 2018).[6] This paper is the first to model both households' and firms' liquidity demand, and the model is calibrated so their relative contributions to intermediaries' funding match data. This allows for a counterfactual analysis to show the relative importance of firms' liquidity demand in affecting interest rates and financial instability.[7] Section 2 and 6 provide evidence on the distinct responses of households' and firms' liquidity demand to asset-price variations that are consistent with the model's predictions.[8] In the run-up to the Great Recession, the financial sector grew significantly (Greenwood and Scharfstein, 2013; Schularick and Taylor, 2012), feeding on cheap funds from major cash pools (Adrian and Shin, 2010; Pozsar, 2014). This paper provides the first analysis of the important role of corporate savings.

In comparison with households' savings and foreign savings, corporate savings have two distinct empirical features: corporate savings comove with asset prices and concentrate in intangible-intensive sectors (Section 2). The first feature is essential for the feedback mechanism. The second feature brings the rise of intangibles into the analysis of interest rates and financial instability.

On the feedback mechanism, this paper develops a new financial accelerator based on firms' savings. It amplifies both trends and cycles. The previous literature focuses on firms' borrowing and business cycles (Kiyotaki and Moore, 1997; Bernanke, Gertler, and Gilchrist, 1999; Gertler and Kiyotaki, 2010). The feedback mechanism exhibits fire-sale dynamics. The liquidity premium on deposits creates a procyclical wedge in the discount rate between bankers, "natural buyers" (Shleifer and Vishny, 2011), and the rest of the economy. Thus, the longer a boom lasts, the sharper asset price falls when negative shocks reduce natural buyers' wealth. This procyclical discount-rate wedge is distinct from the constant cash-flow wedge between intermediaries and households

[6]See also the banking theory literature (Diamond and Dybvig, 1983; Gorton and Pennacchi, 1990; Goldstein and Pauzner, 2005; Dang, Gorton, Holmström, and nez, 2014; Hart and Zingales, 2014; DeAngelo and Stulz, 2015).

[7]Related, using a structural model, Eisfeldt (2007) show that the liquidity premium of Treasury bills cannot be explained by the liquidity demand from consumption smoothing under standard preferences. Eisfeldt and Rampini (2009) document empirically that corporate liquidity needs are correlated with measures of liquidity premium.

[8]Except Eisfeldt and Muir (2016), the empirical literature on corporate cash holdings focuses on trends but not cycles. Another contribution of this paper is the finding of comovement between corporate savings and asset prices.

in Brunnermeier and Sannikov (2014) due to agents' differences in asset-management skills.

By connecting intangible investment and corporate savings, this paper contributes to the literature on the macroeconomic implications of intangibles.[9] Motivated by the empirical studies on the massive cash holdings in intangible-intensive firms (Pinkowitz, Stulz, and Williamson, 2015; Graham and Leary, 2018; Falato, Kadyrzhanovaz, Sim, and Steri, 2018; Begenau and Palazzo, 2021), exogenous variation of intangible-investment efficiency is introduced to trigger firms' liquidity demand. Through corporate savings, intangible investment has an impact on interest rates and financial instability. Moreover, in the model, the fraction of output attributed to intangible capital evolves endogenously in response to firms' investment, which in turn depends on intermediaries' liquidity supply. Therefore, this paper establishes a new connection between industrial structure and financial development (Levine, 1997; Rajan and Zingales, 1998).

2 Corporate Liquidity Demand

This section establishes a robust empirical link between intangible investment and firms' holdings of liquid assets. Moreover, the intangible-liquidity link is stronger when the value of tangible capital (i.e., capitalizable or pledgeable value of future output) increases. The sample is Compustat panel (firm-year) data from 1980 to 2019.[10] Firms' liquidity holdings are given by cash and cash equivalents. Intangible intensity is measured by the ratio of intangible investment to total assets averaged over time for each firm. Firms are sorted into quintiles to form the ranking variable

[9]Previous studies has shown that the rise of intangible capital is important for explaining the secular trends in corporate profits and investment (McGrattan and Prescott, 2010b; Crouzet and Eberly, 2018; Gutiérrez and Philippon, 2017; Peters and Taylor, 2017). Dell'Ariccia, Kadyrzhanova, Minoiu, and Ratnovski (2018) and Döttling and Perotti (2017) emphasize the decline of firms' borrowings from banks as a result of less collateral assets. In contrast, this paper focuses on the liability side of banks' balance sheets, i.e., firms holding banks' liabilities as liquidity buffer. Previous studies also explores broad implications of intangible capital on productivity (Atkeson and Kehoe, 2005; McGrattan, 2016), current account (McGrattan and Prescott, 2010a), stock valuation (Hansen, Heaton, and Li, 2005; Ai, Croce, and Li, 2013; Eisfeldt and Papanikolaou, 2014), and investment (Daniel, Naveen, and Yu, 2018).

[10]This includes Compustat firm-year observations with non-missing data for total assets and sales. All firms incorporated in the United States are included except financials (SIC 6000-6999) and utilities (SIC 4900-4999). The sample starts from 1980 because, before the 1980s, Regulation Q imposed various restrictions on deposit rates. For example, it prohibited banks from paying interest on demand deposits. This practice is inconsistent with the model specification that the deposit rate, r_t, is the price variable that clears the deposit market. Appendix C provides summary statistics.

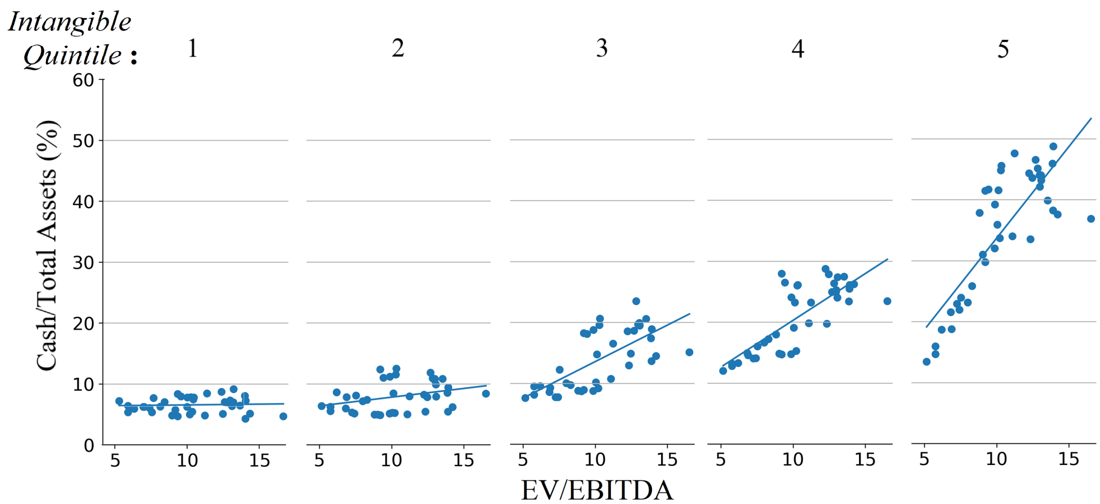

Figure 1: **Capital Valuation and Corporate Cash Holdings by Intangible Quintile**.

"Intan./Assets". Following the literature, intangible investment includes R&D and organizational-capital investment that is 30% of SG&A expenses.[11] Two *aggregate* measures of tangible capital valuations are constructed. Each year, I calculate the market capitalization-weighted average ratio of enterprise value (EV) to earnings before interest, tax, depreciation, and amortization (EBITDA). EV is the present value of a firm's capitalizable output (tangible capital value in the model).[12]

Figure 1 reports scatter charts of cash/assets against capital valuation (and regression lines) for Intan./Assets quintiles. Each point is given by the quintile's market capitalization-weighted average cash/assets in a year and average EV/EBITDA in that year. More intangible firms hold more cash and show a sharper correlation between cash and capital valuation. Appendix D shows similar patterns with tangible EV/EBITDA and Tobin's Q as measures of capital valuation. Tangible EV/EBITDA is the average EV/EBITDA of the firms in the lowest Intan./Assets quintile.[13]

Table 1 reports regression results that correspond to the patterns in Figure 1. The explanatory variables of interest, capital valuation and the quintile ranking variable Intan./Assets, are the same as in Figure 1. Different from Figure 1 that plots the time-series variation of within-quintile average

[11] This follows a large literature on measuring intangible investment (Corrado et al., 2009; Eisfeldt and Papanikolaou, 2013, 2014; Falato et al., 2018; Peters and Taylor, 2017; Belo et al., 2014).

[12] Appendix D uses more restrictive Tangible EV/EBITDA based on firms in the lowest quintile of Intan./Assets.

[13] Two versions of Tobin's Q are calculated, the whole market's average Tobin's Q and tangible Tobin's Q that is the average Tobin's Q of firms in the lowest Intan./Assets quintile. All averages are market capitalization-weighted.

Table 1: Intangible Investment, Capital Valuation, and Corporate Cash Holdings

***Panel A**: Intangibility & Corporate Cash Holdings*

$\frac{\text{Cash}}{\text{Assets}}$	Intangibility = Intan./Assets (quintile)				Intangibility = Intan./Investment			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intangibility	6.600***	6.493***	5.277***	5.009***	0.207***	0.196***	0.186***	0.170***
	(0.440)	(0.455)	(0.320)	(0.335)	(0.015)	(0.016)	(0.010)	(0.010)
Controls	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	152,826	152,826	132,632	132,632	112,171	112,171	98,571	98,571
Adjusted R^2	0.1669	0.1903	0.2588	0.2757	0.0964	0.1185	0.2467	0.2585

***Panel B**: Capital Valuation & Intangible-Driven Corporate Cash Holdings*

$\frac{\text{Cash}}{\text{Assets}}$	Valuation = Ave. EV/EBITDA				Valuation = Tangible EV/EBITDA			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intan./Assets	-2.427**	-2.742**	-1.484	-1.846*	-1.039	-1.511	-0.277	-0.813
	(1.199)	(1.134)	(1.012)	(0.943)	(1.438)	(1.449)	(1.207)	(1.216)
Valuation	-0.731***		-0.590***		-0.789***		-0.738***	
	(0.097)		(0.066)		(0.131)		(0.082)	
Intan./Assets×	0.849***	0.881***	0.638***	0.661***	0.833***	0.884***	0.612***	0.649***
Valuation	(0.121)	(0.116)	(0.098)	(0.94)	(0.153)	(0.157)	(0.127)	(0.131)
Controls	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	152,826	152,826	132,632	132,632	152,826	152,826	132,632	132,632
Adjusted R^2	0.2008	0.2128	0.2763	0.2883	0.1863	0.2044	0.2674	0.2832

Firm-year clustered standard errors in parentheses
* $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$

cash/assets, the regression dependent variable, cash/assets, has both time-series and cross-section variation. I consider different specifications controlling for firm characteristics and/or time fixed effects.[14] Column (1) to (4) in Panel A shows that more intangible-intensive firms hold more cash.[15]

[14]The control variables are selected and winsorzied following Opler et al. (1999) and Bates et al. (2009). They include (Compustat codes in parenthesis): acquisition activity (aqc/at), capex (capx/at), cash flow ([oibdp – xint – dvc – txt]/at), net working capital ([wcap – che]/at), payout dummy (equal to 1 if dvc is positive), leverage ([dlc – dltt]/at), market to book ratio ([at + prcc_f*csho – ceq]/at), R&D to sales ratio (xrd/sale), size (log of at in 2005 dollars), Tobin's Q ([at + prcc_f*csho – ceq – txdb]/[0.1*(at + prcc_f*csho – ceq – txdb) + 0.9*at]), and industry sigma, which is the 10-year mean of the cross-sectional standard deviations of firms' cash flow/assets in a two-digit SIC industry.

[15]This is consistent with previous studies (Begenau and Palazzo, 2021; Pinkowitz et al., 2015; Falato et al., 2018). More broadly, investment need is a key determinant of firms' cash holdings (Denis and Sibilkov, 2010; Duchin, 2010).

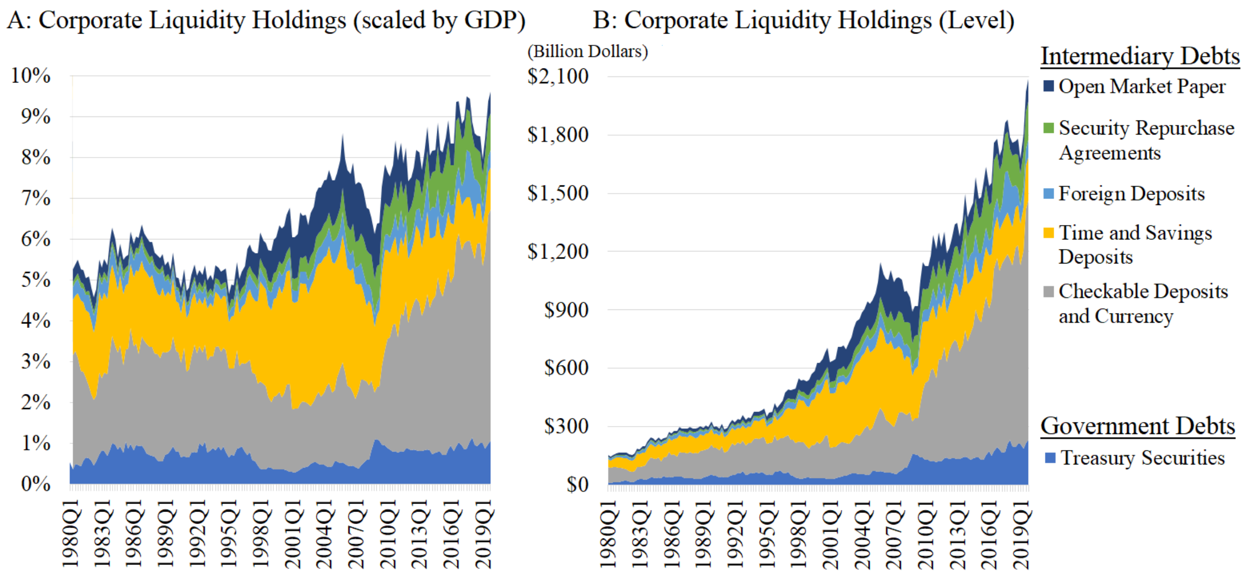

Figure 2: **Decomposing Nonfinancial Firms' Holdings of Liquid Securities**.

In Column (5) to (8), the ranking variable, Intan./Assets, is replaced by intangible investment-to-total investment ratio that maps more directly to the model setup in Section 3. The estimates will guide model calibration. Column (1) to (4) in Panel B report a positive coefficient of the interaction between asset valuation and intangibility that is robust across specifications. As in Figure 1, more intangible firms' cash holdings are more sensitive to capital valuation. In Columns (5) to (8) of Panel B, I use a more restrictive measure of tangible capital valuation, tangible EV/EBITDA. Table D.5 in Appendix C reports similar results with Tobin's Q as measure of capital valuation.[16]

Figure 2 examines the general equilibrium of liquid assets by shifting focus from demand to supply. Nonfinancial firms' liquid assets are mainly issued by financial intermediaries (source: U.S. Financial Accounts). Mutual fund and money market fund holdings are attributed to underlying assets based on sector level tables. Firms are among the major cash pools that feed leverage to intermediaries (Carlson et al., 2016; Pozsar, 2014). Their liquid assets scaled by GDP almost doubled by 2019. The trend was interrupted by the financial crisis and firms flighted to Treasuries,

And, firms with less collateral also tend to hold more cash (Almeida and Campello, 2007; Li, Whited, and Wu, 2016).

[16]Table D.4 also reports the similar results when firms are sorted by asset tangibility (PPE/assets). Less tangible firms exhibit stronger correlation between cash and capital valuation (measured by both EV/EBITDA and Tobin's Q).

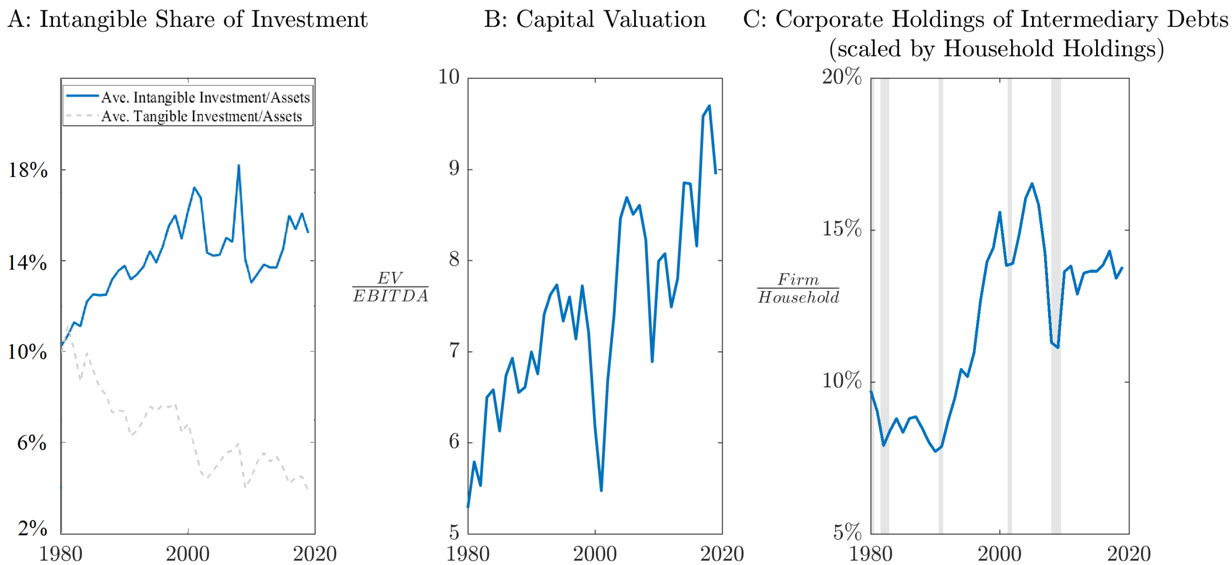

Figure 3: **The Rise of Intangible Investment, Capital Valuation, and Corporate Savings**.

but the trend resumed afterwards. However, the loss of firms' savings for intermediaries in the crisis was recognized by regulators. Retail deposits are assigned 90% to 95% stable funding factor while corporate deposits are assigned 50% (Basel Committee on Banking Supervision, 2014).

The rise of corporate savings in Figure 2 coincided with the secular increase in intangible investment especially relative to tangible investment in Panel A of Figure 3. Moreover, in Panel B of 3, capital valuation exhibits an upward trend, which, according to the evidence in Figure 1 and Table 1, reinforced the rise of intangibles in fueling the corporate savings glut. Along the secular trends, cyclical fluctuations emerge in both investment and capital valuation, feeding procyclicality to corporate savings. Panel C of Figure 3 plots the ratio of firms' holdings of intermediary debts to households' holdings (source: Financial Accounts of the U.S.). Recession years are marked by shaded areas. The ratio trends upward with cyclical drops in recessions, suggesting that, as a source of funding for intermediaries, corporate liquidity holdings are more procyclical than households'. Next, a model is built to generate both the trends and cyclical fluctuations in intangible share of investment, capital valuation, corporate liquidity holdings. The model highlights endogenous risk that arises from the reinforcing procylicality of these variables and becomes stronger and stronger along the secular trends. The model also provides a new account of trends in interest rates and the size of intermediation sector, which have been documented extensively by previous studies.

3 Model

Consider a continuous-time, infinite-horizon economy. The model fixes an information filtration that satisfies the standard regularity conditions (Protter, 1990). The production sector is set up first with a focus on intangible-driven liquidity demand. Later, bankers and households are introduced.

3.1 The Production Sector and Liquidity Demand

Preferences. There is a unit mass of entrepreneurs. Let $\mathbb{E} = [0, 1]$ denote the set of entrepreneurs. Let c_t^E denote a representative entrepreneur's *cumulative* consumption up to time t. Throughout this paper, subscripts denote time, and whenever necessary, superscripts are used to denote agents' type, with "E" for entrepreneurs (and later, "B" for bankers and "H" for households). An entrepreneur maximizes the life-time, risk-neutral expected utility with discount rate ρ:

$$\mathbb{E}\left[\int_{t=0}^{\infty} e^{-\rho t} dc_t^E\right]. \tag{1}$$

Capital and production. Each entrepreneur manages a firm that has tangible and intangible capital. Capital represents efficiency units and is counted by its output: One unit of capital produces one unit of non-durable generic goods per unit of time. In aggregate, the economy has K_t^T and K_t^I units of tangible and intangible capital, respectively, at time t that generate a flow of output, $\left(K_t^T + K_t^I\right) dt$ over dt. A fraction $\delta dt - \sigma dZ_t$ of capital are destroyed over dt. The standard Brownian motion Z_t captures aggregate shocks to production capacity.[17]

The two types of capital differ in liquidity. Tangible capital is liquid. It can be pledged for financing, and entrepreneurs may sell the capital ownership and dutifully manage the capital on

[17]For parsimony, the stochastic depreciation rates are set to be the same for both types of capital. Introducing different depreciation rates for intangible and intangible capital will not change the mechanism and the solution method.

behalf of investors delivering goods produced. Tangible capital represents inventory, equipment, plant, and property. In reality, even though certain tangible assets are not actively traded, the securities backed by their cash flows are traded. In contrast, intangible capital is illiquid. It cannot be pledged for financing, and its ownership cannot be traded. It represents human and organizational capital, customer base, and proprietary technologies that are difficult for investors to repossess.

Investment and liquidity demand. The Poisson arrival of investment needs is independent across entrepreneurs with intensity λ. When hit by the shock, an entrepreneur's firm loses all capital but is endowed with a technology to transform goods into new capital instantaneously.[18] She chooses i_t, the amount of goods invested, and θ_t, the intangible share, to create $\kappa_t^I \theta_t i_t$ units of intangible capital and $\kappa^T (1-\theta_t)\, i_t$ units of tangible capital. Tangible investment efficiency is constant κ^T. Intangible investment efficiency increases over time, $\kappa_t^I = \kappa^I(t)$. As in Lucas (1978), capital corresponds to a stream of future goods, so an increase of κ_t^I means that intangible investment generates more production capacity.

Let q_t^I denote the value of intangible capital (denominated in goods). The entrepreneur is indifferent in consumption timing, so she values the goods from intangible capital simply by Gordon growth formula, accounting for normal-time depreciation and Poisson-arriving destruction

$$q_t^I = \frac{1}{\rho + \delta + \lambda}\,. \tag{2}$$

Henceforth, the time subscript is dropped for q^I. As will be emphasized later in the solution, the unit value of tangible capital, denoted by q_t^T, may vary over time and loads on the aggregate shock,

$$dq_t^T = q_t^T \mu_t^T dt + q_t^T \sigma_t^T dZ_t\,. \tag{3}$$

where the drift and diffusion terms, μ_t^T and σ_t^T, will be endogenously determined in equilibrium.

[18]This specification reflects the lumpiness of investment at micro levels (e.g., Doms and Dunne, 1998). Due to the idiosyncratic nature of investment opportunities, the aggregate investment is smooth, in line with Thomas (2002).

Given q^I and q_t^T, an investing entrepreneur maximizes the investment profits:

$$\max_{\{i_t,\theta_t\}} \left[q^I \kappa_t^I \theta_t + q_t^T \kappa^T (1-\theta_t) - F(\theta_t)\right] i_t - i_t\,, \tag{4}$$

where a convex $F(\theta_t)$ is introduced to avoid counterfactual corner solutions (i.e., $\theta_t \in \{0,1\}$). Due to the illiquidity of intangible capital, the scale of investment is constrained by tangible value:

$$i_t \leq q_t^T \kappa^T i_t (1-\theta_t)\,. \tag{5}$$

Self-financing, $1 \leq q_t^T \kappa^T (1-\theta_t)$, is ruled out by the following condition (see Appendix A).

Assumption 1 *Investment projects are not self-financed:* $\kappa^T \left(\frac{1}{\rho+\delta+\lambda}\right) < 1$.

Under the financial constraint, entrepreneurs would hold liquidity, i.e., assets other than their own capital, which are immune to the Poisson shocks.[19] Holmström and Tirole (1998) point out a solution that is to pool liquid assets (tangible capital) in mutual funds where idiosyncratic shocks are diversified away. Then entrepreneurs hold the mutual-fund shares and use them as liquidity for investment. Let m_t^E denote an entrepreneur's liquidity holdings, so the constraint (5) becomes

$$i_t \leq q_t^T \kappa^T i_t (1-\theta_t) + m_t^E. \tag{6}$$

However, as shown in Figure 2, firms rarely hold direct claims on other firms but instead hold debt securities largely issued by financial intermediaries. Diversification may require intermediaries' expertise.[20] And, under agency frictions that limit equity issuances (e.g., He and Krishnamurthy, 2013), firms hold intermediaries' debt rather than equity. Intermediated liquidity supply is also motivated by studies on banks as inside money creators (e.g., Kiyotaki and Moore, 2000).

[19]It has been well documented that intangible investments rely heavily on firms' internal liquidity (for example, R&D investments in Hall (1992), Himmelberg and Petersen (1994), and Hall and Lerner (2009)).

[20]Introducing intermediaries can also be motivated by their expertise in monitoring (Diamond, 1984), restructuring (Bolton and Freixas, 2000), or enforcing collateralized claims (Rampini and Viswanathan, 2019).

3.2 Intermediated Liquidity Supply

Bankers are introduced to intermediate the supply of liquidity. Entrepreneurs are assumed to hold liquidity in the form of short-term bank debts (referred to as "deposits") that are in turn backed by bankers' holdings of firms' tangible capital. With a slight abuse of notation, m_t^E now represents entrepreneurs' deposit holdings that mature in dt with interests $r_t dt$. I characterize a Markov equilibrium where banks never default, so bank debt is safe and $r_t dt$ is also the realized return.[21]

When the Poisson shocks hit, entrepreneurs use deposits to buy goods as investment inputs. In contrast to the existing macroeconomic models with financial intermediation that emphasize bankers' expertise on lending, this model emphasizes the liability side of bank balance sheets – banks add value to the economy because their debts are held by entrepreneurs as liquidity buffers.

