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Robin Döttling

Essays in Financial Economics

This thesis consists of three essays. The first essay develops a tractable, dynamic equilibrium model, to understand how the zero lower bound constraint on deposit rates (ZLB) affects (optimal) banking regulation and risk-taking incentives. The model shows that the ZLB can make capital requirements less effective, and delivers a novel rationale for cyclically adjusting regulation. The second- and third- chapters center around the question how recent technological advances affect firm financial policies and the wider macro-economy as a whole. Advances in ICT technology since the 1980s have had a major effect on the kind of products firms produce, and the inputs they use. In the past, production largely required tangible inputs such as factories and machinery, whereas digital technologies, R&D, organizational structure, high-skill human capital and other intangible assets dominate the production process of modern firms. The second chapter studies this topic at the micro level, and explores implications for financial-, payout- and compensation-policies, using firm-level data. The third chapter focuses on macroeconomic consequences, and develops a growth model that relates technological change to recent long-term trends, including falling interest rates and a shift of finance away from corporations, towards mortgage finance.

Robin Döttling graduated from the Tinbergen Institute Mphil program in 2014. From 2014-2018, he worked on his PhD thesis at the University of Amsterdam, where he focused on topics in financial intermediation, corporate finance, and macroeconomics. Since 2018, he is an Assistant Professor in Finance at the Rotterdam School of Management, Erasmus University.

Essays in Financial Economics – Robin Döttling



Essays in Financial Economics

Robin Döttling

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ESSAYS IN FINANCIAL ECONOMICS

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together with everyone else in our cohort, helped me fight through the MPhil years.

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I conclude with the lyrics from a track by the great Joris Voorn:

*I cannot remember when
The last time I saw my home and all my friends
But they tell me my life
Has never been better*

*And so I try to make believe
That all the time I spend away is endlessly
Making everything so much better*

*The methods in which how
Return us to home now
Seem surrounded by love and time*

*Then all at once I
I suddenly realize
You were right here by my side*

Contents

Contents	11
Introduction	14
1 Bank Capital in a Zero Interest Environment	15
1.1 Introduction	15
1.1.1 Related Literature	19
1.2 Motivating Evidence	20
1.3 Model Setup	23
1.3.1 Firms	24
1.3.2 Household Problem and Liquidity Demand	25
1.3.3 The Bank's Problem	27
1.3.4 Government	31
1.3.5 Equilibrium	31
1.3.6 Calibration	32
1.3.7 Discussion of the Framework	34
1.3.8 First Best and Inefficiencies	35
1.4 Risk Taking and Capital Regulation at the Zero Lower Bound	37
1.4.1 Zero Lower Bound	37
1.4.2 Do Low Interest Rates Spur Risk Taking?	37
1.4.3 Expectations Matter	39
1.4.4 Discussion of the Mechanism	41
1.5 The Effectiveness of Capital Requirements at the ZLB	42
1.6 Optimal Capital Regulation	45
1.6.1 Welfare Benchmark	45
1.6.2 Results	46
1.6.3 Sensitivity Analysis	49

1.6.4	An Alternative Policy	50
1.7	Conclusion	51
1.8	Paper Appendix	53
1.8.1	Equilibrium conditions	53
1.8.2	Calibration	54
1.8.3	Bank Problem	55
1.8.4	Proof of Proposition 1	56
1.8.5	Proof of Proposition 2	57
1.8.6	Proof of Propositions 3 and 4	58
1.9	First Best with Bank Failure Cost	59
1.10	Additional Evidence	60
1.10.1	Interest Margins and Deposit Rates at the ZLB	60
1.10.2	Evolution of Bank Concentration	61
2	The (Self-)Funding of Intangibles	65
2.1	Introduction	65
2.1.1	Related literature	68
2.2	Model	70
2.2.1	Model setup	71
2.2.2	Precautionary cash holdings	73
2.2.3	Cash holdings and employee compensation	74
2.2.4	Payout policy	77
2.2.5	Empirical Implications	78
2.3	Empirical Methodology	78
2.3.1	Sampling procedure	78
2.3.2	Empirical measures	79
2.3.3	Empirical specifications	82
2.3.4	Summary statistics	84
2.4	Empirical Tests	85
2.4.1	Investment outlays and free cashflows	85
2.4.2	Corporate financing	86
2.4.3	Are HINT firms more financially constrained?	87
2.4.4	Cash Holdings	88
2.4.5	Payouts to external shareholders	91
2.5	Conclusions	91
2.6	Proofs and Extensions of the Model	93

2.6.1	Proof of Proposition 5	93
2.6.2	Deferred cash compensation	93
2.7	Paper Appendix	96
3	Technological Change and the Evolution of Finance	111
3.1	Introduction	111
3.2	Related literature	116
3.3	Model Setup	118
3.3.1	Households	120
3.3.2	Physical Capital and Labor	122
3.3.3	Creation of Intangibles	122
3.3.4	Equilibrium	123
3.3.5	The allocation of savings in steady state	123
3.4	Secular trends	124
3.4.1	Major secular trends	124
3.4.2	Key growth drivers	128
3.5	Analytical comparison of growth drivers	130
3.5.1	Analytical results	130
3.5.2	Strongly redistributive technological progress	131
3.6	Calibration and Empirical Validation	132
3.6.1	Calibration to 1980	132
3.6.2	Individual Drivers and Why They Fail	133
3.6.3	The Joint Effect of Multiple Drivers	135
3.6.4	Cross-country evidence	137
3.7	Rising default rates and policy issues	138
3.8	Conclusion	139
3.9	Paper Appendix	141
3.9.1	General case	141
3.9.2	Strongly redistributive growth	141
3.9.3	The model with default	143
	Summary	146
	Samenvatting	148
	Bibliography	149

Introduction

This thesis consists of three essays, covering topics in Financial- and Macroeconomics.

The first chapter develops a dynamic macro-banking model, to analyze how low interest rates affect optimal banking regulation and risk taking. During the past decade, interest rates across advanced economies have been historically low and even negative, increasing the likelihood of frequently hitting zero in the future. Yet, banks have been hesitant to set negative rates on retail deposits, perhaps due to concerns of