Preferences. There is a unit mass of bankers. Let $\mathbb{B} = [0, 1]$ denote the set of bankers. A representative banker maximizes the life-time, risk-neutral expected utility with discount rate ρ:

$$\mathbb{E}\left[\int_{t=0}^{\infty} e^{-\rho t} dc_t^B\right], \tag{7}$$

where c_t^B denotes a banker's *cumulative* consumption up to time t.

Balance sheet. A banker incurs interest expenses $r_t dt$ on debt liabilities and earns risky return dr_t^T on her holdings of tangible capital, where r_t^T denotes the *cumulative* return that loads on shocks. To characterize dr_t^T, let k_t^{TB} denote a banker's holdings of tangible capital, with "T" and "B" indicating "tangible" and "banker" respectively. Capital stock depreciates stochastically, so

$$dk_t^{TB} = -k_t^{TB}\left(\delta dt - \sigma dZ_t\right) - k_t^{TB}\lambda dt\,. \tag{8}$$

The last term is from the λdt firms that lose capital due to the Poisson shocks. Through diversification, the banker faces a constant rate of destruction instead of idiosyncratic Poisson shocks.

[21] Macro-finance models that are built upon diffusion processes typically do not feature bank default (e.g., Brunnermeier and Sannikov, 2014). Default may be introduced through an aggregate Poisson shock that destroys capital.

By Itô's lemma, equations (3) and (8) imply the following tangible capital return:

$$dr_t^T = \frac{k_t^{TB} dt}{q_t^T k_t^{TB}} + \frac{d\left(q_t^T k_t^{TB}\right)}{q_t^T k_t^{TB}} = \left(\frac{1}{q_t^T} + \mu_t^T - \delta - \lambda + \sigma_t^T \sigma\right) dt + \left(\sigma_t^T + \sigma\right) dZ_t \tag{9}$$

The first term, $1dt/q_t^T$, is dividend yield – the production flow, $1dt$, divided by the unit value, q_t^T. The second to fourth terms, $\left(\mu_t^T - \delta - \lambda\right) dt$, account for the expected unit value change, the quantity depreciation, and the measure of firms hit by the Poisson shocks. The fifth term, $\sigma_t^T \sigma$, is Itô's quadratic covariation. The return loads on the aggregate shock via σ_t^T, the endogenous return volatility of q_t^T (price risk), and σ, the exposure to exogenous depreciation shock (quantity risk).

Let n_t^B denote a representative banker's wealth that has the following law of motion,

$$dn_t^B = x_t^B n_t^B dr_t^T - (x_t^B - 1) n_t^B r_t dt - dc_t^B \,, \tag{10}$$

where $x_t^B \equiv q_t^T k_t^{TB} / n_t^B$ is the asset-to-wealth ratio and debt value is $(x_t^B - 1)n_t^B = q_t^T k_t^{TB} - n_t^B$.

As shown by (10), intermediation involves risk-taking. Bankers issue safe deposits while holding risky tangible capital. Wealth (equity) buffers risk. An undercapitalized banking sector cannot adequately fulfill its role as liquidity supplier. To capture this idea, I assume that banks cannot issue outside equity to replenish wealth, i.e., $dc_t^B \geq 0$ as in Brunnermeier and Sannikov (2014).[22] This can be motivated by agency frictions. As a result, bankers' wealth drives the *intermediation capacity*. In this model, entrepreneurs' liquidity demand from Holmström and Tirole (1998) meets banks' limited balance-sheet capacity from Holmström and Tirole (1997).

[22]By inspecting equation (9), we can see that negative consumption is equivalent to issuing equity to replenish net worth. See also Phelan (2016) and Klimenko, Pfeil, Rochet, and Nicolo (2016) for similar specifications. Note that negative consumption is allowed for entrepreneurs except when liquidity shocks hit. In other words, entrepreneurs are only financially constrained at such Poisson times. Allowing negative consumption is equivalent to assuming large endowments of goods – if goods are non-durable, entrepreneurs always consume to clear the goods market, indifferent between consuming and saving. This fixes their marginal value of wealth at one and required return at ρ.

3.3 The Main Mechanism: Trends and Cycles

The main results are in two categories: (1) the economy's response to the increase of κ_t^I over time (i.e. the trends) and (2) the economy's response to the aggregate shock, dZ_t (i.e., the cycles). First, I explain the trends as I characterize the entrepreneurs' intangible-driven liquidity demand.

When hit by the Poisson shock, an entrepreneur maximizes investment profits given by (4) facing the liquidity constraint (6). Let π_t denote the marginal value of liquidity, i.e., the Lagrange multiplier of constraint (6). The Lagrange function summarizes the entrepreneur's problem:

$$\mathcal{L} = \max_{\{i_t,\theta_t\}} \left[q^I \kappa_t^I \theta_t + q_t^T \kappa^T (1-\theta_t) - F(\theta_t)\right] i_t - i_t + \pi_t \left[m_t^E + q_t^T \kappa^T i_t (1-\theta_t) - i_t\right] . \quad (11)$$

It is assumed that κ^T or κ_t^I is sufficiently high so the constraint (6) binds. The entrepreneur can pledge the value of tangible capital and lever up one unit of liquidity to $1/\left[1 - q_t^T \kappa^T (1-\theta_t)\right]$:

$$i_t = \left(\frac{1}{1 - q_t^T \kappa^T (1-\theta_t)}\right) m_t^E \quad (12)$$

The funds are raised against tangible capital at a fair price so the entrepreneur captures the full surplus per unit of investment, i.e., $\left[q_t^I \kappa_t^I \theta_t + q_t^T \kappa^T (1-\theta_t) - F(\theta_t)\right] - 1$.[23] Therefore, the marginal value of liquidity, π_t, is the marginal profit of investment multiplied by the leverage on liquidity:

$$\pi_t = \underbrace{\left\{\left[q^I \kappa_t^I \theta_t + q_t^T \kappa^T (1-\theta_t) - F(\theta_t)\right] - 1\right\}}_{\textit{marginal profit of investment}} \underbrace{\left(\frac{1}{1 - q_t^T \kappa^T (1-\theta_t)}\right)}_{\textit{leverage on liquidity}} \quad (13)$$

The entrepreneur's choice of θ_t is characterized by the first-order condition that equates the marginal values of intangible and tangible investments:

$$q^I \kappa_t^I - F'(\theta_t) = (1+\pi_t) q_t^T \kappa^T . \quad (14)$$

Note that on the right side of (14), the marginal value of tangible capital, $q_t^T \kappa^T$, is amplified by π_t,

[23]The repayment for funds raised against tangible capital is in the ownership of the tangible capital. The entrepreneur is assumed to dutifully pass the production flows generated by the capital to its owners (i.e., the investors).

because investing more in tangible capital not only creates more production units but also relaxes the funding constraint (6). The next proposition summarizes the entrepreneur's liquidity-holding and investment decisions with a focus on the value of liquidity. Appendix A provides the proof.

Proposition 1 (Liquidity Premium) *Entrepreneurs' investment has the following properties:*
(1) The optimal intangible share of investment, θ_t, in (14) is increasing in κ_t^I;
(2) The marginal value of liquidity, π_t, given by (13), is increasing in κ_t^I and q_t^T.
Given the arrival intensity of investment needs, λ, entrepreneurs accept a deposit rate below ρ:

$$r_t = \rho - \lambda \pi_t \,. \tag{15}$$

Proposition 1 implies several trends in equilibrium. As κ_t^I increases over time, intangible investment creates increasingly more production capacity than tangible investment, so the entrepreneurs optimally choose to tilt investment towards intangibles, i.e., to increase θ_t. As the intangible share increases, the entrepreneurs face a tighter liquidity constraint, so the marginal value of liquidity, π_t, increases, driving down the deposit rate r_t. The entrepreneurs accept $r_t < \rho$. The wedge, $\lambda\pi_t$, depends on the probability of liquidity needs and marginal value of liquidity.

The decline of r_t triggers a feedback mechanism. It lowers bankers' cost of financing and allows them to bid up the price of tangible capital, q_t^T. A higher value of tangible capital enlarges the financing capacity of investment projects, allowing liquidity to be leveraged to larger investments. A higher q_t^T also means investments are more profitable. Therefore, π_t, the marginal value of liquidity holdings, increases further, and r_t drops even lower. The downward trend in r_t and upward trend in q_t^T reinforce each other, generating a corporate savings glut. This savings glut arises endogenously in a closed-economy, distinct from an exogenous savings glut in open economies that has been shown to affect interest rates and asset prices (Caballero, Farhi, and Gourinchas, 2008).

Tangible capital has two sources of value. It produces goods and provides liquidity indirectly by backing bank deposits. The bankers transmit the entrepreneurs' liquidity premium to the value of tangible capital.[24] To fully solve q_t^T, we need a complete characterization of bankers' discount rate, $r_t +$ *risk premium*. For the risk-premium component, we obtain bankers' price of risk from

[24] Related, Giglio and Severo (2012) analyze the liquidity value of tangible capital without financial intermediation.

the dynamics of marginal value of wealth. The homogeneity property of bankers' problem implies a linear value function $q_t^B n_t^B$, where, the marginal value of wealth, q_t^B, evolves in equilibrium

$$\frac{dq_t^B}{q_t^B} = \mu_t^B dt - \gamma_t^B dZ_t. \tag{16}$$

Proposition 2 (Asset Pricing) *The equilibrium expected return on tangible capital is given by*

$$\mathbb{E}_t \left[dr_t^T \right] = r_t dt + \gamma_t^B \left(\sigma_t^T + \sigma \right) dt \,. \tag{17}$$

The equilibrium value of tangible capital satisfies the following equation

$$q_t^T = \frac{1}{\left[r_t + \gamma_t^B \left(\sigma_t^T + \sigma \right) \right] - \left[\mu_t^T + \sigma_t^T \sigma - \delta - \lambda \right]} \,. \tag{18}$$

Appendix A provides the proof. Intuitively, $dZ_t < 0$ reduces bankers' wealth and increases their marginal value of wealth, so the bankers require a risk premium, $\gamma_t^B \left(\sigma_t^T + \sigma \right) dt$, in the expected return on tangible capital.[25] This is a standard asset-pricing result: γ_t^B is the price of risk and $\left(\sigma_t^T + \sigma \right)$ is the quantity of risk, a sum of exogenous risk, σ, and endogenous price risk, σ_t^T (see (3)). In equilibrium, $r_t + \gamma_t^B \left(\sigma_t^T + \sigma \right) \leq \rho$. When both the entrepreneurs, whose discount rate is ρ, and bankers own tangible capital, the expected return is ρ; when only the bankers own tangible capital, the expected return must not be greater than ρ, the entrepreneurs' required return. Being able to issue deposits at interest rate r_t gives the bankers a discount-rate advantage.

Equation (18) resembles the Gordon growth formula. The numerator is cash flow (production). In the denominator, the first component is discount rate and the second is expected growth.[26] As κ_t^I drives up θ_t, the intangible share of investment, and π_t, the marginal value of liquidity, entrepreneurs accept an increasingly low deposit rate $r_t = \rho - \lambda \pi_t$ (see (15)), which drives down

[25]Like Tobin's Q, q_t^B, is a forward looking measure of profits per unit of equity. This offers an alternative view. Due to the negative shocks and their persistent effects under the equity issuance constraint, the whole banking sector becomes undercapitalized and shrinks for a sustained period of time. To clear the markets of tangible capital and deposits, the spread between the expected return on tangible capital and deposit rate will have to widen so that banks would hold tangible capital and issue deposits. As the expected future profits rise, q_t^B increases.

[26]Investment creates new capital instead of grows the existing capital, so it does not add to the growth rate.

the discount rate in (18) and pushes up q_t^T. The bankers transmit the rising liquidity premium on deposits to q_t^T. The transmission is incomplete due to the risk-premium component of their discount rate. The risk premium can be shut down if the bankers were allowed to freely issue equity and thus have unlimited balance-sheet capacity.[27] Comparing (18) and the valuation of illiquid intangible capital (2), we can see that the source of variation in q_t^T is the liquidity value rather than production value. And, the liquidity value varies with the bankers' intermediation capacity.

While the increase in κ_t^I generates the self-enforcing trends in r_t and q_t^T, the endogenous variation of γ_t^B generates the fluctuations along the trends (i.e., the cycles). After positive shocks ($dZ_t > 0$),bankers become wealthier and their price of risk γ_t^B declines, so they bid up q_t^T, which in turn leads to a higher value of liquidity holdings for entrepreneurs (π_t) and a lower r_t. As the bankers' funding cost r_t declines, they push up q_t^T further in an upward spiral. As the bankers expand balance sheet and entrepreneurs hold more deposits, investment booms because the entrepreneurs hold more liquidity and can lever up liquidity due to a higher value of tangible capital.

Endogenous risk accumulates in booms of liquidity creation and investment. As r_t declines, the wedge between the bankers' discount rate, $r_t + \gamma_t^B \left(\sigma_t^T + \sigma\right)$, and entrepreneurs' discount rate, ρ, widen, which makes q_t^T increasingly sensitive to shocks that cause reallocation of tangible capital between the bankers and entrepreneurs. When negative shocks hit, the bankers sell tangible capital back to entrepreneurs who have a higher discount rate. The reallocation causes a decline in asset price, q_t^T. Endogenous asset-price volatility has impact on the real economy. Economic growth is directly tied to q_t^T through the leverage on liquidity and scale of investment (see (12)). A vicious cycle ensues. A lower q_t^T reduces investment profits and π_t, discouraging the entrepreneurs from saving for investments. This causes the rise of r_t, the bankers' funding cost, so the bankers' discount rate increases further, causing q_t^T to continue falling. Moreover, the decline of q_t^T erodes the bankers' wealth, further increasing their price of risk, γ_t^B. The risk premium channel and interest rate channel reinforce each other, generating a powerful response to negative shocks.

The accumulation of endogenous risk is asymmetric. Positive shocks trigger the reallocation of tangible capital to the bankers with low discount rates but eventually cause bankers to consume

[27]Under frictionless equity issuance, $q_t^B = 1$ (i.e., the bankers have no incentive to retain equity), so $\gamma_t^B = 0$.

their wealth as q_t^B, the marginal value of wealth, falls to one (when the bankers become indifferent between retaining wealth and consumption). However, negative shocks cause a continuing reallocation of tangible capital to the entrepreneurs with high discount rates. Such asymmetry sheds light on the recent findings that longer booms precede more severe crises.[28]

The model is built on two frictions. The first is the illiquidity of intangible capital. This leads to the entrepreneurs' demand for liquid assets and links the rising productivity of intangible investment to the decline of interest rate and other endogenous trends. The second friction is that the bankers cannot raise external equity frictionlessly.[29] This generates the response of risk price to shocks (He and Krishnamurthy, 2013; Brunnermeier and Sannikov, 2014; Di Tella, 2017) and the endogenous financial cycles through the interaction between risk premium and interest rate via asset-price variation. Removing the second friction eliminates the amplification of fluctuations along the trends but does not eliminate the trends. If bankers could raise equity freely to replenish net worth, their marginal value of wealth would be pinned to one and price of risk pinned to zero.[30]

This paper continues the tradition of incorporating financial frictions into macroeconomic models. The financial accelerators amplify both trends (driven by κ_t^I) and cycles (triggered by dZ_t). At the core is firms' savings, which stands in contrast to the previous literature that focuses on firms' borrowing (Kiyotaki and Moore, 1997; Bernanke, Gertler, and Gilchrist, 1999; Gertler and Kiyotaki, 2010). Key to the financial cycle is the procyclical wedge in discount rate between bankers, who supply liquidity and are "natural buyers" of tangible capital (Shleifer and Vishny, 2011), and the rest of the economy. The longer a boom lasts, the sharper asset price falls when negative shocks reduce bankers' wealth. This procyclical discount-rate wedge is distinct from the constant cash-flow wedge between intermediaries and households as asset owners in Brunnermeier and Sannikov (2014). The accumulation of endogenous risk via discount-rate wedge also differs

[28]Please refer to Baron and Xiong (2017), Jordà, Schularick, and Taylor (2013), Krishnamurthy and Muir (2016), and López-Salido, Stein, and Zakrajšek (2017) among others. The mechanism is consistent with banks' procyclical payout in data (Baron, 2014; Adrian, Boyarchenko, and Shin, 2016).

[29]Allowing limited equity issuance (e.g., He and Krishnamurthy, 2013) may change the quantitative performances and cause the calibration to deliver different parameter values, but will not change the mechanism.

[30]Without equity issuance friction, the equilibrium of intermediated liquidity supply is the same as the mutual-fund equilibrium that features constant asset price and zero endogenous risk.

from recent studies that emphasize belief heterogeneity (Caballero and Simsek, 2020, 2021).[31]

Discussion: Intangible risk. A potential limitation of the model is that intangible capital valuation in (2) does not reflect risk premium. Eisfeldt and Papanikolaou (2013) models the risk of organizational capital from the cyclical variation in key personnel's outside option. Such risk premium may reduce capital valuation and thus discourages firms from intangible investment, counteracting the rise of κ_t^I. However, other forms of intangibles may serve as a hedge and their negative risk premia offset that of organizational capital. Specifically, an important type of intangible capital is technology.[32] Technological innovation displaces firms and workers that operate with old technologies and have difficulty to adapt (Kogan, Papanikolaou, Schmidt, and Song, 2020). Displacement risk makes technological innovation a hedge against systematic technological changes (Gârleanu, Kogan, and Panageas, 2012; Bena and Garlappi, 2019; Kogan, Papanikolaou, and Stoffman, 2020).

3.4 Aggregation and the Markov Equilibrium

Households. Banks hold tangible capital and issue debts to entrepreneurs who need liquid savings. In reality, households also hold intermediaries' debts. Households' demand is not essential for the main mechanism but it is important to incorporate it for calibration and quantitative analysis.

The literature takes a money-in-utility approach, motivated by the role of intermediaries' debts (e.g., deposits) as means of payment (Sidrauski, 1967; Stein, 2012; Van den Heuvel, 2018). Holdings of monetary assets generate utility flows separable from consumption (Poterba and Rotemberg, 1986; Nagel, 2016; Begenau and Landvoigt, 2018) and are complementary to income levels (Begenau, 2019; Krishnamurthy and Vissing-Jørgensen, 2015).

Consider a unit mass of households, $\mathbb{H} = [0, 1]$. A representative household has labor that produces w_t^H units of goods (labor income). Let W_t^H $(= \int_{i \in \mathbb{H}} w_t^H(i)\, di)$ denote the aggregate labor output, so the total output of the economy is $(K_t^I + K_t^T + W_t^H)dt$. Following the literature, the

[31] In Caballero and Simsek (2020), the economy becomes increasingly vulnerable in booms through the accumulation of wealth and purchasing power tilting towards the levered optimists.

[32] Technology and healthcare sectors are the most relevant as corporate cash holdings mainly reside in these "growth sectors" (Begenau and Palazzo, 2021; Graham and Leary, 2018; Pinkowitz, Stulz, and Williamson, 2015).

utility function is given by

$$\mathbb{E}\left[\int_{t=0}^{\infty} e^{-\rho t}\left(dc_t^H + \frac{\left(w_t^H \beta_t\right)^{\xi}\left(m_t^H\right)^{1-\xi}}{1-\xi}dt\right)\right], \tag{19}$$

where c_t^H is the cumulative consumption process and m_t^H denotes deposit holdings.[33] The scaling variable is a function of time, $\beta_t = \beta(t)$, and will be calibrated for quantitative exercises.

The utility function in (19) implies the following optimality condition for m_t^H:

$$\left(\frac{m_t^H}{\beta_t w_t^H}\right)^{-\xi} = \rho - r_t\,, \tag{20}$$

which equates the marginal utility of holding deposits and marginal cost, i.e., the spread $\rho - r_t$. Rearranging (20) and aggregating over households, we obtain the aggregate household deposits:

$$M_t^H = W_t^H \beta_t (\rho - r_t)^{-\frac{1}{\xi}}\,. \tag{21}$$

To avoid introducing a new state variable, it is assumed that labor output is proportional to that of tangible capital, i.e., $W_t^H = \alpha K_t^T$. In other words, between labor and tangible capital, the labor share of output is a constant, $\alpha/(\alpha+1)$. This is consistent with the finding of Koh, Santaeulàlia-Llopis, and Zheng (2020) that labor share is stable without accounting for output associated with intangibles.[34] Under this assumption, households' deposits demand is given by

$$M_t^H = \alpha K_t^T \beta_t (\rho - r_t)^{-\frac{1}{\xi}}\,, \tag{22}$$

The parameter α only has a scaling effect, so only the calibration of $\beta_t = \beta(t)$ is necessary.

The real-financial linkage. Figure 4 summarizes the model. The economy has three markets to clear (goods, the ownership of tangible capital, and deposits). The output is generated by intangi-

[33] Appendix B discusses the implications of incorporating risk-averse preferences.

[34] Intangibles include research and development, software, and entertainment, literary, and artistic originals (U.S. Bureau of Economic Analysis). Analyzing the decline of labor share (e.g., Karabarbounis and Neiman, 2013), Koh, Santaeulàlia-Llopis, and Zheng (2020) show that it is attributed to the incorporation of output related to intangibles.

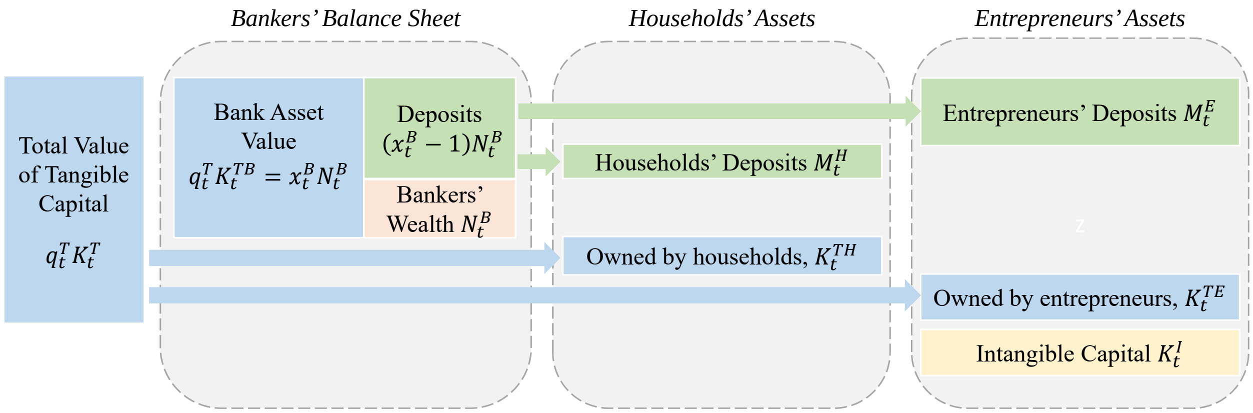

Figure 4: **Model Overview**.

ble capital, tangible capital, and labor. The λdt entrepreneurs who are hit by the Poisson shocks acquire goods to create new capital, and the remaining goods are consumed by the rest of the economy.[35] The entrepreneurs and bankers can trade the ownership of tangible capital at competitive price q_t^T given the stock K_t^T. In the deposit market, the bankers' supply is equal to the demand from the entrepreneurs and households. As in Caballero, Farhi, and Gourinchas (2008), only a fraction of output is capitalizable – the output of tangible capital – and the key inefficiency is a shortage of liquid assets. Depending on the bankers' risk-taking capacity (wealth), the bankers create liquidity by backing deposits with tangible capital. Entrepreneurs' deposits relax the liquidity constraint (6) on investment. Therefore, economic growth depends on the *intermediated liquidity supply*.

As shown in (12), one unit of liquidity is leveraged up to $1/\left[1 - q_t^T \kappa^T (1 - \theta_t)\right]$ units of goods invested. Given the entrepreneurs' aggregate deposits, M_t^E, the aggregate investment comes from the λdt entrepreneurs (hit by the Poisson shocks):

$$\left(\frac{1}{1 - q_t^T \kappa^T (1 - \theta_t)} \right) M_t^E \lambda dt \,. \tag{23}$$

[35]Under agents' risk-neutral utility on consumption flows, their demand for consumption goods is perfectly elastic.

The deposit-market clearing condition links the entrepreneurs' liquidity to bankers' wealth:

$$M_t^E = \left(x_t^B - 1\right) N_t^B - M_t^H \,, \tag{24}$$

where the right side is the deposits issued by bankers minus the households' deposit holdings.

The law of motion of intangible capital is

$$dK_t^I = \underbrace{\left(\frac{1}{1 - q_t^T \kappa^T \left(1 - \theta_t\right)}\right)}_{\textit{leverage}} \underbrace{\left[\left(x_t^B - 1\right) N_t^B - M_t^H\right]}_{\textit{entrepreneurs' liquidity}} \theta_t \kappa_t^I \lambda dt - \underbrace{\left(\delta dt - \sigma dZ_t + \lambda dt\right) K_t^I}_{\textit{depreciation, Poisson destruction}} , \tag{25}$$

and the law of motion of tangible capital is

$$dK_t^T = \left(\frac{1}{1 - q_t^T \kappa^T \left(1 - \theta_t\right)}\right) \left[\left(x_t^B - 1\right) N_t^B - M_t^H\right] \left(1 - \theta_t\right) \kappa^T \lambda dt - \left(\delta dt - \sigma dZ_t + \lambda dt\right) K_t^T \,. \tag{26}$$

Total investment in (23) is split into the tangible and intangible parts by entrepreneurs' choice of intangible share, θ_t. Then investments are multiplied by the productivities, κ_t^I and κ^T.[36].

Equations (25) and (26) highlight the link between intermediation capacity and growth.[37] When bankers are well-capitalized, more deposits are issued. Intermediation creates liquidity that can be leveraged up to create capital. Equations (25) and (26) also show how the financial conditions drive economic fluctuations. Entrepreneurs' leverage on liquidity increases in the value of tangible capital, q_t^T. Therefore, the endogenous asset-price volatility, i.e., σ_t^T in (3), feeds into investment fluctuation, and thus, has a direct impact on the real economy. Moreover, the variation of q_t^T has a direct and levered impact on the bankers' wealth and their capacity of liquidity creation.

State variables. The Markov equilibrium has four state variables, time, which drives κ_t^I and β_t,

[36]The lost capital of entrepreneurs hit by the Poisson shock is evenly endowed to the the rest of entrepreneurs. Therefore, the λdt measure of lost capital lost is not in (25) and (26), and the idiosyncratic Poisson shocks do not affect aggregate production capacity. Accordingly, one interpretation of the Poisson shock is that the λdt entrepreneurs' customer base is seized by the other entrepreneurs through creative destruction (Aghion, Akcigit, and Howitt, 2014)

[37]In response to liquidity creation by bankers and entrepreneurs' choices of investment scale and composition, tangible and intangible capital stocks evolve continuously as documented by the empirical literature (Peters and Taylor, 2017; Falato, Kadyrzhanovaz, Sim, and Steri, 2018; Begenau and Palazzo, 2021).

and the three stock variables, $N_t^B \equiv \int_{i\in\mathbb{B}} n_{i,t}^B di$ (the bankers' aggregate wealth), K_t^I, and K_t^T.[38] These four state variables have a convenient hierarchical property. First, apparently, time progresses linearly and has an autonomous law of motion. Second, $\left(N_t^B, K_t^I, K_t^T\right)$ can be equivalently represented by $\left(\eta_t, K_t^I, K_t^T\right)$, where η_t, the intermediation intensity, is defined by

$$\textit{Intermediation Intensity}: \ \eta_t \equiv \frac{N_t^B}{K_t^T}. \tag{27}$$

It is a ratio of the bankers' wealth to the amount of assets to be intermediated. The next proposition states that its evolution only depends on itself and time, and that the market prices, such as q_t^T and r_t, and the K_t^T-scaled quantities are functions of η_t and time only. To solve the equilibrium, I first focus on the sub-system where η_t and time are the two state variables and solve the market prices and the K_t^T-scaled aggregate quantities, which requires solving a system of differential equations. The solutions of these variables are then fed into the laws of motion of K_t^I and K_t^T (see (25) and (26)) for a complete characterization of equilibrium dynamics. Appendix A provides the proof.

Proposition 3 (Financial System) *The equilibrium law of motion of intermediation intensity is*

$$\frac{d\eta_t}{\eta_t} = \mu^\eta(\eta_t, t)\,dt + \sigma^\eta(\eta_t, t)\,dZ_t, \tag{28}$$

for $\eta_t \in (0, \overline{\eta}(t)]$. $\mu^\eta(\eta_t, t)$ and $\sigma^\eta(\eta_t, t)$ are defined in Appendix A, and $\overline{\eta}(t)$ is a reflecting boundary where the bankers consume. The following prices and K_t^T-scaled quantities are functions of η_t and t: (1) the value of tangible capital, $q_t^T = q^T(\eta_t, t)$; (2) the deposit rate, $r_t = r(\eta_t, t)$; (3) the K_t^T-scaled households' deposits, $\widetilde{M}_t^H = \widetilde{M}^H(\eta_t, t)$; (4) the K_t^T-scaled entrepreneurs' deposits, $\widetilde{M}_t^E = \widetilde{M}^E(\eta_t, t)$; (5) the optimal intangible share of investment, $\theta_t = \theta(\eta_t, t)$; (6) bankers' asset-to-wealth ratio, $x_t^B = x^B(\eta_t, t)$; (7) the bankers' marginal value of wealth, $q_t^B = q^B(\eta_t, t)$.[39]

[38] Capital composition is a key state variable in Eberly and Wang (2008) who study agents' trade-off between diversification benefits and reallocation costs when two sectors are available for investment.

[39] $q_t^B \in [1, +\infty)$ and when $\eta_t = \overline{\eta}(t)$, $q_t^B = 1$ and the bankers consume. Consumption reduces N_t^B, but once q_t^B is above one, consumption stops (retaining wealth is worth $q_t^B > 1$). Thus, $\overline{\eta}(t)$ is a reflecting boundary of η_t. The bankers' HJB equation and Equation (18) implies a system of differential equations for $q^B(\eta_t, t)$ and $q^T(\eta_t, t)$, and once these two functions are solved, the other variables are solved analytically. The details are in Appendix A.

4 Quantitative Analysis

This section starts with calibration and then presents the results on trends and cycles. It ends with counterfactual analysis that demonstrates the quantitative importance of the risk of intangibles.

4.1 Parameter Calibration

Calibration takes five steps. The guiding principles are explained first and details provided later. The first step is to calibrate the investment technology to match the trends in intangible and tangible investments and volatilities along those trends. The productivity of intangible investment, $\kappa^I(t)$, is parameterized as $\kappa^I_t = \kappa^I_0 + \kappa^I_1 t$, and the cost of adjusting investment portfolio is specified as $F(\theta_t) = \frac{\phi}{2}\theta_t^2$. Thus the investment technology is summarized by four parameters, κ^I_0, κ^I_1, κ^T, and ϕ. As will be shown shortly, these specifications generate realistic investment dynamics.

The choice of intangible share, θ_t, drives firms' liquidity needs. After matching investment dynamics, the second step is to calibrate λ, the arrival rate of investment and liquidity needs, so the response of firms' liquidity holdings to changes in θ_t matches the estimate in Section 2.

Third, parameters in households' liquidity utility are calibrated to match the dynamics of household liquidity holdings. This is important for counterfactual analysis where investment technology is adjusted to create scenarios with and without the rise of intangibles while households' liquidity utility is fixed. Fourth, the shock size, σ, is calibrated to generate a volatility of bank asset return in the baseline model that matches data. The match is also important for counterfactual analysis as our focus is on whether endogenous risk emerges as a result of the rise of intangibles.

The fifth and last step is to calibrate ρ, discount rate, and δ, capital depreciation rate. So far, the calibration targets have been quantity variables, such as investment and liquidity holdings. The focus now shifts to the two price variables, interest rate and tangible capital value. However, with only two parameters left, the calibration exercise cannot target different aspects of equilibrium dynamics (the level, trends, volatilities along the trends, etc.) but instead matches the interest rate and capital valuation at the beginning of sample period 1980 to 2019. This leaves the price variables' paths over time completely to the equilibrium forces. Therefore, when examining model

Table 2: Parameter Calibration

	Parameters	Symbol	Value	Moment	Model	Data
(1)	Intangible investment productivity: Intercept	κ_0^I	1.075	Average $\mathbb{E}^\eta\left[\theta\left(\eta,t\right)\right]$	63.9%	61.6%
(2)	Intangible investment productivity: Time coefficient	κ_1^I	0.018	Average annual change of $\mathbb{E}^\eta\left[\theta\left(\eta,t\right)\widetilde{I}\left(\eta,t\right)\right]$	1.6%	1.4%
(3)	Tangible investment productivity	κ^T	0.011	Average annual change of $\mathbb{E}\left[\left(1-\theta\left(\eta,t\right)\right)\widetilde{I}\left(\eta,t\right)\right]$	0.0%	-0.1%
(4)	Investment cost $F\left(\theta\right)=\frac{\phi}{2}\theta_t^2$	ϕ	9.540	Average $\frac{\text{Vol.}^\eta\left[\theta(\eta,t)\widetilde{I}(\eta,t)\right]}{\text{Vol.}^\eta\left[(1-\theta(\eta,t))\widetilde{I}(\eta,t)\right]}$	1.84	2.06
(5)	Investment project arrival rate	λ	0.050	$\dfrac{\mathbb{E}^\eta\left[\frac{\widetilde{M}^E(\eta,20)}{q^T(\eta,20)}\right]-\mathbb{E}^\eta\left[\frac{\widetilde{M}^E(\eta,0)}{q^T(\eta,0)}\right]}{\mathbb{E}^\eta\left[\theta\left(\eta,20\right)\right]-\mathbb{E}^\eta\left[\theta\left(\eta,0\right)\right]}$	0.162	0.170
(6)	Household deposit demand elasticity to deposit rate	ξ	1.100	Average annual change of $\mathbb{E}^\eta\left[\frac{\widetilde{M}^E(\eta,t)+\widetilde{M}^H(\eta,t)}{q^T(\eta,t)}\right]$	0.0%	0.3%
(7)	Household deposit utility scale: Intercept	β_0	0.196	$\mathbb{E}^\eta\left[\frac{\widetilde{M}^E(\eta,t)}{\widetilde{M}^H(\eta,t)}\right],t=0$	9.8%	9.6%
(8)	Household deposit utility scale: Time coefficient ($\leq$ 1992)	β_1	0.019	Average annual change of $\mathbb{E}^\eta\left[\frac{\widetilde{M}^E(\eta,t)}{\widetilde{M}^H(\eta,t)}\right],t\leq 2$	0.32%	0.29%
(9)	Household deposit utility scale: Time coeff. increase ($>$ 1992)	β_2	0.003	Average annual change of $\mathbb{E}^\eta\left[\frac{\widetilde{M}^E(\eta,t)}{\widetilde{M}^H(\eta,t)}\right],t>2$	0.19%	0.20%
(10)	Capital depreciation rate: Vol.	σ	0.020	Vol. of bank asset return	2.9%	2.6%
(11)	Agents' discount rate	ρ	0.062	$\mathbb{E}^\eta\left[r\left(\eta,t\right)\right],t=0$	3.2%	3.5%
(12)	Capital depreciation rate: Mean	δ	0.088	$\mathbb{E}^\eta\left[q^T\left(\eta,t\right)\right],t=0$	6.6	6.8

performances, whether the dynamics of price variables match data is a tougher criterion than the match of quantity variables which benefits from more degrees of freedom in parameter calibration.

Next, I provide more details on calibration. One unit of time in the model is set to one year. For calibration and later comparing the endogenous variables with empirical counterparts, I extract trends in data through 20-year rolling averages from 1980 to 2019 (the sample period in Section 2).[40] In the model, the variation in η_t generates fluctuation along the trends. To extract trends from

[40]Before the 1980s, Regulation Q imposed various restrictions on deposit rates. For example, it prohibited banks from paying interest on demand deposits. This practice is inconsistent with the model specification that the deposit rate, r_t, is the price variable that clears the deposit market.

the solution, I average out η_t at every t.[41] For example, $\mathbb{E}^{\eta}[r(\eta, t=0)]$ is mapped to the first rolling average of interest rates in data, which centers around 1990. The same logic applies to all prices and K_t^T-scaled quantities, which will be used in calibration and, according to Proposition 3, are also functions of η_t and t. The model is solved for $t \in [0, 20]$ because the last moving average in data centers around 2010 (which maps to $t = 20$) and ends in 2019 (the sample end).

The productivity of intangible investment has two parameters, κ_0^I that determines the base rate, and κ_1^I that determines the time trend. κ_0^I is calibrated so the average θ_t matches the sample average of *Intan./Investment* in Section 2. κ_1^I is calibrated so the average annual change in the trend of intangible investment/tangible capital, i.e., $\mathbb{E}^{\eta}[\theta_t I_t/K_t] = \mathbb{E}^{\eta}[\theta_t \widetilde{I}_t]$, matches data.[42] The productivity of tangible investment, κ^T, is calibrated so the average annual change in the trend of tangible investment/tangible capital, i.e., $\mathbb{E}^{\eta_t}[(1-\theta_t)I_t/K_t] = \mathbb{E}^{\eta_t}[(1-\theta_t)\widetilde{I}_t]$, matches data. The parameter ϕ in $F(\theta_t)$ governs the cost of adjusting investment composition and its calibration targets the relative volatilities of intangible and tangible investments. At time t, the conditional distribution of η_t (implied by (28)) is used to calculate the volatility ratio of intangible to tangible investment (both scaled by K_t^T), $\frac{\mathrm{Vol}^{\eta_t}\left[\theta\widetilde{I}\right]}{\mathrm{Vol}^{\eta_t}\left[(1-\theta)\widetilde{I}\right]}$, and the ratio is averaged over time to match the volatility ratio of detrended intangible to tangible investment in data.[43]

The firm's liquidity needs is driven by the random arrival of projects that require intangible investment. The arrival rate λ is calibrated so that the model-implied response of firms' liquidity holdings to the increase of intangible investment matches the estimate in Section 2 (Table 1, Column 8), the change in cash/assets for one unit of change of *Intan./Investment* (θ_t in the model). The model counterpart is $\left(\mathbb{E}^{\eta}\left[\frac{\widetilde{M}^E(\eta,20)}{q^T(\eta,20)}\right] - \mathbb{E}^{\eta}\left[\frac{\widetilde{M}^E(\eta,0)}{q^T(\eta,0)}\right]\right) / \left(\mathbb{E}^{\eta}\left[\theta\left(\eta,20\right)\right] - \mathbb{E}^{\eta}\left[\theta\left(\eta,0\right)\right]\right)$, where the η_t-averages are used as the match focuses on disciplining the trend rather cyclical fluctuations and $\frac{\widetilde{M}_t^E}{q_t^T} = \frac{M_t^E}{q_t^T K_t^T}$ is the ratio of firms' liquidity scaled by tangible capital value that corresponds to the accounting asset value mostly excluding intangibles (e.g., Peters and Taylor, 2017).

[41] Instead of averaging over the simulated paths, the η-averages can be calculated using the t-conditional stationary distribution of η_t, implied by (28), and the solved functions of endogenous variables, for example, $q_t^T = q^T(\eta_t, t)$. Appendix A solves the t-conditional stationary distribution of η_t.

[42] Each year, I calculate cross-section total asset-weighted average of ratio of intangible investment to tangible capital (PPE) (reported in Panel A of Figure D.5 in Appendix C), and calculate the twenty-year rolling averages.

[43] Each year, I take the ratio of intangible investment (scaled by PPE) and tangible investment (scaled by PPE) (see also footnote 42). The resulting time series exhibits a linear trend.

Next, I calibrate the households' liquidity utility. The only goal of incorporating the households' liquidity utility is to generate realistic liquidity demand, especially relative to firms', for the purpose counterfactual analysis where the rise of intangibles and associated liquidity demand of firms will be shut down to examine how interest rate, asset valuation, and other variables respond. The value of ξ, households' liquidity demand elasticity, is chosen so that the model generates a stable path over time of the ratio of safe assets (households' and firms' holdings of deposits) to capitalizable assets (tangible capital value), i.e., $\mathbb{E}^{\eta}\left[\frac{M^E(\eta,t)+M^H(\eta,t)}{q^T(\eta,t)K_t^T}\right] = \mathbb{E}^{\eta}\left[\frac{\widetilde{M}^E(\eta,t)+\widetilde{M}^H(\eta,t)}{q^T(\eta,t)}\right]$ in line with the stability in safe asset share (Gorton, Lewellen, and Metrick, 2012).[44] $\xi = 1.1$, close to households' deposit-demand elasticity in other banking models, e.g., 1.4 from Begenau (2019).

Tangible capital quantity and valuation grow over time, so, under a stable deposit-to-tangible asset ratio, the banking sector grows and both the households and firms hold more deposits over time. However, driven by the rise of intangibles, the firms' deposits grow faster. Next, the scaling function, $\beta(t)$, in households' liquidity utility is specified and calibrated to match the trends of households' liquidity holdings relative to that of firms. $\beta(t)$ is specified as

$$\beta_t = \beta_0 + \beta_1 t + \beta_2 t\,\mathbb{I}_{\{t>2\}}\,. \tag{29}$$

Empirically, the logarithm of households' holdings of intermediary debts has a structural break in its time trend at 1992 ($t = 2$ in the model), detected by supremum Wald test and LR test with p-values below 0.0001 (Andrews, 1993; Perron, 2006). I take logarithm because households' deposit holdings grow exponentially along with capital stock (see (22)) and empirically households' holdings of intermediary debts also exhibit exponential growth.[45] It is important to include the structural break, as, without it, the match of households' liquidity holdings deteriorates significantly. The value of β_0 is chosen so that $\mathbb{E}^{\eta}\left[\frac{\widetilde{M}^E(\eta,0)}{\widetilde{M}^H(\eta,0)}\right]$, i.e., the initial η-average ratio of entrepreneurs' to households' holdings of deposits matches the rolling average of data centering at 1990.[46] The

[44] The empirical counterpart is the ratio of nonfinancial firms' and households' holdings of intermediary debts (listed in Figure 2) to the value of fixed assets of nonfinancial firms' from the Bureau of Economic Analysis (current-cost net stock). I subtract the value of intellectual properties to obtain the value of tangible asset.

[45] I also use supremum Wald and LR tests on the ratio of households' holdings of intermediary debts to households' total asset and detect a structural break in the level at 1992. Figure D.4 in Appendix C reports the raw data.

[46] Data is plotted in Panel C of Figure 3. Figure 2 list the debt instruments that map to deposits in the model.

value of β_1 is chosen so the average annual change of $\left\{\mathbb{E}^{\eta}\left[\frac{\widetilde{M}^E(\eta,t)}{\widetilde{M}^H(\eta,t)}\right]\right\}_{n\leq 2}$ matches its empirical counterpart, and β_2 is set so the average annual change of $\left\{\mathbb{E}^{\eta}\left[\frac{\widetilde{M}^E(\eta,t)}{\widetilde{M}^H(\eta,t)}\right]\right\}_{n>2}$ matches data.

The shock size, σ, is chosen so the model generates a volatility of bankers' return that matches data (Gornall and Strebulaev, 2018). Later, when conducting counterfactual analysis by shutting down the rise of intangibles, I will fix the exogenous risk, σ, and show how endogenous risk responds. The discount factor, ρ, is chosen so $\mathbb{E}^{\eta}\left[r\left(\eta,0\right)\right]$ matches the average rate of intermediary debts in 1990.[47] The capital depreciation rate, δ, is chosen so $\mathbb{E}^{\eta}\left[q^T\left(\eta,0\right)\right]$ matches the average EV/EBITDA ratio in 1990.[48] Capital generates one unit of goods per year, so $q_t^T = q_t^T/1$ is the ratio of capital value to its annual output. Because tangible capital produces all capitalizable output, its value maps to firms' enterprise value (EV), which is the present value of cash flows reflected in debt and equity markets. The calibration of ρ and δ fixes the starting points of interest rate and capital valuation but leaves their paths over time to be determined by equilibrium forces.

4.2 The Rise of Intangibles and Long-Run Trends

The results are in two categories, the economy's response to a rising κ_t^I over time (trends) and response to shocks, dZ_t (cycles). This subsection focuses on the trends. Table 3 reports how the economy evolves over time. According to the calibration of κ_0^I and κ_1^I, the productivity of intangible investment, $\kappa^I(t)$, increases by around 1.6% per year. Firms tilt investment towards intangibles gradually over time, increasing θ_t from 55.2% to 72.7% over twenty years. Column 1 shows the model generates a trend in intangible share of investment that matches data closely in every year. Note that the calibration of κ_1^I targets the average rate of change but does not guarantee the match with data every year. The year-by-year match suggests that the model has a proper specification of intangible investment productivity and a proper mapping from investment

[47] The short-term interest rates are the real rates with the consumer price index as deflator. The debt instruments correspond to the list in Figure 2, which include: (1) jumbo ($\geq$\$100,000) and non-jumbo checking deposits, savings deposits, certificate of deposits, and money market; (2) 1-, 2-, and 3-month AA-rated financial commercial papers; (3) 3- and 6-month bankers acceptance; (4) 1-, 2-, and 3-month AA-rated asset-backed commercial papers; (5) GCF repo rate with Treasury securities, mortgage-backed securities, and agency- and GSE-backed securities as collateral; (6) Fed fund. Data is from FRED, except the repo rates from the Federal Reserve Bank of New York.

[48] The average is taken over median EV/EBITDA ratios of 11 Fama-French nonfinanical industries (Compustat).

Table 3: Trends in Intangible Investment, Corporate Liquidity, Interest Rate, and Capital Valuation

Time	Intangible Inv. Share $\mathbb{E}^{\eta}\left[\theta(\eta,t)\right]$	$\frac{\text{Firm Deposits}}{\text{Capital Value}}$ $\mathbb{E}^{\eta}\left[\frac{\widetilde{M}^{E}(\eta,t)}{q^{T}(\eta,t)}\right]$	$\frac{\text{Firm Deposits}}{\text{HH Deposits}}$ $\mathbb{E}^{\eta}\left[\frac{\widetilde{M}^{E}(\eta,t)}{\widetilde{M}^{H}(\eta,t)}\right]$	Interest Rate $\mathbb{E}^{\eta}\left[r\left(\eta,t\right)\right]$	Capital Valuation $\mathbb{E}^{\eta}\left[q^{T}\left(\eta,t\right)\right]$	Financial Risk Multiplier $\max_{\eta}\left\{\frac{\sigma^{T}(\eta,t)+\sigma}{\sigma}\right\}$
$t=0$	55.2%	7.6%	9.8%	3.24%	6.6	2.7
Data '90	54.4%	6.3%	9.6%	3.45%	6.8	
$t=4$	58.7%	8.5%	11.1%	2.11%	6.9	3.2
Data '94	58.2%	7.1%	10.8%	2.59%	6.9	
$t=8$	62.2%	8.2%	10.7%	0.95%	7.3	3.6
Data '98	61.9%	7.9%	12.2%	1.77%	7.3	
$t=12$	65.7%	9.2%	12.2%	-0.20%	7.6	4.0
Data '02	66.0%	8.4%	13.1%	0.97%	7.5	
$t=16$	69.1%	10.2%	13.7%	-1.50%	7.8	4.4
Data '06	69.1%	9.1%	13.8%	0.46%	7.7	
$t=20$	72.6%	10.4%	14.1%	-2.88%	7.9	4.7
Data '10	72.7%	9.7%	14.0%	-0.36%	8.0	

productivity to the intangible share through the setup of firms' investment problem.

As θ_t increases, firms face a tighter financial constraint and hold more liquidity. The calibration of λ, the arrival rate of investment needs, targets the response of firms' liquidity-to-tangible asset ratio to variation in θ_t. In Column 2 of Table 3, the trend in $\mathbb{E}^{\eta}\left[\frac{\widetilde{M}^{E}(\eta,t)}{q^{T}(\eta,t)}\right]=\mathbb{E}^{\eta}\left[\frac{M_t^E}{q_t^T K_t^T}\right]$ captures the well documented rise in firms' cash-to-asset ratio before 2010s. The ratio increased from 6.3% by more than 50% to 9.7% in data. In the model, it started at a higher level, 7.6%, and increased to 10.4%.[49] Later in the counterfactual analysis, I will examine how the economy responds when the rise of intangibles is shut down and thus the trend in firms' liquidity demand is muted. In this scenario, households' liquidity utility becomes the sole driver behind trends in liquidity demand. Therefore, it is important to match the relative dynamics of firms' vs. households' liquidity holdings in the baseline model, and it is done through the calibration of households' liquidity utility as explained in Section 4.1. The results are reported in Column 3 of Table 3.

[49]The discrepancy in level is due to the omission of other determinants of firms' liquidity holdings that, unlike intangibles, do not exhibit trends over time. This paper focuses on intangible-induced trends in firms' liquidity demand.

The rising intangible share of investment, θ_t, drives up the marginal value of liquidity, π_t, by tightening firms' financial constraint. The upward trend in π_t in turn leads to a downward trend in r_t, the yield on liquid assets in Column 4 of Table 3. The bankers take advantage of a lower funding cost and push up tangible capital value, q_t^T. Column 5 reports an upward trend in capital valuation that closely matches the data.[50] Importantly, these trends reinforce each other. A rising q_t^T further increases π_t and thereby lowers r_t (see Proposition 1). Multiplicity may arise due to the feedback mechanism: A solution has low r_t, high q_t^T, high π_t, and high θ_t while the other has high r_t, low q_t^T, low π_t, and low θ_t. The solution with θ_t closest to data is chosen.[51] Multiplicity helps explain why the rise of intangibles and corporate savings glut are largely a U.S. phenomenon.

As κ_t^I increases and the economy becomes more intangible-intensive, it also becomes increasingly fragile. By Itô's lemma, the total value of capitalizable output, $q_t^T K_t^T$, evolves as

$$\frac{d\left(q_t^T K_t^T\right)}{q_t^T K_t^T} = \left(\mu_t^T - \delta - \lambda + \sigma_t^T \sigma\right) dt + \left(\sigma_t^T + \sigma\right) dZ_t \, , \tag{30}$$

A natural measure of endogenous risk is the ratio of total shock exposure of $q_t^T K_t^T$ (including σ_t^T, the endogenous volatility of q_t^T) to the exogenous shock exposure from stochastic depreciation:

$$\textit{Financial Risk Multiplier}: \quad \frac{\sigma_t^T + \sigma}{\sigma} \, . \tag{31}$$

This ratio is a function of t and η_t (see Proposition 3). The last column of Table 3 reports the maximum (over η_t) at $t = 0, 4, ..., 20$. It also reports the corresponding years in data to show the model-implied accumulation of endogenous risk in real time. Over twenty years, the endogenous risk multiplier almost doubled as the economy became increasingly intangible-intensive.

Overall the solution matches data reasonably well except for a lower and more negative r_t in the 2000s.[52] This may be explained by the omission of zero lower bound (ZLB) on nominal

[50] Tangible capital represents the capitalizable production capacity. The ratio of q_t^T to one unit of goods produced per unit of time (one year) maps to EV-to-EBITDA ratio, since, by definition, enterprise value (EV) is the present value of the capitalizable output of a firm, reflected in the debt and equity markets.

[51] Note that θ_t is still endogenous and optimally chosen by firms. If the firms' investment and liquidity management problems have not been properly specified, none of the solutions is likely to match data.

[52] Under risk-neutral preferences, the elasticity of intertemporal substitution (EIS) is infinite. If EIS were finite, an

rates that binds in reality and, under nominal price rigidity, translates into a lower bound on real rates (Eggertsson and Woodford, 2003; Fischer, 2016; Korinek and Simsek, 2016; Caballero and Simsek, 2020). In fact, the model suggests that the rise of intangibles leads to a strong liquidity demand and thereby widens the wedge between the natural real rate without nominal rigidity and the actual rate, exacerbating the liquidity trap at ZLB (Christiano, Eichenbaum, and Rebelo, 2011; Eggertsson and Krugman, 2012; Caballero and Farhi, 2017; Guerrieri and Lorenzoni, 2017). While the rise of intangibles is largely a U.S. phenomenon, the resultant liquidity trap may spread globally (Caballero, Farhi, and Gourinchas, 2021). Appendix C discusses the model mechanism under ZLB and its intricate interactions with the economic forces in New Keynesian models.

4.3 Endogenous Financial Risk and Economic Fluctuation

This subsection focuses on economic fluctuations along the trend, driven by the intermediation intensity, η_t. Figure 5 plots six endogenous variables against η_t. The plots are for $t = 20$ (which maps to 2010 in data) and end at $\overline{\eta}(t)$, the endogenous upper boundary of η_t beyond which the bankers optimally consume (see Proposition 3). To understand the economy's response to shocks, first consider positive shocks that move η_t to the right. Panel A of Figure 5 plots the bankers' price of risk (or required Sharpe ratio) for holding tangible capital:

$$\gamma_t^B = \frac{\mathbb{E}_t\left[dr_t^T\right] - r_t}{\sigma_t^T + \sigma}\,, \tag{32}$$

which declines as η_t increases and eventually reaches zero at $\overline{\eta}(t)$. This implies a procyclical intermediation capacity. In Panel B, the discount rate for tangible capital, i.e., the expected return $\mathbb{E}\left[dr_t^T\right]$, is at ρ when η_t is low to clear the market by attracting demand from entrepreneurs and households whose discount rate is ρ. However, as η_t increases, bankers eventually hold all tangible capital and the discount rate falls below ρ. Recall that the cash flow of tangible capital is constant, so what drives the variation of q_t^T is the discount rate. Therefore, as the discount rate declines following positive shocks that increase η_t, the value of tangible capital, q_t^T, increases as shown in

increase in κ_t^I may put upward pressure on r_t: As investment productivity increases and the economy grows faster, consumption grows faster so the prevailing risk-free rate rises, which implies a higher rate on liquid assets, r_t.

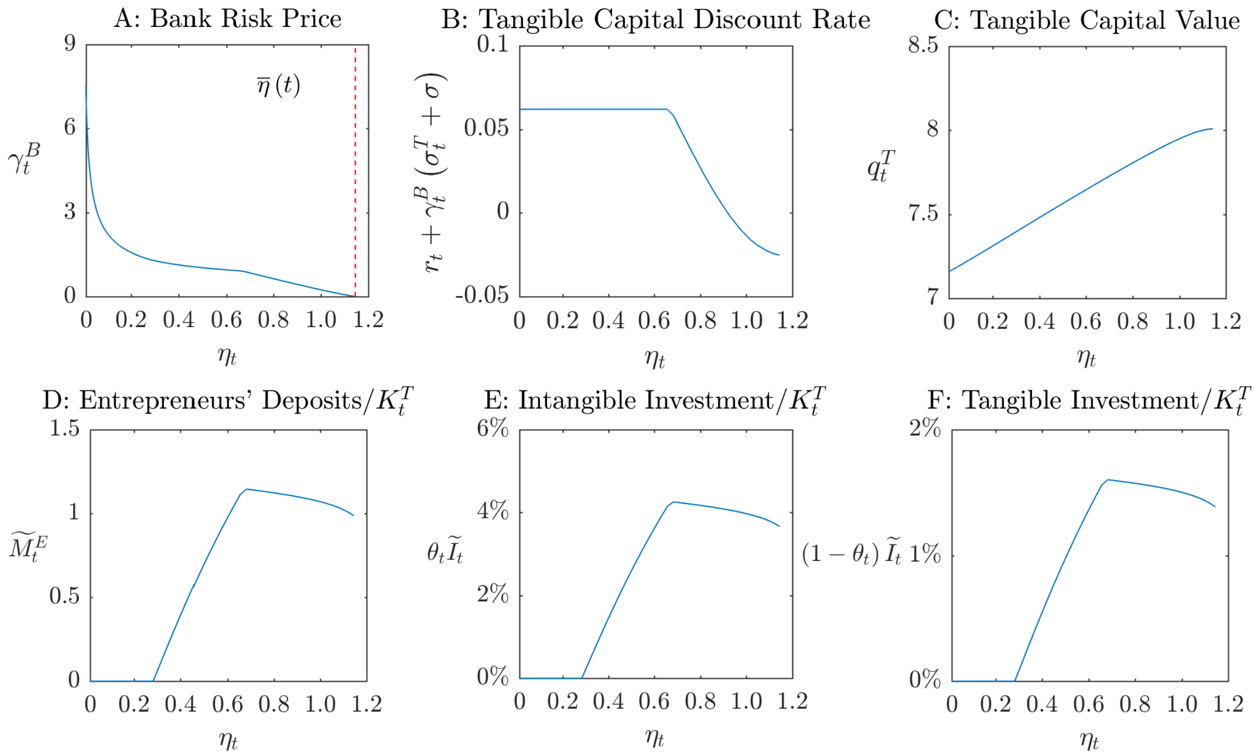

Figure 5: **Financial Cycle**.

Panel C. Note that the increase of q_t^T in η_t is smooth even though the decrease of discount rate in η_t is not. Under rational expectation, q_t^T is forward-looking, so any increase of η_t raises the probability of low discount-rate regions, and therefore, increases q_t^T in every state of the world.

As q_t^T increases, a feedback mechanism emerges. Investment becomes more profitable, and the leverage on liquidity is higher, so holding liquidity is more profitable. Therefore, entrepreneurs accept a lower r_t (Proposition 1), holding more deposits as shown in Panel D of Figure 5.[53] A lower r_t further reduces the bankers' discount rate, leading to an even higher q_t^T. In the process, the entrepreneurs hold more liquidity and invest more as shown in Panels E and F. Note that when scaled by K_t^T, the run-up of entrepreneurs' deposits and investments stops when the growth of the bankers' wealth outpaces that of the tangible capital value (bank asset value). When this occurs, bank equity crowds out debt on the balance sheet, causing a reduction in deposits/tangible capital.

[53] When $\eta_t < 0.28$ (1.7% probability), $M_t^E = 0$ and r_t is below what entrepreneurs accept (i.e., $r_t < \rho - \lambda\pi_t$ and (15) no longer holds). r_t is solved by equating households' demand and bankers' supply. See Appendix A.2

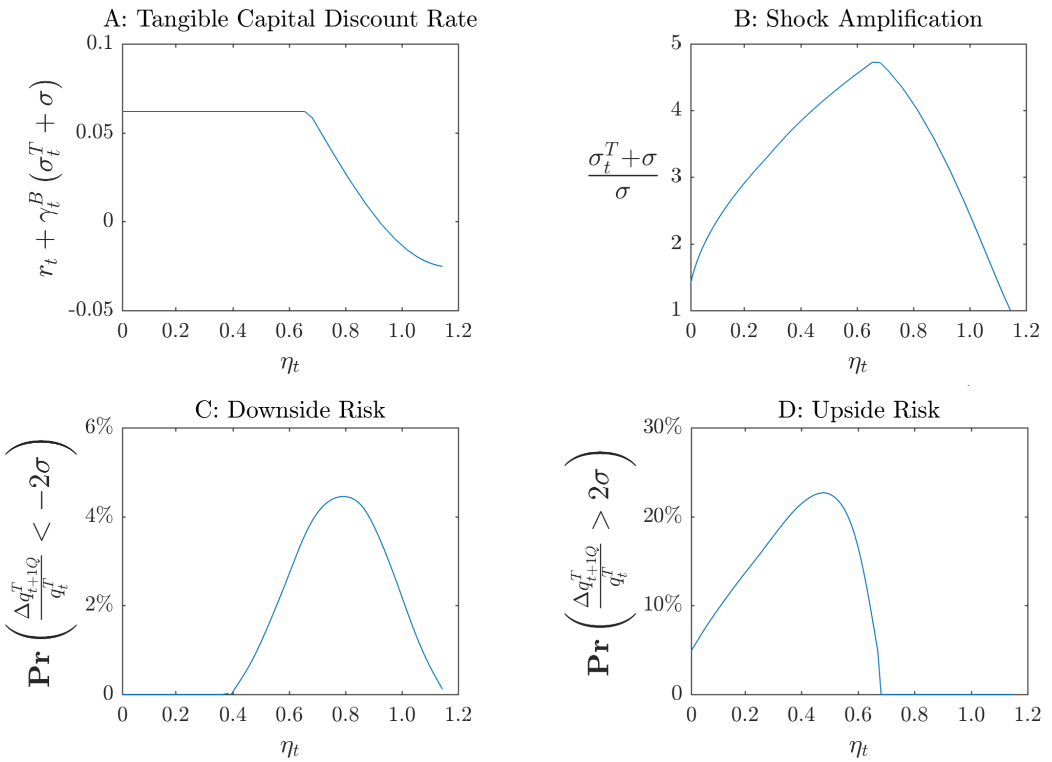

Figure 6: **Endogenous Risk Accumulation**.

The upward spiral triggered by positive shocks, $dZ_t > 0$, seems benign, featuring a boom of liquidity creation and investment. However, endogenous risk accumulates. Consider a value of η_t near zero in Panel A of Figure 6 (reproducing Panel B of Figure 5). The discount rate stays at ρ with a large probability. However, as we move to the right, η_t approaches the cutoff point where the discount rate falls below ρ. As a result, even small shocks can cause a large discount-rate change and variation of q_t^T. Therefore, q_t^T becomes more sensitive to shocks (i.e., higher σ_t^T) as η_t moves to the right. This explains why in Panel B of Figure 6, the risk multiplier, $(\sigma_t^T + \sigma)/\sigma$, is increasing in η_t. The amplification becomes stronger as booms prolong, so even small negative shocks trigger vicious downward spiral.[54] The mechanism eventually subdues as η_t approaches its upper bound where bankers are sufficiently rich and the sensitivity of discount rate to η_t diminishes.

The accumulation of endogenous risk in booms is asymmetric. Positive shocks trigger the

[54]This mechanism offers a new explanation of the findings that long periods of banking expansion often precede severe crises (e.g., Jordà, Schularick, and Taylor, 2013; Baron and Xiong, 2017).

reallocation of tangible capital to bankers with low discount rates but eventually cause them to consume wealth at $\overline{\eta}(t)$; in contrast, negative shocks cause a continuing reallocation of tangible capital away from bankers. Panels C and D plot respectively the probabilities of a 2σ decrease and a 2σ increase of q_t^T in one quarter.[55] Note that at sufficiently low (high) values of η_t, a further decrease (increase) by 2σ is impossible as it goes beyond the equilibrium range of q_t^T. Following positive shocks, the probability of a drop in q_t^T increases as η_t increases. It eventually declines as shock amplification weakens (Panel B). The probability of an increase in q_t^T also rises but declines earlier, suggesting that risk accumulation is downward biased. Following negative shocks, the economy moves leftward. The downside risk in q_t^T rises in Panel C, while the upside risk is relatively insensitive in Panel D. This offers a new explanation of why downside risks rise faster than upside risks as financial conditions deteriorate Adrian, Boyarchenko, and Giannone (2019).

4.4 Counterfactual Analysis

The equilibrium dynamics is driven by upward trends in liquidity demand from both firms and households. In the following, I construct two hypothetical scenarios to examine the quantitative importance of the rise of intangibles. In *Intan. Trend*, the increase of intangible investment productivity is preserved while the trend in households' liquidity demand is shut down (i.e., $\beta_1 = 0$ and $\beta_2 = 0$). In *HH Trend*, the increase of intangible investment productivity is shut down (i.e., $\kappa_1^I = 0$) while the trend in households' liquidity demand remains. *HH Trend* sets a benchmark corresponding the existing literature on households' liquid asset demand and its implications on interest rate, asset price, and financial instability (Kiyotaki and Moore, 2000; Moreira and Savov, 2017; Krishnamurthy and Vissing-Jørgensen, 2015; Piazzesi and Schneider, 2016; Egan, Lewellen, and Sunderam, 2018; Van den Heuvel, 2018; Begenau, 2019; Begenau and Landvoigt, 2018).[56]

Panel A and B of Figure 7 show respectively the trends of interest rate, $\mathbb{E}^{\eta}\left[r\left(\eta, t\right)\right]$, and asset price (tangible capital value), $\mathbb{E}^{\eta}\left[q^T\left(\eta, t\right)\right]$ for the three scenarios. A common pattern emerges across the two panels: Removing the trend in intangibles (*HH Trend*) moderates the downward

[55]Given the model solution, these probabilities can be calculated using the Feynman–Kac PDEs.

[56]See also the banking theory literature (Diamond and Dybvig, 1983; Gorton and Pennacchi, 1990; Goldstein and Pauzner, 2005; Dang, Gorton, Holmström, and nez, 2014; Hart and Zingales, 2014; DeAngelo and Stulz, 2015).

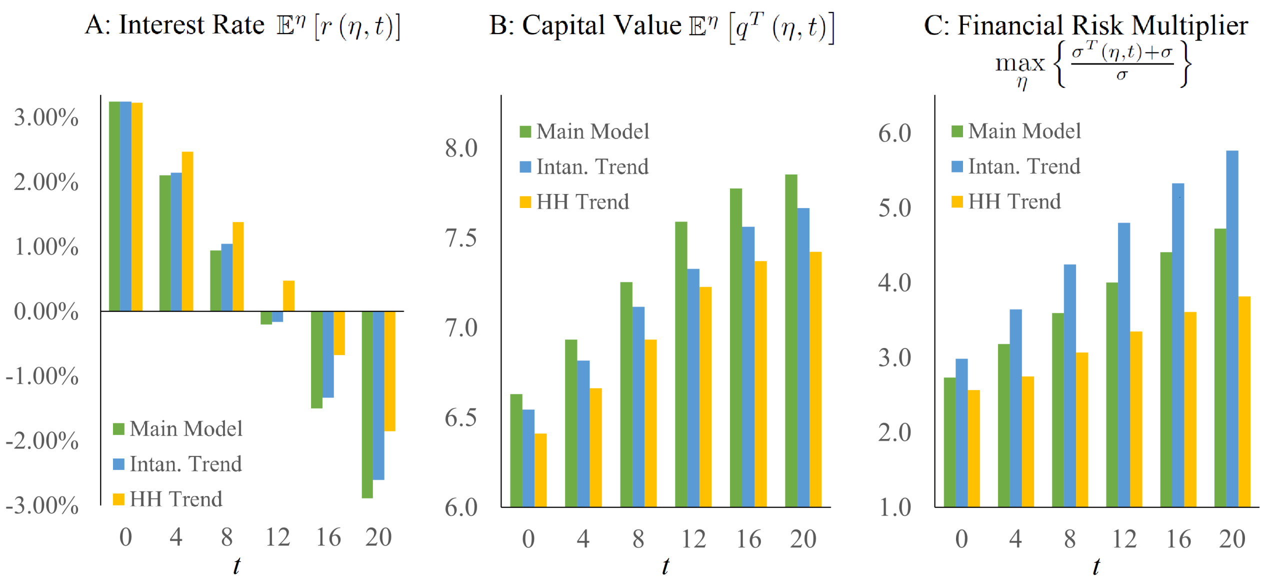

Figure 7: **Counterfactual Analysis**

trend in interest rate and upward trend asset price more than removing the trend in households' liquidity demand (*Intan. Trend*) does. This suggests the rise of intangibles and the resultant trend in firms' demand for liquid assets is a more potent force than households' liquidity demand.

The greater quantitative importance of firms' liquidity demand seems puzzling given the fact that firms' liquidity holdings are only 1/7 that of households by $t = 20$ and 1/10 at $t = 0$ both in the baseline model and data. This observation ignores the fact that once the trend in households' liquidity needs is removed, the firms' liquidity holdings will increase in equilibrium and rise faster over time in the absence of households' competition. The counterfactual, *Intan. Trend*, does not and should not fix the equilibrium level of firms' liquidity holdings to that of the main model. What should be fixed are the parameters underlying firms' liquidity management problems; likewise, in *HH Trend*, households' liquidity holdings increase in the absence of firms' competition as the rise of intangibles is shut down while parameters in households' liquidity utility are fixed.

In Panel C of Figure 7, *Intan. Trend* generates the most endogenous risk, the main model the second highest, and *HH Trend* the lowest, and the wedges widen over time as the different trends in the three models unfold. This finding is particularly interesting because one would have expected the main model to generate the most endogenous risk by having both firms' and households' liquidity needs trending up over time and feeding leverage to bankers. The key to understanding this result is the distinct cyclical property of firms' and households' liquidity demand. Consider positive shocks. The subsequent increase in q_t^T encourages the firms to save more as investment becomes more profitable and the leverage on liquidity holdings, backed by tangible capital, increases. The increase of liquidity value, π_t, drives down r_t. As r_t declines, the households' liquidity holdings decrease, counteracting the increase in firms' liquidity demand (see (22)). Following negative shocks, the opposite happens: q_t^T and π_t decline, resulting in a higher r_t that induces households to hold more liquidity, counteracting the decrease in firms' demand. In sum, firms' liquidity demand exhibits procyclicality, while the households' demand features countercyclicality.[57] In the main model, the two forces act against each other, while in *Intan. Trend*, there is only an upward trend in firms' demand for liquid assets so its procyclicality is fully unleashed.[58]

Section 2 provides evidence that firms' liquidity demand increases in asset valuation, i.e., the procyclicality key to the quantitative importance of intangible-driven liquidity needs. Next, I show that empirically, households' demand for liquid assets decreases in measures of asset valuation, counteracting the procyclicality in firms' liquidity demand as in the model. For time-series regressions in Panel A of Table 4, the dependent variable is quarterly household holdings of intermediary debts scaled by GDP from 1980 to 2019.[59] The explanatory variables are measures of capital valuation (see Section 2) and housing price-to-rent ratio (summary statistics in Appendix C). Column (6) shows that financial-market and housing valuations together explain 31% of variation.[60]

The analysis of aggregate data has a small sample size and does not utilize cross-sectional variations. Next, I use household-level micro data. The financial-market valuation metrics do not have regional variation and thus excluded. The Panel Study of Income Dynamics (PSID) reports biannual information on households' financials from 1999 to 2017.[61] The dependent variable is

[57]The countercycality is in line with flight to safety in crises (Caballero and Krishnamurthy, 2008).

[58]Note that in line with previous studies (Stein, 2012; Krishnamurthy and Vissing-Jørgensen, 2015), households' liquidity demand still generates endogenous risk by lowering r_t and creating a discount-rate wedge between the bankers and the rest of the economy, but its countercyclicality dampens the effects from interest rate level.

[59]The data source is the Financial Accounts of the U.S. Intermediary debts are listed in Figure 2 and indirect holdings via money-market funds and mutual funds are attributed to underlying securities.

[60]This is the ratio of two time series in FRED: (1) "All-Transactions House Price Index for the United States"; (2) "Consumer Price Index for All Urban Consumers: Rent of Primary Residence in U.S. City Average".

[61]Liquidity holdings include checking/savings deposits, money market funds, certificates of deposit, Treasury secu-

Table 4: Asset Valuations and Household Holdings of Financial Intermediaries' Debts

***Panel A**: Regression Analysis of Aggregate Data*

LHS: HH Holdings of Intermediary Debts scaled by GDP	(1)	(2)	(3)	(4)	(5)	(6)
RHS: Financial-Market Valuation Metrics =	Tangible EV/EBITDA	Average EV/EBITDA	Tangible Tobin's Q	Average Tobin's Q		Tangible EV/EBITDA
Financial-Market Valuation	-0.017***	-0.010***	-0.190***	-0.095***		-0.016***
	(0.002)	(0.002)	(0.019)	(0.012)		(0.002)
Housing-Market Valuation (Price/Rent)					-0.142***	-0.060**
					(0.024)	(0.024)
Observations	160	160	160	160	160	160
Adjusted R^2	0.3015	0.1953	0.2880	0.2456	0.0771	0.3138

Heteroscedasticity-consistent standard errors in parentheses
* $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$

***Panel B**: Regression Analysis of Micro Data*

HH Cash Holdings scaled by Income	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln$ (Housing Price Index)	-0.059	-0.119***	-0.114***	-0.046	-0.086***	-0.081**
	(0.045)	(0.040)	(0.040)	(0.037)	(0.031)	(0.039)
Controls	No	No	No	Yes	Yes	Yes
Household FE	No	Yes	Yes	No	Yes	Yes
State FE	No	No	Yes	No	No	Yes
Year FE	No	No	Yes	No	No	Yes
Observations	70,442	70,032	70,032	65,280	65,215	65,215
Adjusted R^2	0.0001	0.2389	0.2495	0.1370	0.3438	0.3510

State-time clustered standard errors in parentheses
* $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$

the liquidity holdings normalized by household income. The explanatory variable of interest is the log difference of state-level home price index from the Federal Housing Finance Agency (FHFA). Rent data are unavailable so the log difference is taken to address apparent non-stationarities in these house prices. Panel B of Table 4 reports a statistically significant negative response of house-

rities (not including I.R.A.). A breakdown into instruments issued by intermediaries and the government is unavailable, but as shown in Figure D.3 in Appendix C, Treasury securities account for less than 15%. Related, to analyze households' mortgage refinancing behavior, Chen, Michaux, and Roussanov (2020) use data from Financial Accounts of the U.S. for time-series analysis and PSID (including households' liquidity holdings) for panel-data analysis. The regression samples starts in 2001 because the calculation of log difference requires housing price.

Table 5: Intangible Investment and Credit Constraint

	Intangibility = Intan./Assets (decile)			Intangiblity = – PPE/Assets (decile)		
	(1)	(2)	(3)	(4)	(5)	(6)
Leverage = $\frac{\text{Debts}}{\text{Assets}}$	Total Debts	Asset-Based Loans	Cash Flow-Based Loans	Total Debts	Asset-Based Loans	Cash Flow-Based Loans
Intangibility	-1.219***	-0.745***	-0.715***	-0.914***	-0.728***	-0.158
	(0.092)	(0.083)	(0.197)	(0.090)	(0.076)	(0.118)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	114,626	39,750	39,819	114,608	39,749	39,818
Adjusted R^2	0.2159	0.0891	0.1298	0.2116	0.0934	0.1263

Firm-year clustered standard errors in parentheses
$* \ p < 0.1$ $** \ p < 0.05$ $*** \ p < 0.01$

holds' liquidity holdings to an increase in house prices, robust to different combinations of control variables and fixed effects (FE).[62] Including control variables and fixed effects increases the adjusted R^2 to above 34% (in Columns (5) and (6)) by reducing noise, allowing the correlation to emerge between households' liquidity holdings and housing price variation. The evidence suggests that in line with the model setup, households' liquidity holdings respond negatively to asset-price increase, opposite to the positive response in firms' liquidity holdings (see Section 2).

5 Extension: Intangible Capital of Limited Pledgeability

A key ingredient of the model is the financial constraint due to illiquidity of intangible capital. The panel regression in Table 5 shows that more intangible firms borrow less, which indicates tighter credit constraints. The sample is from Section 2.[63] All specifications show a negative correlation

[62]Following studies on household consumption-savings decisions and portfolio allocation (Bergstresser and Poterba, 2004; Campbell and Cocco, 2007; Bogan, 2015; Chetty, Sándor, and Sziedl, 2017; Stroebel and Vavra, 2019), I construct the following control variables using PSID data: the log difference of total household income, the log difference of total household wealth, the number of people in a household, the age of household head, the education level of household head, a homeowner dummy, and a couple dummy (equal to one if the household head lives with a partner). I consider household, state, and year fixed effects. Note that the number of observations decline after household FE is added because 65 households only appear once in the panel. Appendix C provides summary statistics.

[63]Control variables are included following Lian and Ma (2019) who share their loan categorization data: Size (log total assets in 2005 dollars); market-to-book ratio; cash-to-asset ratio; EBITDA-to-asset ratio ([sale – cogs – xsga]/at);

between intangibility and leverage. In Column (1), a one-decile difference in intangibility is associated with 1.219% reduction of leverage. Credit relies on collateral or creditors' contractual rights to future cash flows (Lian and Ma, 2019). With different measures of intangibility, Columns (2) and (5) and Columns (3) and (6) show that intangible firms are disadvantaged on both fronts.

As the U.S. economy becomes more intangible-intensive, the legal system develops to improve the pledgeability of intangibles. Mann (2018) find that firms use patents as collateral. New markets also emerge for the exchange of intangibles. Akcigit, Celik, and Greenwood (2016) document that, between 1976 to 2006, 16% of U.S. registered patents were traded. This section presents an extension that reflects improved pledgeability of intangible capital. Specifically, when hit by the Poisson shock, an entrepreneur may raise funds from households against χ fraction of intangible capital as collateral.[64] The repayment is in the form of intangible capital ownership. Equivalently, the entrepreneur may sell intangible capital to households rather than pledge it as collateral. It is assumed that the bankers do not lend against intangibles as collateral or own intangibles; otherwise the χ fraction of pledgeable intangibles and tangible capital are indistinguishable.[65] One potential limitation of the model is that tangible and intangible capital do not have richer attributes to further differentiate from each other and thereby allow banks to own certain types of intangibles. In practice, intangibles are mainly financed by non-bank intermediaries (e.g., venture capital funds).

The improved pledgeability of intangibles relax the entrepreneurs' funding constraint:

$$i_t \leq m_t^E + q_t^T \kappa^T (1-\theta_t)\, i_t + \chi \left(q^I \kappa_t^I \theta_t i_t\right). \tag{33}$$

According to Corrado et al. (2016), intellectual properties accounted for 37.7% of intangible investment in the U.S. from 1995 to 2016.[66] Therefore, given that 16% of patents were traded

net cash receipts-to-asset ratio ([oancf + xint]/at); inventory-to-asset ratio (invt/at). Time fixed effects are added to absorb common variations, such as tax changes, banking regulation changes, bankruptcy law change etc.

[64] External financing from intangibles can be related to venture capital (VC). Akcigit, Dinlersoz, Greenwood, and Penciakova (2019) examine both empirically and theoretically the role of VC in creating endogenous growth.

[65] The assumption that intangible capital is still less liquid than tangible capital can be motivated by the search friction in patent trading (Akcigit, Celik, and Greenwood, 2016): (1) the market is specialized (often involving lawyers as middlemen); (2) the sensitivity of intellectual property makes potential participants reluctant to reveal information.

[66] The other categories of intangibles include brand, database, design, organizational capital, softwares, training etc.

Table 6: Pledgeable Intangibles and the Reinforcing Trends

Time	Intangible Inv. Share $\mathbb{E}^{\eta}[\theta(\eta,t)]$	$\frac{\text{Firm Deposits}}{\text{Capital Value}}$ $\mathbb{E}^{\eta}\left[\frac{\widetilde{M}^{E}(\eta,t)}{q^{T}(\eta,t)}\right]$	Interest Rate $\mathbb{E}^{\eta}[r(\eta,t)]$	Capital Valuation $\mathbb{E}^{\eta}\left[q^{T}(\eta,t)\right]$	Financial Risk Multiplier $\max_{\eta}\left\{\frac{\sigma^{T}(\eta,t)+\sigma}{\sigma}\right\}$
Model $t=0$	55.2%	7.6%	3.24%	6.6	2.7
Pledgeable Intan.	57.3%	27.3%	2.58%	7.8	3.6
Model $t=4$	58.7%	8.5%	2.11%	6.9	3.2
Pledgeable Intan.	61.8%	30.4%	1.06%	8.5	4.4
Model $t=8$	62.2%	8.2%	0.95%	7.3	3.6
Pledgeable Intan.	66.6%	33.2%	-0.64%	9.2	5.2
Model $t=12$	65.7%	9.2%	-0.20%	7.6	4.0
Pledgeable Intan.	71.6%	36.2%	-2.59%	9.9	6.0
Model $t=16$	69.1%	10.2%	-1.50%	7.8	4.4
Pledgeable Intan.	76.9%	38.8%	-4.81%	10.4	6.8
Model $t=20$	72.6%	10.4%	-2.88%	7.9	4.7
Pledgeable Intan.	82.7%	42.1%	-7.32%	10.7	7.6

(Akcigit, Celik, and Greenwood, 2016), χ is calibrated to be $6.0\% = 37.7\% \times 16\%$.[67]

Table 6 shows that the improved pledgeability of intangibles amplifies the mechanism. The intangible share of investment is higher, and its increase over time becomes convex. In contrast, the main model produces a linear trend, yielding an increase of 3.5% every four years driven by the linear increase of κ_t^I. The difference widens from 2.1% at $t = 0$ to 10.1% by $t = 20$. The improved pledgeability of intangibles increases the leverage on liquidity holdings and the marginal value of liquidity. The feedback mechanism is strengthened, resulting in a much higher level and faster growth of entrepreneurs' liquidity holdings, a sharper decline of the interest rate, and a stronger upward trend in the value of tangible capital. Under a stronger feedback mechanism,

[67] This value is in the same magnitude as the value implied by the finding of Mann (2018). He finds that 38% of US patenting firms had previously pledged patents as collateral for financing, and these firms performed 20% of R&D expense and patenting in Compustat, implying $\chi = 38\% \times 20\% = 7.6\%$.

the financial risk multiplier is higher than that of the main model as shown in the last column of Table 6. A lower level of the interest rate widens the discount-rate wedge between bankers and the rest of the economy, making the value of tangible capital more sensitive to shocks that trigger reallocation between the two groups. A more volatile value of tangible capital translates into more volatile liquidity creation and investment. Moreover, the concave upward trend in the financial risk multiplier of the main model becomes a linear trend once intangibles become more pledgeable.

6 Conclusion

This paper studies the macroeconomic causes and consequences of corporate savings gluts. In response to the structural changes in investment technology, a self-perpetuating savings glut can arise endogenously in the production sector as firms optimally choose to invest more in intangibles while financial intermediaries issue an increasing amount of liquid securities, taking advantage of the resulting low interest rates and bidding up asset prices. The economy becomes increasingly fragile along the trends because financial intermediaries' funding cost advantage becomes increasingly large. As a result, asset prices, which drive firms' external financing capacity and investments, become increasingly sensitive to shocks that trigger reallocation between agents with low (bankers) and high discount rates (the rest of the economy). The counterfactual analysis shows that corporate savings have a significant impact on interest rates, asset prices, and endogenous financial risk. Recent developments in making intangibles more tradable amplify the mechanism.

An interesting direction for future research is to incorporate nominal frictions into the model. The corporate savings glut contributes to a negative real rate in the model that, combined with low inflation, implies a binding lower bound on the nominal rates (Eggertsson and Woodford, 2003; Fischer, 2016). This suggests that the rise of intangible investment can trigger a more severe liquidity trap (Christiano, Eichenbaum, and Rebelo, 2011; Eggertsson and Krugman, 2012; Caballero and Farhi, 2017; Guerrieri and Lorenzoni, 2017). Moreover, a liquidity trap triggered by one country's transition towards an intangible-intensive economy can spread to the rest of the world through current accounts and policy responses (Caballero, Farhi, and Gourinchas, 2021).

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A Proofs and Solution Algorithm

A.1 Proofs

Ruling out self-financing. If entrepreneurs' investment projects can be self-financed, entrepreneurs do not need to hold liquidity for investment and the liquidity premium is zero. The equilibrium value of tangible capital is the production value, i.e., $1/(\rho+\delta+\lambda)$. If Assumption 1 holds, then even if entrepreneurs set the intangible share of investment, θ_t, to zero, the external financing capacity, $\kappa^T q_t^T = \kappa^T \left(\frac{1}{\rho+\delta+\lambda}\right)$ is still below 1, which is the cost of investment. This contradicts that investment is self-financed. Therefore, under Assumption 1, the investment project cannot be self-financed.

Proof of Proposition 3. First, I show that there exists an upper bound $\overline{\eta}(t)$ such that $\eta_t \leq \overline{\eta}(t)$. Note that $q_t^B \geq 1$ in equilibrium because if $q_t^B < 1$, bankers are better off consuming (worth 1) than retaining wealth (worth q_t^B). As will be shown later, q_t^B is a bivariate function, $q_t^B = q^B(\eta_t, t)$. Fixing t, let $\overline{\eta}(t)$ denote that lowest value of η_t where bankers consume. Therefore, $q^B(\overline{\eta}(t), t) = 1$ and $q_t^B > 1$ at $\eta_t < \overline{\eta}(t)$. Suppose there exists $\eta' > \overline{\eta}(t)$ such that η_t reaches η'. This leads to a contradiction – it is no longer optimal for bankers to consume at $\overline{\eta}(t)$ because their marginal value of wealth will surely increase: at $\overline{\eta}(t)$, if η_t increases, q_t^B will not decline because $q_t^B \geq 1$, and if η_t decreases, q_t^B will surely increase because, by definition of $\overline{\eta}(t)$, $q_t^B > 1$ for $\eta_t < \overline{\eta}(t)$. Therefore, η_t cannot increase beyond $\overline{\eta}(t)$, the upper boundary given by bankers' consumption optimality.

Next, I derive the law of motion of η_t in $(0, \overline{\eta}(t))$. According to (10), bankers' wealth satisfies the following law of motion in the region where bankers' consumption is zero, i.e., $\eta_t \in (0, \overline{\eta}(t))$:

$$\frac{dN_t^B}{N_t^B} = \mu_t^N dt + \sigma_t^N dZ_t\,, \tag{A.1}$$

where

$$\mu_t^N = r_t + x_t^B \left(\mathbb{E}_t\left[dr_t^T\right] - r_t\right)\,, \tag{A.2}$$

and

$$\sigma_t^N = x_t^B \left(\sigma_t^T + \sigma\right)\,. \tag{A.3}$$

The expression of expected return of tangible capital holdings, $\mathbb{E}_t\left[dr_t^T\right]$, can be obtained from (9).

By Itô's lemma, the law of motion of η_t is given by

$$\frac{d\eta_t}{\eta_t} = \mu_t^{\eta} dt + \sigma_t^{\eta} dZ \,, \tag{A.4}$$

where

$$\mu_t^{\eta} = \mu_t^{N} - \mu_t^{KT} - \sigma_t^{N} \sigma + \sigma^2 \,, \tag{A.5}$$

(where μ_t^{KT} is the expected instantaneous growth rate of K_t^T) and

$$\sigma_t^{\eta} = x_t^B \left(\sigma_t^T + \sigma\right) - \sigma \,. \tag{A.6}$$

According to (26), the expected instantaneous growth rate of K_t^T is given by

$$\begin{aligned} \mu^{KT} &= \frac{\left(\frac{1}{1-q_t^T \kappa^T (1-\theta_t)}\right) \left[\left(x_t^B - 1\right) N_t^B - M_t^H\right] (1-\theta_t)\, \kappa^T \lambda}{K_t^T} - \delta \\ &= \left(\frac{1}{1 - q_t^T \kappa^T (1-\theta_t)}\right) \left[\left(x_t^B - 1\right) \eta_t - \alpha \left(\frac{\rho - r_t}{\beta(t)}\right)^{-\frac{1}{\xi}}\right] (1-\theta_t)\, \kappa^T \lambda - \delta \,, \end{aligned} \tag{A.7}$$

where the second equation uses the definition of η_t and households' aggregate deposit demand given by (22). In A.2, q_t^T, r_t, x_t^B, θ_t, $\mathbb{E}_t\left[dr_t^T\right]$, σ_t^T, and the rest of variables listed in Proposition 3 are shown to be bivariate functions of η_t and t.

Proof of Proposition 1. First, I solve the investment problem of entrepreneurs who are hit by the Poisson shocks, and then embed the solution to the entrepreneurs' dynamic optimization. An investing entrepreneur solves the problem summarized by the Lagrange function (11):

$$\mathcal{L} = \max_{\{i_t, \theta_t\}} \left[q^I \kappa_t^I \theta_t + q_t^T \kappa^T (1-\theta_t) - F(\theta_t)\right] i_t - i_t + \pi_t \left[m_t^E + q_t^T \kappa^T i_t (1-\theta_t) - i_t\right] \,. \tag{A.8}$$

Given κ_t, q_t^T, m_t^E, q^I and κ^T, the entrepreneur chooses θ_t and i_t. The first-order condition (F.O.C.) for θ_t is

$$q^I \kappa_t^I - q_t^T \kappa^T (1+\pi_t) - F'(\theta_t) = 0 \,, \tag{A.9}$$

and the F.O.C. for i_t is (i.e., (13) in the main text)

$$\pi_t = \left\{ \left[q^I \kappa_t^I \theta_t + q_t^T \kappa^T (1-\theta_t) - F(\theta_t) \right] - 1 \right\} \left(\frac{1}{1 - q_t^T \kappa^T (1-\theta_t)} \right) \tag{A.10}$$

The F.O.C. for θ_t equates the marginal value of investing in intangibles and the marginal value of investing in tangibles (which includes both the value of tangible capital and the shadow value from relaxing the liquidity constraint). The F.O.C. for i_t solves the marginal value of liquidity as equal to the net profits of investment multiplied by the leverage on liquidity holdings. The liquidity constraint binds so the total investment is given by

$$i_t = \frac{m_t^E}{1 - (1-\theta_t)\kappa^T q_t^T} \,. \tag{A.11}$$

Next, I prove that θ_t is increasing in κ^I. First, note that, from (A.10),

$$\begin{aligned} \frac{\partial \pi_t}{\partial \theta_t} &= \left[q^I \kappa_t^I - q_t^T \kappa^T - F'(\theta_t) \right] \left(\frac{1}{1 - q_t^T \kappa^T (1-\theta_t)} \right) \\ &\quad - \left\{ \left[q^I \kappa_t^I \theta_t + q_t^T \kappa^T (1-\theta_t) - F(\theta_t) \right] - 1 \right\} \frac{q_t^T \kappa^T}{\left[1 - q_t^T \kappa^T (1-\theta_t) \right]^2} \\ &= \frac{q_t^T \kappa^T \pi_t}{1 - q_t^T \kappa^T (1-\theta_t)} - \frac{q_t^T \kappa^T \pi_t}{1 - q_t^T \kappa^T (1-\theta_t)} = 0 \,, \end{aligned} \tag{A.12}$$

where the second equation follows from (A.9) and (A.10). Differentiating (A.9) with respect to (w.r.t.) κ_t^I, I obtain

$$q^I - q_t^T \kappa^T \frac{\partial \pi_t}{\partial \theta_t} \frac{\partial \theta_t}{\partial \kappa_t^I} - q_t^T \kappa^T \frac{\partial \pi_t}{\partial \kappa_t^I} - F''(\theta_t) \frac{\partial \theta_t}{\partial \kappa_t^I} = 0 \,. \tag{A.13}$$

Rearranging the equation and using (A.12), I solve

$$\frac{\partial \theta_t}{\partial \kappa_t^I} = \frac{q^I - q_t^T \kappa^T \frac{\partial \pi_t}{\partial \kappa_t^I}}{F''(\theta_t)} \,. \tag{A.14}$$

According to (A.10), the partial derivative of π_t w.r.t. κ_t^I is

$$\frac{\partial \pi_t}{\partial \kappa_t^I} = \frac{q^I \theta_t}{1 - q_t^T \kappa^T (1-\theta_t)} \,. \tag{A.15}$$

Using this equation to substitute out $\frac{\partial \pi_t}{\partial \kappa_t^I}$ in (A.14), I obtain

$$\frac{\partial \theta_t}{\partial \kappa_t^I} = \frac{1}{F''(\theta_t)} \left[q^I - q_t^T \kappa^T \frac{q^I \theta_t}{1 - q_t^T \kappa^T (1-\theta_t)} \right] = \frac{q^I \left(1 - q_t^T \kappa^T\right)}{F''(\theta_t) \left[1 - q_t^T \kappa^T (1-\theta_t)\right]} . \tag{A.16}$$

In equilibrium, $q_t^T \kappa^T$ must be smaller than 1, because otherwise the entrepreneur sets $\theta_t = 0$ (i.e., investing all in tangible capital) and self-finances the project to achieve infinite profits. Therefore, the right side of (A.16) is positive, i.e., θ_t is increasing in κ_t^I.

The right side of (A.15) is positive, so π_t is increasing in κ_t^I. Finally, I prove that π_t is increasing in q_t^T. Differentiating (A.10) w.r.t. q_t^T, I obtain

$$\begin{aligned} \frac{\partial \pi_t}{\partial q_t^T} =& \frac{\kappa^T (1-\theta_t)}{1 - q_t^T \kappa^T (1-\theta_t)} - \left\{ \left[q^I \kappa_t^I \theta_t + q_t^T \kappa^T (1-\theta_t) - F(\theta_t) \right] - 1 \right\} \frac{\left[-\kappa^T (1-\theta_t) \right]}{\left[1 - q_t^T \kappa^T (1-\theta_t)\right]^2} \\ =& \frac{\kappa^T (1-\theta_t)}{1 - q_t^T \kappa^T (1-\theta_t)} + \pi_t \frac{\kappa^T (1-\theta_t)}{1 - q_t^T \kappa^T (1-\theta_t)} = \frac{\kappa^T (1-\theta_t)}{1 - q_t^T \kappa^T (1-\theta_t)} (1+\pi_t) > 0 . \end{aligned} \tag{A.17}$$

Next, I solve (15), i.e., the optimality condition for entrepreneurs' optimal liquidity holdings. Entrepreneurs maximize the life-time utility, $\mathbb{E}\left[\int_{t=0}^{+\infty} e^{-\rho t} dc_t^E\right]$ given the following law of motion of wealth:

$$dw_t^E = -dc_t^E + \mu_t^w w_t^E dt + \sigma_t^w w_t^E dZ_t + \left(\widehat{w}_t^E - w_t^E\right) dN_t,$$

$\mu_t^w w_t^E$ and $\sigma_t^w w_t^E$ are the drift and diffusion terms that depend on choices of tangible capital and deposit holdings and will be elaborated later. dN_t is the increment of the idiosyncratic counting (Poisson) process. At the Poisson time, an entrepreneur's wealth jumps by the total profits from investment minus the value of lost tangible capital holdings (denoted by k^{TE}),

$$\begin{aligned} \widehat{w}_t^E - w_t^E =& \left\{ \left[q^I \kappa_t^I \theta_t + q_t^T \kappa^T (1-\theta_t) - F(\theta_t) \right] - 1 \right\} \left(\frac{1}{1 - q_t^T \kappa^T (1-\theta_t)} \right) m_t^E - q_t^T k_t^{TE} \\ =& \pi_t m_t^E - q_t^T k_t^{TE} . \end{aligned} \tag{A.18}$$

Note that w_t^E does not contain the existing stock of intangible capital, because when analyzing entrepreneurs' decisions, the production flows from intangible capital can be treated as goods that are directly consumed, given entrepreneurs' indifference in the timing of consumption.

I conjecture that the value function is linear in wealth w_t^E: $v_t^E = \zeta_t^E w_t^E + v^I$, where ζ_t^E is the marginal value of liquid wealth (i.e., without counting the value of intangible capital), and v^I is the present value of consumption from intangible capital. Consider a generic equilibrium diffusion process for ζ_t^E:

$$d\zeta_t^E = \zeta_t^E \mu_t^\zeta dt + \zeta_t^E \sigma_t^\zeta dZ_t,$$

where $\zeta_t^E \mu_t^\zeta$ and $\zeta_t^E \sigma_t^\zeta$ are the drift and diffusion terms, respectively. Entrepreneurs' marginal value of wealth, ζ_t^E, is a summary statistic of their investment opportunity set, which depends on the overall industry dynamics, so it does not jump when an individual is hit by the Poisson shocks.

Under this conjecture, the Hamilton-Jacobi-Bellman (HJB) equation is

$$\rho\zeta_t^E w_t^E dt = \max_{dc^E, k_t^{TE}, m_t^E} dc_t^E - \zeta_t^E dc_t^E + \{w_t^E \zeta_t^E \mu_t^\zeta + w_t^E \zeta_t^E \mu_t^w + w_t \zeta_t^E \sigma_t^\zeta \sigma_t^w + \lambda \zeta_t^E [\widehat{w}_t - w_t]\} dt \,.$$

Note that the consumption flow from intangible capital and $\rho v^I dt$ cancel each other out, because, by definition, v^I is the ρ-discounted present value of consumption flow.

Entrepreneurs can choose any $dc_t^E \in \mathbb{R}$, so ζ_t^E must be equal to one, and thus, I have also confirmed the value function conjecture. Since ζ_t^E is a constant equal to one, μ_t^ζ and σ_t^ζ are both zero. The HJB equation can be simplified:

$$\rho\zeta_t^E w_t^E dt = \max_{k_t^{TE} \geq 0, m_t^E \geq 0} \mu_t^w w_t^E dt + \lambda dt \left(\pi_t m_t^E - q_t^T k_t^{TE}\right). \tag{A.19}$$

Wealth drift includes production, the value change of tangible capital holdings, and the deposit return:

$$\mu_t^w w_t^E dt = \underbrace{k_t^{TE} dt + \mathbb{E}_t \left(q_{t+dt}^T k_{t+dt}^{TE} - q_t^T k_t^{TE}\right)}_{\mathbb{E}_t\left[dr_t^T\right] q_t^T k_t^{TE}} + r_t m_t^E dt.$$

Let $d\psi_t^E$ denote the Lagrange multiplier of the budget constraint, $q_t^T k_t^{TE} + m_t^E \leq w_t^E$. The first-order condition (F.O.C.) for optimal deposit holdings per unit of capital is: $m_t^E \geq 0$, and

$$m_t^E \left(r_t dt + \pi_t \lambda dt - d\psi_t^E\right) = 0.$$

The F.O.C. for optimal tangible capital holdings is : $k_t^{TE} \geq 0$, and

$$k_t^{TE} \left(-\mathbb{E}_t \left[dr_t^T\right] + d\psi_t^E\right) = 0.$$

Substituting these optimality conditions into the HJB equation, we have

$$\rho v_t^E dt = w_t^E d\psi_t^E.$$

Because $\zeta_t^E = 1$, $v_t^E = w_t^E$, and $d\psi_t^E = \rho dt$. Substituting $d\psi_t^E = \rho dt$ into the F.O.C. for m_t^E, we have

$$\rho - r_t = \lambda \pi_t.$$

Substituting $d\psi_t = \rho dt$ into the F.O.C. for k_t^{TE} and rearranging the equation, we have

$$\mathbb{E}_t \left[dr_t^T \right] = \rho dt \,,$$

that is, when entrepreneurs hold tangible capital, they require an expected return of ρ.

Binding liquidity constraint. Consider the following inequalities:

$$\max_{\theta_t} \left[q^I \kappa_t^I \theta_t + q_t^T \kappa^T (1 - \theta_t) - F(\theta_t) \right] \geq q^I \kappa_t^I - F(1) \geq q^I \kappa_0^I - F(1) \ ,$$

where the first step follows $q_t^T \geq q^I$ (due to the additional liquidity value of tangible capital) and the optimality of θ_t, and the second step follows from $\kappa_t^I \geq \kappa_0^I$. Therefore, as long as

$$q^I \kappa_0^I - F(1) > 1 \,, \tag{A.20}$$

we have

$$\begin{aligned} \pi_t &= \max_{\theta_t} \left\{ \left[q^I \kappa_t^I \theta_t + q_t^T \kappa^T (1 - \theta_t) - F(\theta_t) \right] - 1 \right\} \left(\frac{1}{1 - q_t^T \kappa^T (1 - \theta_t)} \right) \\ &\geq \left[q^I \kappa_0^I - F(1) - 1 \right] \left(\frac{1}{1 - q_t^T \kappa^T (1 - \theta_t)} \right) > 0 \end{aligned}$$

and the liquidity constraint binds. Note that $\left(\frac{1}{1 - q_t^T \kappa^T (1 - \theta_t)} \right) > 0$ from Assumption 1. The calibrated parameter values satisfy the condition given by (A.20).

Proof of Proposition 2. Conjecture that the bank's value function takes the linear form: $v_t^B =$

$q_t^B n_t^B$. Consider the following generic equilibrium diffusion process for q_t^B,

$$dq_t^B = q_t^B \mu_t^B dt - q_t^B \gamma_t^B dZ_t.$$

Define $dy_t^B = dc_t^B / n_t^B$, the consumption-to-wealth ratio of bankers. Under the conjectured functional form, the HJB equation is

$$\begin{aligned}\rho v_t^B dt &= \max_{dy_t^B} \left\{ \left(1 - q_t^B\right) \mathbb{I}_{\{dy_t^B > 0\}} n_t^B dy_t^B \right\} + \mu_t^B q_t^B n_t^B + \\ &\quad \max_{x_t^B} \left\{ r_t + x_t^B \left(\mathbb{E}_t \left[dr_t^T \right] - r_t \right) - x_t^B \gamma_t^B \left(\sigma_t^T + \sigma \right) \right\} q_t^B n_t^B,\end{aligned}$$

Dividing both sides by $q_t^B n_t^B$, n_t^B is eliminated, which confirms the homogeneity property,

$$\rho = \max_{dy_t^B} \left\{ \frac{\left(1 - q_t^B\right)}{q_t^B} \mathbb{I}_{\{dy_t^B > 0\}} dy_t^B \right\} + \mu_t^B + \max_{x_t^B} \left\{ r_t + x_t^B \left(\mathbb{E}_t \left[dr_t^T \right] - r_t \right) - x_t^B \gamma_t^B \left(\sigma_t^T + \sigma \right) \right\}, \tag{A.21}$$

and the conjecture of linear value function. The indifference condition for x_t^B is

$$\mathbb{E}_t \left[dr_t^T \right] = r_t + \gamma_t^B \left(\sigma_t^T + \sigma \right) . \tag{A.22}$$

Substituting the expression of $\mathbb{E}_t \left[dr_t^T \right]$ given by (9) and using (15), I obtain (18).

Substituting the optimality conditions into the HJB equation, I obtain

$$\mu_t^B = \rho - r_t \,. \tag{A.23}$$

The result that $\gamma_t^B = 0$ when bankers consume is given by the smooth-pasting condition, $\partial q^B (\eta_t, t) / \partial \eta_t = 0$ (so by Itô's lemma, $\gamma_t^B = 0$), which is discussed in more details in A.2. The upper boundary $\overline{\eta}(t)$ is given by the value-matching condition of bankers' consumption, $q^B (\overline{\eta}(t), t) = 1$, and is jointly determined with the function $q_t^B = q^B (\eta_t, t)$ in the solution of PDEs of $q^B (\eta_t, t)$ and $q^T (\eta_t, t)$ in A.2.

Conditional stationary distribution of η_t. Following Brunnermeier and Sannikov (2014), I derive the conditional stationary probability density of η_t. Fixing κ_t^I and β_t, the probability density of η_t

at time t, $p(\eta, t)$, satisfies the Kolmogorov forward equation

$$\frac{\partial}{\partial t} p(\eta, t) = -\frac{\partial}{\partial \eta}\left(\eta \mu^{\eta}(\eta) p(\eta, t)\right) + \frac{1}{2}\frac{\partial^2}{\partial \eta^2}\left(\eta^2 \sigma^{\eta}(\eta)^2 p(\eta, t)\right).$$

Note that, fixing κ_t^I and β_t, μ_t^{η} and σ_t^{η} are functions of η_t as shown in A.2. A stationary density is a solution to the forward equation that does not vary with time (i.e. $\frac{\partial}{\partial t} p(\eta, t) = 0$). So I suppress the time variable, and denote stationary density as $p(\eta)$. Integrating the forward equation over η, $p(\eta)$ solves the following first-order ordinary differential equation within the reflecting boundary:

$$0 = C - \eta \mu^{\eta}(\eta) p(\eta) + \frac{1}{2}\frac{d}{d\eta}\left(\eta^2 \sigma^{\eta}(\eta)^2 p(\eta)\right), \quad \eta \in (0, \overline{\eta}].$$

The integration constant C is zero because of the reflecting boundary. The boundary condition for the equation is the requirement that probability density is integrated to one (i.e. $\int_{\underline{\eta}}^{\overline{\eta}} p(\eta)\, d\eta = 1$).

A.2 Solution Algorithm

The full solution of the model consists of two parts: first, the laws of motion of state variables, and, second, the endogenous variables as functions of state variables, for example, $q_t^T = q^T(\eta_t, t)$. The Markov equilibrium has four state variable: time, η_t, K_t^I, and K_t^T. As shown in the main text, time has an exogenous and autonomous law of motion, while the last three variables' laws of motions depend on the endogenous variables that are functions of these state variables. To simplify the notation, I suppress the time subscripts in the following.

First, I construct a mapping from η, t, $q^B(\eta, t)$, $q^T(\eta, t)$, $\partial q^B(\eta, t)/\partial \eta$, $\partial q^T(\eta, t)/\partial \eta$, $\partial q^B(\eta, t)/\partial t$ and $\partial q^T(\eta, t)/\partial t$ to the second-order derivatives with respect to η, $\partial^2 q^B(\eta, t)/\partial \eta^2$ and $\partial^2 q^T(\eta, t)/\partial \eta^2$, i.e., a system of second-order partial differential equations for $q^B(\eta, t)$ and $q^T(\eta, t)$. Once I solved these two functions, the rest of the price variables and K^T-scaled aggregate quantities can be solved as they will be shown to depend only on η, t, the levels and derivatives of $q^B(\eta, t)$ and $q^T(\eta, t)$. This confirms the statement in Proposition 3 that these variables are bivariate functions of η and t. After solving the price variables and K^T-scaled aggregate quantities, the laws of motion of K_t^I, K_t^T, and η_t are given by (25), (26), and (28), respectively.

Constructing PDEs for $q^B(\eta, t)$ and $q^T(\eta, t)$. Inputs are η, t (and thus, $\kappa^I(t)$ and $\beta(t)$), the levels and first derivatives of $q^B(\eta, t)$ and $q^T(\eta, t)$. Outputs are $\partial^2 q^B(\eta, t)/\partial \eta^2$ and $\partial^2 q^T(\eta, t)/\partial \eta^2$. It is convenient to define the following notations of elasticities:

$$\epsilon^T \equiv \frac{\partial q^T/q^T}{\partial \eta/\eta} \text{ and } \epsilon^B \equiv \frac{\partial q^B/q^B}{\partial \eta/\eta}\,.$$

Step 1: Calculate σ^η, σ^T, γ^B, x^B, and r.

Proposition 1 solves the optimal intangible share of investment, θ, and the marginal value of liquidity, π, that entrepreneurs assign to deposits, as functions of q^I (constant, see (2)), q^T, and $\kappa^I(t)$ and the parameters. Given $F(\theta_t) = \frac{\phi}{2}\theta^2$, (A.9) implies a quadratic equation for θ when π is is substituted out using (A.10). Once θ is solved, (A.10) solves π. In the following, I will discuss different cases, but the values of these variables will not change across different cases.

First, consider the case where entrepreneurs do not hold any deposits. With $M^E = 0$, the deposit-market clearing condition (24) is

$$\left(x^B - 1\right)\eta = M^H/K^T = \alpha\left(\frac{\rho - r}{\beta(t)}\right)^{-\frac{1}{\xi}}, \tag{A.24}$$

where the second equation is obtained from households' aggregate deposit demand (22). Within this case, there are two scenarios. First, bankers hold all tangible capital, so $q^T K^T = x^B N^B$, i.e.,

$$x^B = q^T/\eta\,, \tag{A.25}$$

and then from (A.24), r is calculated. If $r > \rho - \lambda\pi$, then entrepreneurs prefer to hold deposits, and I switch a different case where entrepreneurs hold deposits (to be discussed below). If $r \leq \rho - \lambda\pi$, I proceed to calculate σ^η, σ^T, and γ^B. Jointly using $\sigma^\eta = x^B\left(\sigma^T + \sigma\right) - \sigma$ from (A.6) and $\sigma^T = \epsilon^T\sigma^\eta$ from Itô's lemma, I obtain σ^η and σ^T. Using Itô's lemma again, I obtain $\gamma^B = -\epsilon^B\sigma^\eta$. Now the bankers' discount rate is given by $r + \gamma^B\left(\sigma^T + \sigma\right)$. If $\rho < r + \gamma^B\left(\sigma^T + \sigma\right)$, then the rest of the economy has a lower discount rate than bankers, so bankers cannot hold all tangible capital, and I switch to the scenario where entrepreneurs do not hold deposits and bankers do not hold all tangible capital (to be discussed in the next paragraph). If $\rho > r + \gamma^B\left(\sigma^T + \sigma\right)$, this scenario is internally consistent and I proceed to Step 2.

Now consider the scenario where entrepreneurs do not hold deposits and bankers do not hold all tangible capital. In this scenario, x^B is calculated as follows. Given that the rest of the economy holds tangible capital, the expected return on tangible capital is ρ, and from Proposition 2,

$$\rho = r + \gamma^B \left(\sigma^T + \sigma\right) . \tag{A.26}$$

By Itô's lemma,

$$\sigma^T = \epsilon^T \sigma^\eta \text{ and } \gamma^B = -\epsilon^B \sigma^\eta . \tag{A.27}$$

I substitute these expressions of σ^T and γ^B into (A.26) to obtain a quadratic equation of σ^η, and the roots are

$$\sigma^\eta = \frac{-\epsilon^B \sigma \pm \sqrt{\left(\epsilon^B \sigma\right)^2 - 4\epsilon^B \epsilon^T \left(\rho - r\right)}}{2\epsilon^B \epsilon^T} .$$

I study a Markov equilibrium where $\epsilon^B \leq 0$ (i.e., bankers' marginal value of wealth declines in η_t), $\epsilon^T \geq 0$ (i.e., the value of tangible capital increases in η_t), and $\rho - r \geq 0$, so the only positive root is

$$\sigma^\eta = \frac{-\epsilon^B \sigma - \sqrt{\left(\epsilon^B \sigma\right)^2 - 4\epsilon^B \epsilon^T \left(\rho - r\right)}}{2\epsilon^B \epsilon^T} . \tag{A.28}$$

A positive root is selected because bankers have levered positions in tangible capital, so the shock impact is greater on N^B than on K^T, and thus, η responds positively to the Brownian shock. Using $\sigma^\eta = x^B \left(\sigma^T + \sigma\right) - \sigma$ from (A.6), I obtain

$$x^B = \frac{\sigma^\eta + \sigma}{\sigma^\eta \epsilon^T + \sigma} . \tag{A.29}$$

Using (A.29) to substitute out x^B in (A.24), I obtain

$$\left(\frac{\sigma^\eta + \sigma}{\sigma^\eta \epsilon^T + \sigma} - 1\right) \eta = \alpha \left(\frac{\rho - r}{\beta\left(t\right)}\right)^{-\frac{1}{\xi}} . \tag{A.30}$$

Using (A.28) to substitute out σ^η on the left side of (A.30), I obtain an equation for r. Once r is solved, I use (A.28) to solve σ^η, use (A.29) to solve x^B, and use (A.27) to solve σ^T and γ^B. Proceed to Step 2.

Finally, consider the case where entrepreneurs hold deposits. From Proposition 1, the equilibrium deposit rate is given by

$$r = \rho - \lambda \pi . \tag{A.31}$$

Given r, the deposit demand of households (scaled by K^T) is given by (22), and I obtain the aggregate deposit demand, $\left(M^E + M^H\right)/K^T$. Next, consider the scenario where bankers hold all tangible capital, i.e., $x^B = q^T/\eta$. From (A.29), I solve σ^η, and from (A.27), I solve σ^T and γ^B. Now the bankers' discount rate is given by $r + \gamma^B\left(\sigma^T + \sigma\right)$. If $\rho < r + \gamma^B\left(\sigma^T + \sigma\right)$, then the rest of economy have lower discount rate than bankers, so bankers cannot hold all tangible capital and I switch to the scenario where entrepreneurs hold deposits and bankers do not hold all tangible capital. If $\rho \geq r + \gamma^B\left(\sigma^T + \sigma\right)$, this scenario is internally consistent and I proceed to Step 2.

Now consider the scenario where entrepreneurs hold deposits and bankers do not hold all tangible capital. The expected return on tangible capital is ρ, so from Proposition 2,

$$\rho = r + \gamma^B\left(\sigma^T + \sigma\right) . \tag{A.32}$$

Using (A.31) to substitute r with $\rho - \lambda\pi$, I obtain

$$\lambda\pi = \gamma^B\left(\sigma^T + \sigma\right) . \tag{A.33}$$

Using Itô's lemma, i.e., (A.27), I substitute σ^T and γ^B out with $\epsilon^T\sigma^\eta$ and $-\epsilon^B\sigma^\eta$ respectively to obtain a quadratic equation of σ^η, and the roots are

$$\sigma^\eta = \frac{-\epsilon^B\sigma \pm \sqrt{\left(\epsilon^B\sigma\right)^2 - 4\epsilon^B\epsilon^T\lambda\pi}}{2\epsilon^B\epsilon^T}.$$

I study a Markov equilibrium where $\epsilon^B \leq 0$ (i.e., bankers' marginal value of wealth declines in η_t), $\epsilon^T \geq 0$ (i.e., the value of tangible capital increases in η_t), and, as the shadow price of funding constraint on investment, $\pi \geq 0$, so the only positive root is

$$\sigma^\eta = \frac{-\epsilon^B\sigma - \sqrt{\left(\epsilon^B\sigma\right)^2 - 4\epsilon^B\epsilon^T\lambda\pi}}{2\epsilon^B\epsilon^T}. \tag{A.34}$$

Using Itô's lemma again, i.e., (A.27), I solve σ^T and γ^B. Using $\sigma^\eta = x^B\left(\sigma^T + \sigma\right) - \sigma$ from (A.6), I solve x^B. Proceed to Step 2.

Step 2: Calculating the Second-Order Derivatives

The drift and diffusion of η are given in the proof of Proposition 3. Given q^T, π, γ^B, and σ^T,

(18) solves μ^T. The following equation, obtained by Itô's lemma, solves $\frac{\partial^2 q^T}{\partial \eta^2}$:

$$\mu^T q^T = \frac{\partial q^T}{\partial t} + \frac{\partial q^T}{\partial \eta}\mu^\eta \eta + \frac{1}{2}\frac{\partial^2 q^T}{\partial \eta^2}\left(\sigma^\eta \eta\right)^2 \,. \tag{A.35}$$

According to (A.23), $\mu_t^B = \rho - r_t$, so the following equation, obtained by Itô's lemma, solves $\frac{\partial^2 q^B}{\partial \eta^2}$:

$$\mu^B q^B = \frac{\partial q^B}{\partial t} + \frac{\partial q^B}{\partial \eta}\mu^\eta \eta + \frac{1}{2}\frac{\partial^2 q^B}{\partial \eta^2}\left(\sigma^\eta \eta\right)^2 \,. \tag{A.36}$$

Boundary conditions for PDEs for $q^B\left(\eta, t\right)$ and $q^T\left(\eta, t\right)$. Tangible capital has constant cash flow, one unit of goods per unit of time, so what causes its price to vary is the discount-rate changes. Close to $\eta = 0$, an absorbing state, the banking sector is extremely small, so the discount rate (expected return) is fixed at ρ to induce the rest of economy to own tangible capital and clear the market. Thus, q^T should not vary as η approaches zero:

$$\lim_{\eta \to 0} \frac{\partial q^T(\eta, t)}{\partial \eta} = 0 \,. \tag{A.37}$$

Moreover, when bankers are extremely undercapitalized, their marginal value of wealth approaches infinity,

$$\lim_{\eta \to 0} q^B\left(\eta, t\right) = +\infty \,, \tag{A.38}$$

because q^B is the present value of one unit of equity, and it increases when the banking sector shrinks, widening the return spread between holding tangible capital and issuing deposits.

The upper boundary of η, $\overline{\eta}$, where bankers consume, is a reflecting boundary, so to rule out arbitrage (i.e., perfectly predictable variation of asset price),

$$\frac{\partial q^T(\overline{\eta}, t)}{\partial \eta} = 0 \,. \tag{A.39}$$

For consumption to be optimal at $\overline{\eta}$, bankers' marginal value of wealth, q^B, satisfies the value-matching condition,

$$q^B\left(\overline{\eta}, t\right) = 1 \,, \tag{A.40}$$

and the smooth-pasting condition

$$\frac{\partial q^B(\overline{\eta}, t)}{\partial \eta} = 0\,. \tag{A.41}$$

Finally, it is assumed that the linear trends of κ^I and β end at $t = \bar{t}$. When solving the model, I map $\bar{t}$ to 2010 in the data. When t reaches $\bar{t}$ and κ^I and β no longer vary, the economy converges to a time-homogeneous Markov equilibrium where the price variables and K^T-scaled quantities are functions of η_t only. Therefore, the boundary condition on the time dimension for $q^B(\eta, t)$ and $q^T(\eta, t)$ is the convergence to $\overline{q}^B(\eta)$ and $\overline{q}^T(\eta)$ of the time-homogeneous Markov equilibrium.

The functions, $\overline{q}^B(\eta)$ and $\overline{q}^T(\eta)$, of the time-homogeneous Markov equilibrium at $\bar{t}$ can be solved by a system of ordinary differential equations (ODEs) that are constructed following the same aforementioned procedure, except that at the very last step, by Itô's lemma, the second-order derivatives are solved by

$$\mu^B \overline{q}^B = \frac{d\overline{q}^B}{d\eta}\mu^\eta \eta + \frac{1}{2}\frac{d^2\overline{q}^B}{d\eta^2}\left(\sigma^\eta \eta\right)^2\,. \tag{A.42}$$

and

$$\mu^T \overline{q}^T = \frac{d\overline{q}^T}{d\eta}\mu^\eta \eta + \frac{1}{2}\frac{d^2\overline{q}^T}{d\eta^2}\left(\sigma^\eta \eta\right)^2\,. \tag{A.43}$$

The ODEs have the following conditions in analogy to (A.37) to (A.41):

As η approaches zero: (1) $\lim_{\eta \to 0} \frac{d\overline{q}^T(\eta)}{d\eta} = 0$; (2) $\lim_{\eta \to 0} \overline{q}^B(\eta) = +\infty$.

At the upper reflecting boundary, $\overline{\eta}$: (3) $\frac{d\overline{q}^T(\eta)}{d\eta} = 0$; (4) $\overline{q}^B(\overline{\eta}) = 1$; (5) $\frac{d\overline{q}^B(\eta)}{d\eta} = 0$.

Prices and K^T-scaled quantities in Proposition 3. The solution procedure has solved q_t^T, r_t, x_t^B, θ_t as bivariate functions of η_t and t because they only depend on η_t, t, q_t^T, ϵ^T, and ϵ^B. From (22), households' aggregate deposit holdings, M_t^H/K_t^T, is $\alpha\left(\frac{\rho - r_t}{\beta(t)}\right)^{-\frac{1}{\xi}}$. Entrepreneurs' aggregate deposit holdings (scaled by K_t^T), M_t^E/K_t^T, is given by

$$\frac{M_t^E}{K_t^T} = \frac{\left(x_t^B - 1\right)N_t^B - M_t^H}{K_t^T} = \left(x_t^B - 1\right)\eta_t - \alpha\left(\frac{\rho - r_t}{\beta(t)}\right)^{-\frac{1}{\xi}}\,. \tag{A.44}$$

The aggregate intangible investment (scaled by K_t^T) is $\theta_t M_t^E/K_t^T$ and the aggregate tangible investment (scaled by K_t^T) is $(1-\theta_t)\,M_t^E/K_t^T$. Now it has been proven that the price variables and K_t^T-scaled aggregate quantities listed in Proposition 3 are bivariate functions of η_t and t.

The hierarchy of state variables. Time has its autonomous law of motion. The law of motion of η_t in the proof of Proposition 3 only depends on η_t and time t. The law of motion of K_t^T (i.e., (26) in the main text) only depends on η_t, time t, and K_t^T: using (A.7), I obtain

$$\frac{dK_t^T}{K_t^T} = \left[\left(\frac{\left(x_t^B - 1\right)\eta_t - \alpha\left(\frac{\rho - r_t}{\beta(t)}\right)^{-\frac{1}{\xi}}}{1 - q_t^T \kappa^T \left(1 - \theta_t\right)}\right)\kappa^T \left(1 - \theta_t\right)\lambda - \delta\right] dt + \sigma dZ_t\,, \tag{A.45}$$

where the drift is solved in the proof of Proposition 3 and the endogenous variables on the right side are bivariate functions of η_t and t. Finally, rewriting (25) from the main text, I obtain the law of motion of K_t^I, which depends on all four state variables,

$$\begin{aligned}\frac{dK_t^I}{K_t^I} &= \frac{K_t^T}{K_t^I}\left[\left(x_t^B - 1\right)\frac{N_t^B}{K_t^T} - \frac{M_t^H}{K_t^T}\right]\left(\frac{1}{1 - q_t^T \kappa^T \left(1 - \theta_t\right)}\right)\theta_t \kappa^I\left(t\right)\lambda dt - \left(\delta dt - \sigma dZ_t\right) \\ &= \left[\frac{K_t^T}{K_t^I}\left(\frac{\left(x_t^B - 1\right)\eta_t - \alpha\left(\frac{\rho - r_t}{\beta(t)}\right)^{-\frac{1}{\xi}}}{1 - q_t^T \kappa^T \left(1 - \theta_t\right)}\right)\kappa^I\left(t\right)\theta_t \lambda - \delta\right] dt + \sigma dZ_t\,. \end{aligned} \tag{A.46}$$

Solving the model with tradable intangibles. Allowing χ fraction of intangible capital to be tradable among entrepreneurs and households only change the optimality conditions for θ and i. The rest of solution algorithm is the same as that of the main model. The F.O.C. for θ_t is

$$q^I \kappa^I \left(1 + \chi\pi\right) - q^T \kappa^T \left(1 + \pi\right) - F'\left(\theta\right) = 0\,. \tag{A.47}$$

In contrast to (A.9), the marginal benefit of creating intangible capital has an additional component $q^I \kappa^I \chi \pi$ from relaxing the financial constraint. The F.O.C. for i is

$$\pi = \left\{\left[q^I \kappa^I \theta + q^T \kappa^T \left(1 - \theta\right) - F\left(\theta\right)\right] - 1\right\}\left(\frac{1}{1 - q^T \kappa^T \left(1 - \theta\right) - \chi q^I \kappa^I \theta}\right) \tag{A.48}$$

Given that $F\left(\theta\right) = \frac{\phi}{2}\theta^2$, (A.47) implies a quadratic equation for θ when π is substituted out by (A.48). Once θ is solved, (A.48) solves π.

B Risk Aversion and Finite EIS

In this section, I extend the model to incorporate risk-averse preferences and finite EIS (elasticity of intertemporal substitution) showing that the solution of the extended model can be achieved by making two modifications to the solution of the model in the main text. First, the functions of endogenous variables, such as $q^T(\eta_t, t)$, can be derived by the procedure in A.2 with the time discount rate ρ replaced by a function $\rho(\eta_t, t)$. The functional form of $\rho(\eta_t, t)$ depends on the risk-averse utility functions in the extended model.

Second, the laws of motion of state variables in the solution of the main model become the laws of motion under the risk-neutral measure in the extended model with risk aversion. To characterize the dynamics under the physical measure (probability measure of data generating process), a change of measure shall be performed using Girsanov's Theorem. The Markov equilibrium has four state variable: time, η_t, K_t^I, and K_t^T. A change of measure affects the laws of motion of the last three by adjusting their drifts. The adjustments depend on (1) the state variables' loadings of the aggregate shock (i.e., their diffusions) and (2) the consumers' price of risk implied by the risk-averse utility functions and the equilibrium process of aggregate consumption. This method of extending risk-neutral models to incorporate risk-averse preferences can be applied to other macro-finance models with risk-neutral preferences, for example, Brunnermeier and Sannikov (2014).

After establishing these results, I characterize the conditions under which the equilibrium of the main (risk-neutral) model serves as an adequate approximation to the equilibrium of the extended model. The model solution has two parts, first, the endogenous variables as functions of state variables, for example, $q_t^T = q^T(\eta_t, t)$, and, second, the laws of motion of state variables. I show that the first part of the solution is an adequate approximation if the expected growth rate of consumption is stable, which holds in the model and is consistent with the theories and evidence on long-run consumption risk (Bansal and Yaron, 2004; Hansen, Heaton, and Li, 2008; Schorfheide, Song, and Yaron, 2018). I also show that ignoring risk aversion has little impact on the laws of motion of state variables under the standard risk aversion parameter in the asset pricing literature.

Incorporating preferences with risk aversion and finite EIS. Next, I introduce risk-averse preferences to the household sector. Entrepreneurs and bankers are reinterpreted as firms that maximize the present value of payouts to household shareholders, so households are the ultimate consumers in this economy. It is assumed that households face a complete market. For households, the relevant shock is the aggregate Brownian shock dZ_t. The market is complete if households can trade tangible capital and risk-free assets.[68] No arbitrage and complete markets imply the existence of a unique stochastic discount factor (SDF), denoted by Λ_t, which, in equilibrium, is determined by the households' marginal value of wealth (Duffie, 2001). The following analysis takes the equilibrium process of Λ_t as given,

$$\frac{d\Lambda_t}{\Lambda_t} = -\rho_t dt - \gamma_t^H d\widehat{Z}_t \,, \tag{B.1}$$

where ρ_t is the households' time discount rate in equilibrium and γ_t^H is the households' price of risk. The endogenous discount rate ρ_t replaces the parameter ρ in the main text. After analyzing the entrepreneurs' and banks' problems, I specify the households' preferences and solve Λ_t. The stochastic process $\widehat{Z}_t$ is the cumulative aggregate shock under the physical measure.

By Girsanov's Theorem, we know the following connection between the aggregate shock to capital stock, dZ_t, under the risk-neutral measure and $d\widehat{Z}_t$, the shock under the physical measure,

$$dZ_t = d\widehat{Z}_t + \gamma_t^H dt \,. \tag{B.2}$$

The idiosyncratic Poisson shocks do not affect the change of measure because they are not priced in the SDF. Entrepreneurs' information filtration under the physical measure is generated by $\widehat{Z}_t$ and the idiosyncratic Poisson shocks that trigger investment needs. Their information filtration under the risk-neutral measure is generated by Z_t and the same idiosyncratic Poisson shocks. For bankers, idiosyncratic risks are diversified away, so the relevant information filtration is generated by Z_t under the risk-neutral measure and $\widehat{Z}_t$ under the physical measure.

Girsanov's Theorem implies a connection between objective functions under the physical and risk-neutral measures: a representative entrepreneur i maximize

$$\mathbb{E}\left[\int_{t=0}^{\infty} e^{-\rho_t t} dc_{i,t}^E\right] = \widehat{\mathbb{E}}\left[\int_0^{\infty} \frac{\Lambda_t}{\Lambda_0} dc_{i,t}^E\right] \,, \tag{B.3}$$

and

$$\mathbb{E}\left[\int_{t=0}^{\infty} e^{-\rho_t t} dc_{i,t}^B\right] = \widehat{\mathbb{E}}\left[\int_0^{\infty} \frac{\Lambda_t}{\Lambda_0} dc_{i,t}^B\right] \,, \tag{B.4}$$

where $\widehat{\mathbb{E}}\left[\cdot\right]$ is the rational-expectation operator under the physical measure, distinguished from

[68] For risk-free assets, it is assumed that households can lend to and borrow from each other (in equilibrium, at the risk-free rate ρ_t), i.e., the negative drift of SDF in (B.1), and unlike deposits, such risk-free assets do not bring deposit-in-utility for households or relax entrepreneurs' liquidity constraints. They may represent personal IOUs.

$\mathbb{E}\left[\cdot\right]$, the rational-expectation operator under the risk-neutral measure, and, following the notations in Appendix A, $c^E_{i,t}$ and $c^B_{j,t}$ denotes the cumulative payout of non-financial firms and banks.

The full solution of the model consists of two parts: first, the endogenous variables as functions of state variables, for example, $q^T_t = q^T\left(\eta_t, t\right)$, and, second, the laws of motion of state variables. The next proposition states the connection between an extended model with power utility and the model in the main text. The proof is at the end of this section. This method of incorporating risk-averse preferences into an originally risk-neutral model applies to any utility function. I use power (CRRA) utility as an example.

Proposition B.1 *Households have power utility over consumption and deposit-in-utility introduced in (19) and maximize*

$$\mathbb{E}\left[\int_{t=0}^{\infty} e^{-\delta_H t}\left(\frac{\left(c^H_t\right)^{1-\underline{\gamma}_H}}{1-\underline{\gamma}_H}dt + \beta_t\frac{\left(m^H_t/w^H_t\right)^{1-\xi}}{1-\xi}\right)\right], \tag{B.5}$$

where δ_H and $\underline{\gamma}_H$ are the parameters for discount factor and relative risk aversion, respectively, and c^H_t denote the rate of consumption (instead of cumulative consumption).

The solutions of endogenous variables as functions of state variables can be obtained by the procedure in A.2 with the parameter ρ replaced by the following function:

$$\begin{aligned}\rho\left(\eta_t,t\right) = \underline{\delta}_H + \underline{\gamma}_H\mu^{KT}\left(\eta_t,t\right) + \underline{\gamma}_H\epsilon^{\widetilde{C}1}\left(\eta_t,t\right)\left[\mu^{\eta}\left(\eta_t,t\right) + \frac{1}{2}\epsilon^{\widetilde{C}2}\left(\eta_t,t\right)\sigma^{\eta}\left(\eta_t,t\right)^2 + \sigma^{\eta}\left(\eta_t,t\right)\sigma\right] \\ + \frac{1}{2}\left(\underline{\gamma}_H^2 - \underline{\gamma}_H\right)\left[\epsilon^{\widetilde{C}1}\left(\eta_t,t\right)\sigma^{\eta}\left(\eta_t,t\right) + \sigma\right]^2,\end{aligned} \tag{B.6}$$

where $\mu^{\eta}\left(\eta_t,t\right)$, $\sigma^{\eta}\left(\eta_t,t\right)$, and $\mu^{KT}\left(\eta_t,t\right)$ are given by (A.5), (A.6), and (A.7) respectively in A.1, and $\epsilon^{\widetilde{C}1}\left(\eta_t,t\right)$ is the elasticity of K^T_t-scaled aggregate consumption, $\widetilde{C}^H_t \equiv C^H_t/K^T_t$, to η_t,

$$\epsilon^{\widetilde{C}1}\left(\eta_t,t\right) \equiv \frac{\partial\widetilde{C}^H\left(\eta_t,t\right)}{\partial\eta_t}\frac{\eta_t}{\widetilde{C}^H\left(\eta_t,t\right)}, \tag{B.7}$$

and $\epsilon^{\widetilde{C}2}\left(\eta_t,t\right)$ is the elasticity of $\frac{\partial\widetilde{C}^H(\eta_t,t)}{\partial\eta_t}$ to η_t,

$$\epsilon^{\widetilde{C}2}\left(\eta_t,t\right) \equiv \frac{\partial^2\widetilde{C}^H\left(\eta_t,t\right)}{\partial\eta_t^2}\frac{\eta_t}{\left(\frac{\partial\widetilde{C}^H(\eta_t,t)}{\partial\eta_t}\right)}. \tag{B.8}$$

By Girsanov's Theorem, the laws of motion of η_t, K_t^T, and K_t^I are given by (A.4), (A.45), and (A.46) respectively with dZ_t, the Brownian shock under the risk-neutral measure, replaced by

$$d\widehat{Z}_t + \gamma^H(\eta_t, t)\, dt \tag{B.9}$$

where $d\widehat{Z}_t$ is the Brownian shock under the physical measure, and $\gamma^H(\eta_t, t)$ is given by

$$\gamma^H(\eta_t, t) = \underline{\gamma}_H \left[\epsilon^{\widetilde{C}1}(\eta_t, t)\, \sigma^\eta(\eta_t, t) + \sigma\right], \tag{B.10}$$

which is the households' price of risk in equilibrium.

Comparing risk-neutral and risk-averse models. In the comparison between the risk-neutral and risk-averse models, a key object is $\epsilon^{\widetilde{C}1}(\eta_t, t)$, the the elasticity of K_t^T-scaled aggregate consumption, $\widetilde{C}_t^H \equiv C_t^H / K_t^T$, to η_t. Given $C_t^H = \widetilde{C}_t^H K_t^T$, by Itô's lemma, the volatility of consumption growth, σ_t^C is given by

$$\sigma_t^C = \epsilon^{\widetilde{C}1}(\eta_t, t)\, \sigma^\eta(\eta_t, t) + \sigma\,. \tag{B.11}$$

The constant return-to-scale technology implies that the volatility of capital growth, σ, is the volatility of output growth. Empirically, consumption growth is less volatile in data than output growth (e.g., Blanchard and Simon, 2001). Therefore, if the preference parameters are calibrated to match consumption volatility (as typically done in the asset-pricing literature (Cochrane, 2005a)), we have

$$\epsilon^{\widetilde{C}1}(\eta_t, t) < 0\,. \tag{B.12}$$

The model solution has two parts: first, the endogenous variables as functions of state variables, for example, $q_t^T = q^T(\eta_t, t)$, and, second, the laws of motion of state variables. Therefore, according to Proposition B.1, a potential misspecification from ignoring risk aversion has two consequences. First, in the algorithm that solves the functions of endogenous variables in A.2, ρ should be replaced by $\rho(\eta_t, t)$. Second, the laws of motions of state variables are in fact risk-neutral dynamics. The dynamics under the physical measure require an adjustment of drifts by replacing dZ_t with $d\widehat{Z}_t + \gamma^H(\eta_t, t)\, dt$ (see B.2).

To analyze the impact of ignoring risk aversion on the functions of endogenous variables, I examine whether $\rho(\eta_t, t)$ can be approximated by a constant. The expression of $\rho(\eta_t, t)$ in (B.6) can be simplified with the consumption growth volatility in (B.11):

$$\rho\left(\eta_t,t\right)=\underline{\delta}_H+\underline{\gamma}_H\mu^{KT}\left(\eta_t,t\right)+\underline{\gamma}_H\epsilon^{\widetilde{C}1}\left(\eta_t,t\right)\left[\mu^{\eta}\left(\eta_t,t\right)+\frac{1}{2}\epsilon^{\widetilde{C}2}\left(\eta_t,t\right)\sigma^{\eta}\left(\eta_t,t\right)^2+\sigma^{\eta}\left(\eta_t,t\right)\sigma\right]$$
$$+\frac{1}{2}\left(\underline{\gamma}_H^2-\underline{\gamma}_H\right)\left(\sigma_t^C\right)^2 . \qquad \text{(B.13)}$$

Let $O\left(\sigma^2\right)$ denote the terms that involve the squared volatilities of growth rates (which all contain σ^2). Because volatilities and expectations of growth rates are of similar magnitudes in this model where aggregate quantities are driven by geometric Brownian motions, these volatility-squared terms tend to be small. Therefore, I use the following expression

$$\rho\left(\eta_t,t\right)=\underline{\delta}_H+\underline{\gamma}_H\mu^{KT}\left(\eta_t,t\right)+\underline{\gamma}_H\epsilon^{\widetilde{C}1}\left(\eta_t,t\right)\mu^{\eta}\left(\eta_t,t\right)+O\left(\sigma^2\right) . \qquad \text{(B.14)}$$

The first and second terms are standard in consumption-based asset pricing models. Given the constant return-to-scale technology, the capital growth rate, $\mu^{KT}\left(\eta_t,t\right)$, is the growth rate of aggregate output. In an endowment economy, the aggregate output (agents' endowments) is equal to the aggregate consumption in equilibrium, so, in these consumption-based models, the equilibrium risk-free rate only contains the first two terms on the right side of (B.14) (e.g., Lucas, 1978).

The third term is unique to this model. The drift of η_t, $\mu^{\eta}\left(\eta_t,t\right)$, is the expected growth rate of the ratio of bankers' wealth to tangible capital value. Because bankers hold a leveraged position in tangible capital, and the expected return on tangible capital is positive, bankers' wealth grows faster than tangible capital in expectation, and $\mu^{\eta}\left(\eta_t,t\right)$ is positive. Given that $\epsilon^{\widetilde{C}1}\left(\eta_t,t\right)<0$ (see (B.12)), the third term on the right side of (B.14) is negative.

The economy becomes more intangible-intensive over time, and firms hold more cash, which leads to an upward trend in investment and output growth. The counteracting force is also getting stronger. As the economy becomes more intangible-intensive, the liquidity premium on deposits, ρ_t-r_t, becomes larger, which increases bankers' return on wealth, and thus, pushes up $\mu^{\eta}\left(\eta_t,t\right)$.

Assuming $\rho\left(\eta_t,t\right)$ is a constant in the main model is equivalent to assuming that these two forces, $\underline{\gamma}_H\mu^{KT}\left(\eta_t,t\right)>0$ and $\underline{\gamma}_H\epsilon^{\widetilde{C}1}\left(\eta_t,t\right)\mu^{\eta}\left(\eta_t,t\right)<0$, cancel each other out. The first force is from output growth. The second is from the fact that consumption is less volatile than output growth and, due to leverage, bankers' expected return on wealth is greater than tangible capital. Empirically, this assumption means that the *expected* consumption growth rate is stable. A stable consumption growth rate is consistent with the findings of highly persistent expected consumption growth in the literature on long-run risk (Bansal and Yaron, 2004; Hansen, Heaton, and Li, 2008; Schorfheide, Song, and Yaron, 2018). approximating $\rho\left(\eta_t, t\right)$ by a constant does not cause significant misspecification. When this approximation is adequate, the functions of endogenous variables, for example, $q_t^T = q^T\left(\eta_t, t\right)$, that are solved in A.2 and presented in Section 4.2, are adequate approximations to the functions from the risk-averse model.

Next, I examine the impact of ignoring risk-aversion on the laws of motion of state variables. According to Proposition B.1, the dynamics of capital stocks given by (A.45) and (A.46) should be adjusted by replacing the Brownian shock under the risk-neutral measure, dZ_t, by the Brownian shock under the physical measure (i.e., the real shock that drives the data generating processes), $d\widehat{Z}_t$, plus a drift adjustment $\gamma^H\left(\eta_t, t\right) dt$:

$$\frac{dK_t^T}{K_t^T} = \left[\left(\frac{\left(x_t^B - 1\right)\eta_t - \alpha\left(\frac{\rho_t - r_t}{\beta(t)}\right)^{-\frac{1}{\xi}}}{1 - q_t^T \kappa^T\left(1-\theta_t\right)}\right)\kappa^T\left(1-\theta_t\right)\lambda - \delta\right] dt + \underbrace{\sigma\gamma^H\left(\eta_t, t\right) dt}_{\textit{risk adjustment}} + \sigma d\widehat{Z}_t\,, \tag{B.15}$$

and

$$\frac{dK_t^I}{K_t^I} = \left[\frac{K_t^T}{K_t^I}\left(\frac{\left(x_t^B - 1\right)\eta_t - \alpha\left(\frac{\rho_t - r_t}{\beta(t)}\right)^{-\frac{1}{\xi}}}{1 - q_t^T \kappa^T\left(1-\theta_t\right)}\right)\kappa^I\left(t\right)\theta_t\lambda - \delta\right] dt + \underbrace{\sigma\gamma^H\left(\eta_t, t\right) dt}_{\textit{risk adjustment}} + \sigma dZ_t\,. \tag{B.16}$$

Consider a relative risk aversion $\underline{\gamma}_H = 5$, which is a common value in the asset pricing literature (Cochrane, 2005a). Given that $\epsilon^{\widetilde{C}1}\left(\eta_t, t\right) < 0$ and $\sigma^\eta\left(\eta_t, t\right) > 0$ (see (A.6)), I obtain the following upper bound on the households' price of risk: from (B.34),

$$\gamma^H\left(\eta_t, t\right) = \underline{\gamma}_H\left[\epsilon^{\widetilde{C}1}\left(\eta_t, t\right)\sigma^\eta\left(\eta_t, t\right) + \sigma\right] \leq \underline{\gamma}_H\sigma = 0.1\,, \tag{B.17}$$

where the last equation substitutes in the value of $\underline{\gamma}_H$ and σ. Given that $\sigma = 0.02$ and $\gamma^H\left(\eta_t, t\right) < 0.1$, the risk adjustment term is bounded above by 0.002. Therefore, ignoring risk aversion understates the expected growth rate of capital (and output), and the wedge is bounded above by 0.2%. The physical-measure dynamics feature higher growth rates than those of the risk-neutral dynamics because, when changing from the physical measure to the risk-neutral measure, probability mass shifts towards the relatively worse states of the world, i.e., the risk-averse attitude is reflected by probability re-weighting. A similar calculation can be applied to the law of motion of η_t. The risk adjustment increases the drift of η_t, and, averaging over time t and η_t on the simulated paths, such an increase is less than 6% of the drift, (i.e., $< 0.06 \times \mu_t^{\eta}$).

In the main text, I report the model's solutions in two ways: (1) the values of endogenous variables at different points in time, averaged over η_t (e.g., Section 4.2) and (2) endogenous variables as functions of η_t (e.g., Section 4.3). The impact of ignoring risk aversion on the laws of motion of state variable only affects (1), and (2) depends on whether replacing $\rho(\eta_t, t)$ with a constant ρ is an adequate approximation, as previously discussed.

This concludes the discussion on the consequences of model misspecification from ignoring risk aversion. Next, I derive the equations in Proposition B.1.

Proof of Proposition B.1. First, I solve the entrepreneurs' problem and the bankers' problem under the risk-neutral measure, taking as given the stochastic discount factor (SDF). After specifying the households'/consumers' risk-averse utility function, I solve the SDF and perform the change of measure to obtain the physical-measure dynamics of the extended model. This method of solving models under the risk-neutral measure and then analyzing the physical-measure dynamics by applying Girsanov's Theorem is often used in settings of complete markets (Duffie, 2001).

The entrepreneurs' investment problem stays intact as it is a static problem happening only at idiosyncratic Poisson times. Therefore, the Lagrange function defined by (11) still summarizes the investment problem, and the marginal value of liquidity for the investment projects, π_t, is given by (13). Because the time discount rate changes from ρ to ρ_t, (15) in Proposition 1 is now

$$r_t = \rho_t - \lambda \pi_t \,. \tag{B.18}$$

The rest of Proposition 1 hold.

Given the homogeneity property of the bankers' problem, their value function is still $q_t^B n_t^B$, where the marginal value of equity, $q_t^B = q^B(\eta_t, t)$, has the law of motion (16) under *the risk-neutral measure*. Proposition 2 can still be used to characterize the valuation of tangible capital and the bankers' required expected return on tangible capital holdings under the *risk-neutral* measure. Note that if bankers can also access complete markets as households can, their marginal value of wealth, q_t^B, will be pinned to one, and their price of risk, γ_t^B, to zero. Being able to freely trade the aggregate shock with households is equivalent to being able to freely raise equity from households

(Di Tella, 2017). Therefore, it is assumed that bankers cannot hedge the aggregate shock.[69]

Bankers' required expected return under the risk-neutral measure is (17) in Proposition 2. Under the physical measure, by Girsanov's Theorem, it becomes

$$\widehat{\mathbb{E}}_t\left[dr_t^T\right] = r_t + \gamma_t^B\left(\sigma_t^T + \sigma\right) + \gamma_t^H\left(\sigma_t^T + \sigma\right) . \tag{B.19}$$

Under the physical measure, banks require risk compensations not only due to the equity issuance constraint, $\gamma_t^B\left(\sigma_t^T + \sigma\right)$, but also on behalf of the household shareholders, $\gamma_t^H\left(\sigma_t^T + \sigma\right)$.

The valuation equation (18) for tangible capital in Proposition 2 still holds. The derivation in Appendix A applies under the risk-neutral measure. Equation (18) can also be derived under the physical measure but the law of motion of q_t^T and the stochastic depreciation of capital holdings have to be adjusted by the change of measure. Under the risk-neutral measure:

$$\frac{dq_t^T}{q_t^T} = \mu_t^T dt + \sigma_t^T dZ_t\,, \tag{B.20}$$

and, given (B.2), under the physical measure

$$\frac{dq_t^T}{q_t^T} = \left(\mu_t^T + \gamma_t^H\sigma_t^T\right)dt + \sigma_t^T d\widehat{Z}_t\,, \tag{B.21}$$

where the price of risk γ_t^H is multiplied by the quantity of risk σ_t^T. When moving from (B.21) to (B.20), the drift is adjusted downward, reflecting a risk adjustment via the shift of probability mass towards relatively worse states of the model. Risk aversion is reflected in the adjustment of the probability mass. The stochastic depreciation rate of capital under the physical measure is

$$\left(\delta - \gamma_t^H\sigma\right) + \sigma d\widehat{Z}_t\,. \tag{B.22}$$

The expected depreciation rate is adjusted upward when moving from the physical measure, $\delta -$

[69]Imperfect hedging can be easily incorporated. For example, bankers can only hedge a fraction χ^B of aggregate risk due to agency friction and the need to keep "skin in the gamme" (He and Krishnamurthy, 2013). Note that given that hedging is free and bankers are effectively risk averse, bankers will hedge as much as they can. Then bankers' risk exposure for one dollar of holdings of tangible capital is $\left(1-\chi^B\right)\left(\sigma_t^T+\sigma\right)$ in equilibrium, i.e., scaled down by χ^B fraction. Bankers' required expected return under the risk-neutral measure becomes $r_t+\gamma_t^B\left(1-\chi^B\right)\left(\sigma_t^T+\sigma\right)$. After the scaling, the same solution procedure still applies. Because the scaling reduces bankers' discount rate and increase the value of tangible capital and entrepreneurs' leverage on liquidity holdings, it amplifies the feedback mechanism.

$\gamma_t^H \sigma$, to the risk-neutral measure, δ, as the probability mass is shifted towards relatively worse states of the world to reflect risk aversion encoded in the SDF. The expected return of tangible capital holdings consists of the dividend yield, $1/q_t^T$, the expected price appreciation, $\mu_t^T + \gamma_t^H \sigma_t^T$, the expected capital depreciation, $\left(\delta - \gamma_t^H \sigma\right) + \lambda$ (counting both the normal-time depreciation and idiosyncratic Poisson destruction), and the quadratic covariation $\sigma_t^T \sigma$ from Itô's calculus, which does not change due to the volatility-invariance property of change of measure Duffie (2001). In equilibrium, the expected return is equal to bankers' required expected return in (B.19):

$$r_t + \gamma_t^B \left(\sigma_t^T + \sigma\right) + \gamma_t^H \left(\sigma_t^T + \sigma\right) = \frac{1}{q_t^T} + \left(\mu_t^T + \gamma_t^H \sigma_t^T\right) - \left[\left(\delta - \gamma_t^H \sigma\right) + \lambda\right] + \sigma_t^T \sigma \,.$$

Note that $\gamma_t^H \left(\sigma_t^T + \sigma\right)$ shows up on both sides. Rearranging the equation, we obtain (18).

For any stochastic process, its dynamics under the risk-neutral measure can be adjusted to obtain the dynamics under the physical measure. For instance, under the risk-neutral measure,

$$\frac{dq_t^B}{q_t^B} = \mu_t^B dt - \gamma_t^B dZ_t \,, \tag{B.23}$$

so, (B.2) implies that the law of motion of q_t^B under the physical measure is given by

$$\frac{dq_t^B}{q_t^B} = \left(\mu_t^B - \gamma_t^B \gamma_t^H\right) dt - \gamma_t^B d\widehat{Z}_t \,, \tag{B.24}$$

where the diffusion stays the same (i.e., the standard diffusion-invariance result) and the drift of q_t^B is "risk-adjusted". Note that q_t^B is high in the relatively worse states of the world where banks are undercapitalized. The expected appreciation of q_t^B is adjusted upward when moving from (B.24) to (B.23) because, when changing from the physical measure to risk-neutral measure, more probability mass is shifted towards the relatively worse states of the world.

Given the function $\rho\left(\eta_t, t\right)$, the procedure in A.2 can be used to solve all the variables listed in Proposition 3, and then, the laws of motion of η_t, K_t^T, and K_t^I can be derived. These laws of motion are under the risk-neutral measure, so a change of measure needs to be performed to obtain the physical-measure laws of motion. As I have shown for q_t^T and q_t^B, change of measure simply entails substituting out the Brownian shock under the risk-neutral measure, dZ_t, using (B.2).

Using the procedure in A.2 to solve the model's dynamics under the risk-neutral measure only requires the function $\rho\left(\eta_t, t\right)$. It does not require the households' utility function. To perform the change of measure, I need to have the price of risk, γ_t^H, as a function of the state variables.

Next, I solve the SDF, linking ρ_t and γ_t^H to households' consumption (and wealth) dynamics. Specifically, I confirm that ρ_t only depends on η_t and time t, i.e., $\rho_t = \rho(\eta_t, t)$, and solve the functional form. I also solve the households' price of risk, γ_t^H, as a function of these state variables.

In the following, I consider the standard time-separable power utility as an example. In this case, the stochastic discount factor is the time-discounted marginal utility of consumption (Cochrane, 2005b):

$$\Lambda_t = e^{-\delta_H t} \left(c_t^H\right)^{-\underline{\gamma}_H} \,. \tag{B.25}$$

In equilibrium, given that there is a unit mass of households, individual consumption is equal to the aggregate consumption, C_t^H. Denote the equilibrium law of motion of aggregate consumption under the physical measure by

$$\frac{dC_t^H}{C_t^H} = \mu_t^C dt + \sigma_t^C d\widehat{Z}_t \,. \tag{B.26}$$

By Itô's lemma, the law of motion of the SDF, Λ_t, is given by

$$\frac{d\Lambda_t}{\Lambda_t} = -\left[\underline{\delta}_H + \underline{\gamma}_H \mu_t^C - \frac{1}{2}\underline{\gamma}_H \left(\underline{\gamma}_H + 1\right)\left(\sigma_t^C\right)^2\right] dt - \underline{\gamma}_H \sigma_t^C d\widehat{Z}_t \,. \tag{B.27}$$

To solve μ_t^C and σ_t^C, consider the goods market-clearing condition:

$$C_t^H dt + \frac{M_t^E}{1 - q_t^T \kappa^T (1-\theta_t)} \lambda dt = (1+\alpha) K_t^T dt \,. \tag{B.28}$$

The left side is the sum of households' consumption and the goods invested by the λdt measure of entrepreneurs who are hit by the Poisson shock. The right side is the goods produced by tangible capital and labor. For simplicity, the goods produced by intangibles are assumed to be consumed directly by the entrepreneurs, who run the firms, as compensation for their human capital (Hart and Moore, 1994; Bolton, Wang, and Yang, 2019). Adding intangibles' output to (B.29) expands the dimension of state variables in ρ_t from two (i.e., η_t and t) to four, because both K_t^T and K_t^I show up in (B.29), and, given their distinct laws of motion, they have to be tracked separately. Dividing both sides of (B.29) by $K_t^T dt$ and rearranging it, we have

$$\widetilde{C}_t^H = 1 + \alpha - \frac{\lambda \widetilde{M}_t^E}{1 - q_t^T \kappa^T (1-\theta_t)} \,, \tag{B.29}$$

where, following the notations in the main text, I denote K_t^T-scaled values by " $\widetilde{\cdot}$ ".

The procedure in A.2 solves the endogenous variables on the right side of (B.29) as functions of η_t and time t. Therefore, K_t^T-scaled aggregate consumption,

$$\widetilde{C}_t^H = \widetilde{C}^H(\eta_t, t) \ , \tag{B.30}$$

is a known function of η_t and t. so I can obtain $\epsilon^{\widetilde{C}1}(\eta_t, t)$ and $\epsilon^{\widetilde{C}2}(\eta_t, t)$. Note that under *the risk-neutral measure*, by Itô's lemma, I obtain

$$\begin{aligned}
\frac{dC_t^H}{C_t^H} &= \frac{d\widetilde{C}^H(\eta_t, t)}{\widetilde{C}^H(\eta_t, t)} + \frac{dK_t^T}{K_t^T} + \epsilon^{\widetilde{C}}(\eta_t, t)\,\sigma^\eta(\eta_t, t)\,\sigma dt\,, && \text{(B.31)}\\
&= \left\{\epsilon^{\widetilde{C}1}(\eta_t, t)\left[\mu^\eta(\eta_t, t) + \frac{1}{2}\epsilon^{\widetilde{C}2}(\eta_t, t)\,\sigma^\eta(\eta_t, t)^2 + \sigma^\eta(\eta_t, t)\,\sigma\right] + \mu^{KT}(\eta_t, t)\right\} dt\\
&+ \left[\epsilon^{\widetilde{C}1}(\eta_t, t)\,\sigma^\eta(\eta_t, t) + \sigma\right] dZ_t && \text{(B.32)}
\end{aligned}$$

where the risk-neutral measure dynamics, $\mu^\eta(\eta_t, t)$, $\sigma^\eta(\eta_t, t)$, and $\mu^{KT}(\eta_t, t)$ are given by (A.5), (A.6), and (A.7) respectively in A.1. To change the measure, using (B.2) to substitute dZ_t with $d\widehat{Z}_t + \gamma_t^H dt$, I obtain

$$\begin{aligned}
\frac{dC_t^H}{C_t^H} &= \left\{\epsilon^{\widetilde{C}1}(\eta_t, t)\left[\mu^\eta(\eta_t, t) + \frac{1}{2}\epsilon^{\widetilde{C}2}(\eta_t, t)\,\sigma^\eta(\eta_t, t)^2 + \sigma^\eta(\eta_t, t)\,\sigma\right] + \mu^{KT}(\eta_t, t)\right\} dt\\
&+ \left[\epsilon^{\widetilde{C}1}(\eta_t, t)\,\sigma^\eta(\eta_t, t) + \sigma\right]\gamma_t^H dt + \left[\epsilon^{\widetilde{C}1}(\eta_t, t)\,\sigma^\eta(\eta_t, t) + \sigma\right] d\widehat{Z}_t && \text{(B.33)}
\end{aligned}$$

According the law of motion of Λ_t given by (B.27), the price of risk is

$$\gamma_t^H = \underline{\gamma}_H \sigma_t^C = \underline{\gamma}_H\left[\epsilon^{\widetilde{C}1}(\eta_t, t)\,\sigma^\eta(\eta_t, t) + \sigma\right] . \tag{B.34}$$

I substitute out γ_t^H in the drift term of (B.33) with the solution (B.34) and obtain

$$\begin{aligned}
\mu_t^C &= \mu^C(\eta_t, t) && \text{(B.35)}\\
&= \epsilon^{\widetilde{C}1}(\eta_t, t)\left[\mu^\eta(\eta_t, t) + \frac{1}{2}\epsilon^{\widetilde{C}2}(\eta_t, t)\,\sigma^\eta(\eta_t, t)^2 + \sigma^\eta(\eta_t, t)\,\sigma\right] + \mu^{KT}(\eta_t, t)\\
&+ \underline{\gamma}_H\left[\epsilon^{\widetilde{C}1}(\eta_t, t)\,\sigma^\eta(\eta_t, t) + \sigma\right]^2
\end{aligned}$$

Substituting the solutions of μ_t^C and σ_t^C into the drift term of (B.27), I obtain

$$
\begin{aligned}
\rho_t &= \rho\left(\eta_t, t\right) \qquad\qquad \text{(B.36)} \\
&= \underline{\delta}_H + \underline{\gamma}_H \mu^{KT}\left(\eta_t, t\right) + \underline{\gamma}_H \epsilon^{\widetilde{C}1}\left(\eta_t, t\right)\left[\mu^{\eta}\left(\eta_t, t\right) + \frac{1}{2}\epsilon^{\widetilde{C}2}\left(\eta_t, t\right)\sigma^{\eta}\left(\eta_t, t\right)^2 + \sigma^{\eta}\left(\eta_t, t\right)\sigma\right] \\
&\quad + \frac{1}{2}\left(\underline{\gamma}_H^2 - \underline{\gamma}_H\right)\left[\epsilon^{\widetilde{C}1}\left(\eta_t, t\right)\sigma^{\eta}\left(\eta_t, t\right) + \sigma\right]^2 .
\end{aligned}
$$

C Discussion: The Implications of Zero Lower Bound

While the model does not feature any nominal variables, it is important to discuss the implications of zero lower bound and examine the robustness of results in the broader context of New Keynesian models. As shown in Table 3, the equilibrium outcome matches data well except a lower and more negative interest rate in the later sample periods. The rise of intangible capital over time increases firms' demand for liquid assets and thereby exerts downward pressure on the (natural) real rate. As discussed in Section 4, this trend widens the wedge between the natural real rate and real rate under nominal price rigidity and zero lower bound, exacerbating output loss due to the liquidity trap (Eggertsson and Woodford, 2003; Christiano, Eichenbaum, and Rebelo, 2011; Eggertsson and Krugman, 2012; Fischer, 2016; Korinek and Simsek, 2016; Caballero and Farhi, 2017; Guerrieri and Lorenzoni, 2017; Caballero and Simsek, 2020; Caballero, Farhi, and Gourinchas, 2021). In the following, I will discuss in more details how nominal frictions and zero lower bound interact in the shock amplification mechanism with a particular focus on the cyclical dynamics.

The feedback mechanism in my model emphasizes a discount rate channel of asset-price variation. The bankers have low discount rates (or cost of capital) because firms attach a liquidity premium to their debts as assets that hedge the intangible investment needs. Following positive shocks, the bankers become richer via a leveraged position in tangible capital, and as these low discount-rate agents acquire more assets, they push up asset prices. Higher asset prices imply stronger investment-driven liquidity needs, further reducing the bankers' discount rate and causing asset prices to rise more. An increasing liquidity premium means a widening discount-rate gap between the bankers and entrepreneurs. This implies that reallocation of assets away from the bankers, triggered by negative shocks, will cause a large decline in asset price.

There are two ways to think about how ZLB affects the mechanism. The first is to simply assume that r_t cannot be negative because there exists an exogenous supply of liquid assets that is perfectly elastic at $r_t = 0$. This certainly dampens the mechanism because the key to the mechanism is (liquid) asset shortage and the endogenous supply of assets by risk-taking financial intermediaries. However, where does the unlimited liquidity supply come from? This triggers the second way to think about ZLB, which is more in line with the New Keynesian tradition. I will argue that ZLB does not kill the discount-rate channel of financial instability but introduces a new asymmetric cash-flow channel at ZLB. Specifically, the mechanism in the model dampens the New Keynesian mechanism on the upside (i.e., in response to positive shocks) but does not necessarily interfere it on the downside, generating asymmetric output cycles.

Following Caballero and Simsek (2020), let us assume extremely sticky (constant) prices, so $r_t \geq 0$ because the nominal rate ($= r_t$) cannot be negative. And, let us adopt the AK technology and variable capital utilization as in Caballero and Simsek (2020). Moreover, to model the aggregate demand channel, we need to introduce a different preference and endogenize ρ_t, the agents' required return or discount rate which will depend on consumption growth in equilibrium. The wedge between ρ_t and the interest rate on liquid assets (bankers' debts in particular), r_t, is the liquidity premium. In equilibrium, $\rho_t - r_t$ is driven by households' liquidity demand and firms' liquidity demand that depends on the intangible investment productivity and asset price (present value of capitalizable output of tangible capital), just as in the main text.

Consider positive shocks at $r_t = 0$. The standard wealth effect drives up the aggregate demand and, through variable capital utilization, output increases. However, the mechanism in my model generates a counteracting force. As the bankers become richer through their leveraged position, these low discount-rate agents acquire more assets. The asset price rises and raises the liquidity premium, $\rho_t - r_t$ (see Proposition 1). Given that r_t cannot fall below zero, what has to adjust is ρ_t, the agents' required savings rate that depends on the consumption growth rate in equilibrium. ρ_t must increase and this weakens the aggregate demand. So the mechanism in my model counteracts the standard New Keynesian mechanism in response to positive shocks.

Next, consider negative shocks at $r_t = 0$. The aggregate demand and output decline through the wealth effect. The asset price decline reduces the liquidity premium $\rho_t - r_t$. Because r_t can rise above zero, a lower $\rho_t - r_t$ does not necessarily require a lower ρ_t (and a higher consumption growth), so my model does not generate a counteracting force against the standard New Keynesian mechanism in response to negative shocks. Therefore, incorporating my model into a New Keynesian setting with ZLB generates asymmetric cycles with dampened upside relative to a standard New Keynesian model but similar downside. What differs from the standard New Keynesian model is that here ZLB is applied to r_t, the interest rate on liquid assets, rather than ρ_t. Moreover, the wedge, $\rho_t - r_t$, depends on the endogenous variation in asset prices.

It is worth noting that the discount-rate channel of financial instability is still at work. The discount-rate gap between the bankers and the rest of economy still widens following positive shocks, and this implies an increasingly strong response to negative shocks that trigger asset reallocation from low discount-rate bankers to high discount-rate households/consumers. The existence of ZLB does not kill this mechanism. It simply infuses this mechanism into the aggregate demand channel of New Keynesian models through the endogenous ρ_t (consumers' discount rate or required savings return), and it does so in an asymmetric fashion by dampening the upside and but not necessarily interfering the downside. What the New Keynesian setup does to my model is to bring in a new cash-flow channel. Specifically, it makes the cash flow per unit of assets/capital (i.e., the output) variable through utilization, and, due to the asymmetry in output cycle, the shock amplification through the cash-flow channel is also asymmetric (stronger for negative shocks).

D Additional Tables and Figures

D.1 Summary Statistics

Table D.1: Summary Statistics for Nonfinancial Firm Cash and Leverage Regressions

Variable	Below Median Intan./Asset			Above Median Intan./Asset		
	Mean	Median	Std.	Mean	Median	Std.
Cash/Assets (%)	12.395	5.759	16.758	24.521	15.597	24.682
Intangible Investment/Investment	0.434	0.427	0.302	0.802	0.840	0.156
Intangible Investment/Total Assets	0.043	0.042	0.029	0.238	0.178	0.270
PPE/Total Assets	0.364	0.315	0.261	0.194	0.156	0.152
Leverage (%)	29.388	27.127	22.415	18.078	12.170	20.327
Asset-backed Loans/Total Assets (%)	10.771	2.891	16.564	7.964	1.314	13.674
Cashflow-backed Loans/Total Assets (%)	20.288	15.972	23.055	12.639	0.591	24.402
Acquisitions/Total Assets	0.027	0.000	0.067	0.015	0.000	0.048
Cashflow/Total Assets	0.049	0.063	0.122	-0.056	0.051	0.287
Dividend Dummy	0.398	0.000	0.489	0.227	0.000	0.419
EBITDA/Total Assets	0.103	0.115	0.518	-0.034	0.087	0.524
Inventory/Total Assets	0.120	0.067	0.148	0.177	0.147	0.163
Net Cash Receipts/Total Assets	0.091	0.100	0.468	-0.036	0.061	0.557
Net Working Capital/Total Assets	0.071	0.053	0.182	0.107	0.113	0.229
Log Real Assets (Size)	5.827	5.789	2.109	4.538	4.407	1.967
Tobin's Q	1.452	1.241	0.746	1.961	1.595	1.180

Table D.2: Summary Statistics for Household Time Series Regression

Variable	Mean	Std.	p20	p40	p60	p80
Liquid Holdings/GDP	0.505	0.066	0.435	0.496	0.541	0.570
Average EV/EBITDA	10.364	2.793	7.479	9.652	11.170	13.027
Tangible EV/EBITDA	8.888	2.154	7.102	8.165	9.207	10.450
Average Tobin's Q	1.823	0.342	1.526	1.693	1.903	2.055
Tangible Tobin's Q	1.414	0.185	1.256	1.394	1.496	1.534
Price/Rent Ratio	1.27	0.129	1.177	1.201	1.250	1.333
Observations	160					

Table D.3: Summary Statistics for Household Panel Data Regression

Variable	Mean	Std.	p20	p40	p60	p80
Cash/Income	0.205	0.584	0	0.011	0.052	0.180
$\Delta \ln$ (Housing Price Index)	0.064	0.128	-0.038	0.059	0.098	0.139
Age	45.296	16.390	30	38	48	59
Couple Status	0.693	0.791	0	0	1	1
Education Level	13.124	2.657	12	12	14	16
Home ownership Status	0.551	0.497	0	0	1	1
Household Size	2.641	1.483	1	2	3	4
$\Delta \ln$ (Household Income)	0.036	1.390	-1.073	-0.286	0.364	1.144
$\Delta \ln$ (Wealth excluding Home Equity)	-0.034	6.808	-4.879	-0.870	0.862	4.623
Observations	76,834					

D.2 Corporate Liquidity Demand

Table D.4: Asset Tangibility, Capital Valuation, and Corporate Cash Holdings

***Panel A**: EV/EBITDA & Intangible-Driven Corporate Cash Holdings*

$\frac{\text{Cash}}{\text{Assets}}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PPE/Assets	-0.496	-0.223	-1.699***	-1.441***	-0.846**	-0.400	-1.909***	-1.476***
(decile)	(0.372)	(0.336)	(0.315)	(0.282)	(0.412)	(0.399)	(0.313)	(0.303)
Ave. EV/EBITDA	1.848***		1.020***					
	(0.275)		(0.244)					
PPE/Assets×	-0.259***	-0.281***	-0.136***	-0.153***				
Ave. EV/EBITDA	(0.034)	(0.032)	(0.027)	(0.025)				
Tan. EV/EBITDA					1.825***		0.882***	
					(0.331)		(0.273)	
PPE/Assets×					-0.267***	-0.307***	-0.141***	-0.174***
Tan. EV/EBITDA					(0.040)	(0.041)	(0.031)	(0.031)
Controls	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	152,801	152,801	133,632	133,632	152,801	152,801	133,632	133,632
Adjusted R^2	0.1795	0.1859	0.3096	0.3164	0.1745	0.1838	0.3076	0.3159

***Panel B**: Tobin's Q & Intangible-Driven Corporate Cash Holdings*

$\frac{\text{Cash}}{\text{Assets}}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PPE/Assets	-0.533	0.021	-1.752***	-1.280***	0.927	1.297*	-1.125**	-0.836
(decile)	(0.632)	(0.621)	(0.415)	(0.415)	(0.837)	(0.735)	(0.555)	(0.519)
Ave. Tobin's Q	9.908***		4.836**					
	(2.587)		(1.800)					
PPE/Assets×	-1.483***	-1.729***	-0.776***	-0.961***				
Ave. Tobin's Q	(0.327)	(0.332)	(0.211)	(0.214)				
Tan. Tobin's Q					20.213***		10.620***	
					(4.560)		(3.152)	
PPE/Assets×					-2.937***	-3.136***	-1.430***	-1.555***
Tan. Tobin'sQ					(0.577)	(0.513)	(0.373)	(0.347)
Controls	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	152,801	152,801	133,632	133,632	152,801	152,801	133,632	133,632
Adjusted R^2	0.1726	0.1827	0.3072	0.3155	0.1732	0.1823	0.3077	0.3151

Firm-year clustered standard errors in parentheses
* $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$

Table D.5: Intangible Investment, Tobin's Q, and Corporate Cash Holdings

$\frac{\text{Cash}}{\text{Assets}}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intan./Assets	-2.724	-3.372	-1.629	-2.272	-8.200***	-8.730***	-5.672**	-6.244***
(quintile)	(2.219)	(2.227)	(1.761)	(1.783)	(2.650)	(2.532)	(2.117)	(2.070)
Ave. Tobin's Q	-5.072***		-4.586***					
	(0.981)		(0.682)					
Intan./Assets×	4.993***	5.326***	3.729***	3.963***				
Ave. Tobin's Q	(1.215)	(1.235)	(0.958)	(0.983)				
Tan. Tobin's Q					-10.064***		-7.866***	
					(1.568)		(1.253)	
Intan./Assets×					10.317***	10.669***	7.648***	7.925***
Tan. Tobin's Q					(1.923)	(1.856)	(1.530)	(1.512)
Controls	No	No	Yes	Yes	No	No	Yes	Yes
Year FE	No	Yes	No	Yes	No	Yes	No	Yes
Observations	152,826	152,826	133,632	133,632	152,826	152,826	133,632	133,632
Adjusted R^2	0.1843	0.2038	0.2671	0.2831	0.1880	0.2057	0.2699	0.2842

Firm-year clustered standard errors in parentheses
* $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$

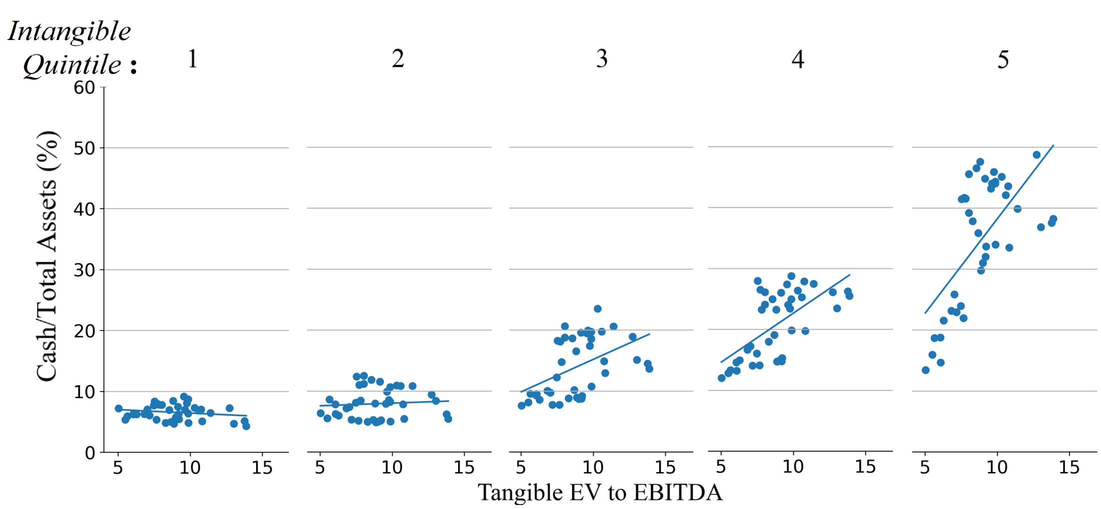

Figure D.1: **Intangible Intensity, Tangible Capital Valuation, and Corporate Cash Holdings**.

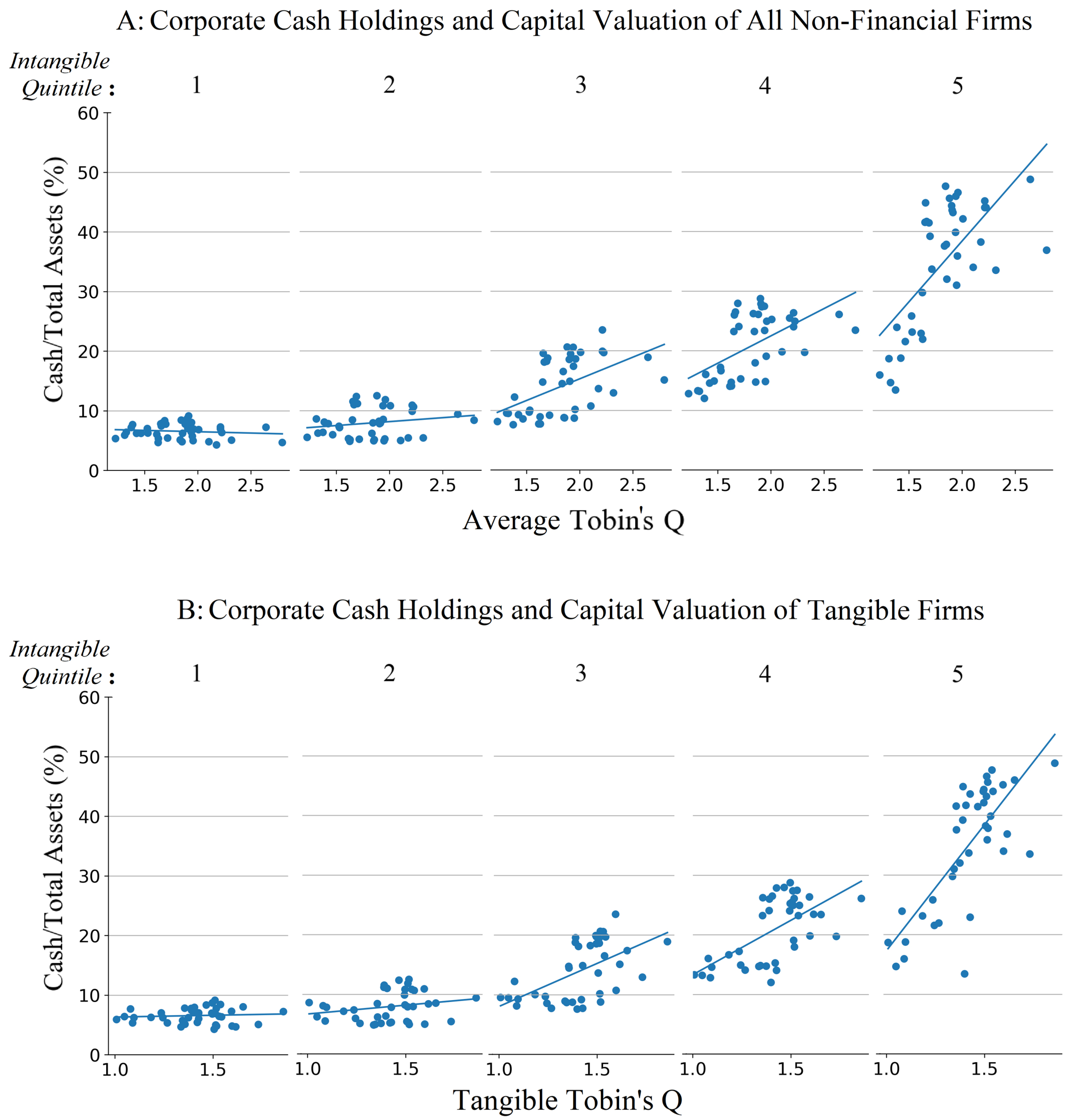

Figure D.2: **Intangible Intensity, Tobin's Q, and Corporate Cash Holdings**.

D.3 Household Liquidity Demand

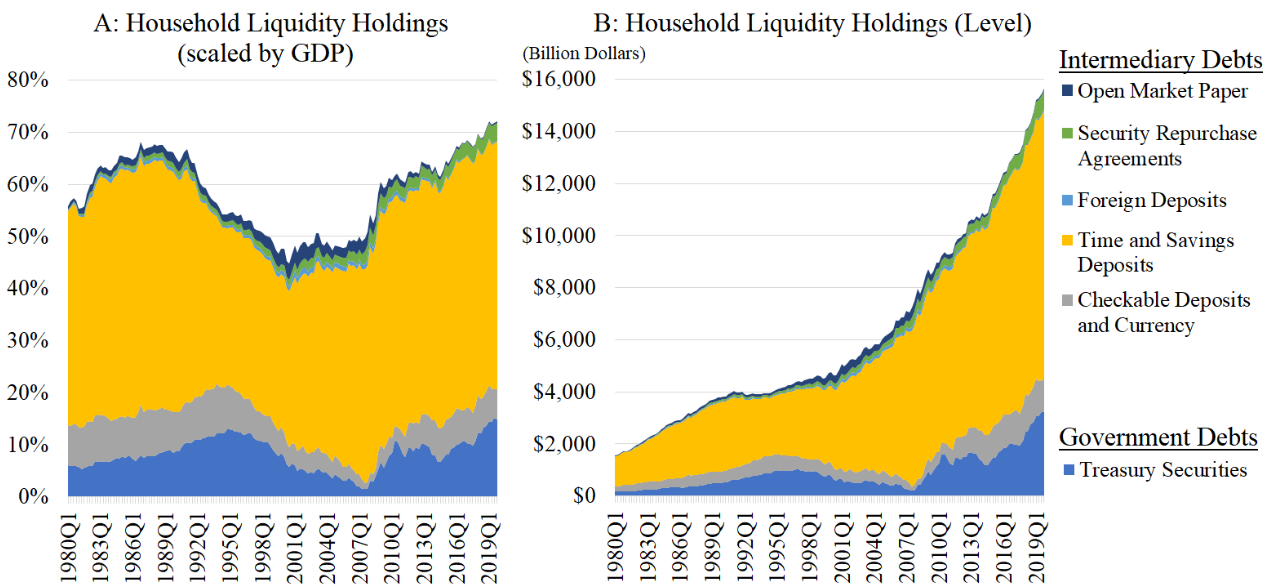

Figure D.3: **Decomposing Households' Holdings of Liquid Securities**.

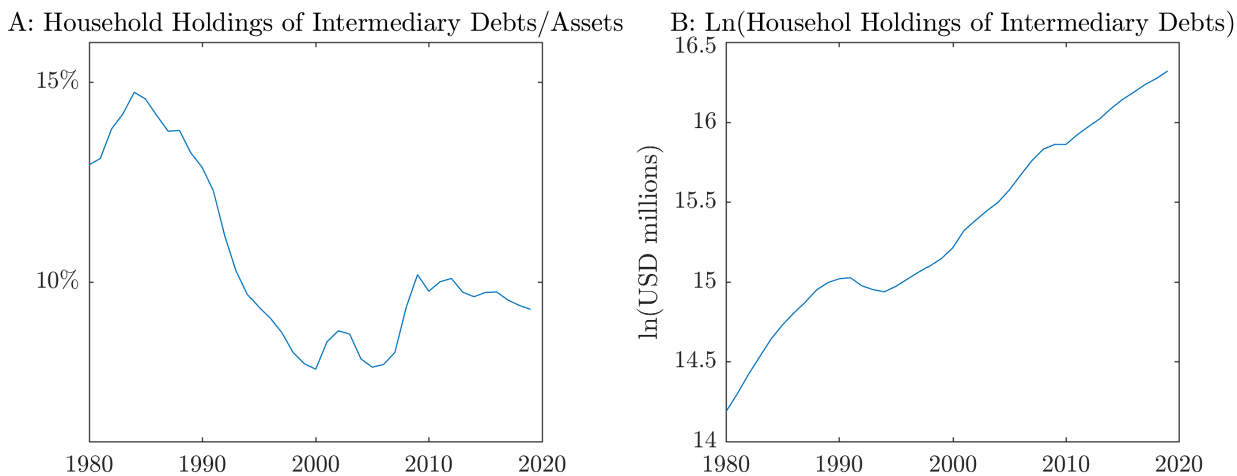

Figure D.4: **Households' Holdings of Intermediary Debts**.

D.4 Additional Figures from Calibration

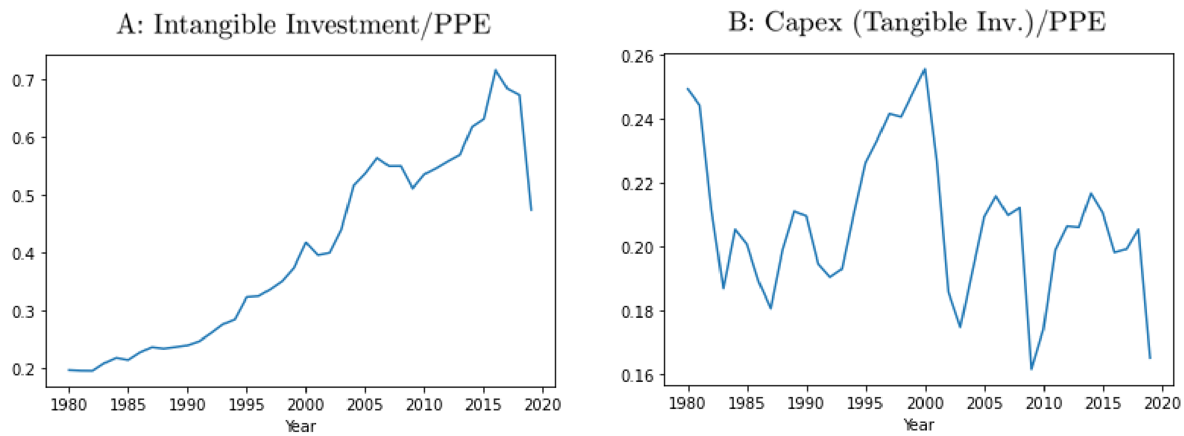

Figure D.5: **PPE-Scaled Corporate Investments**.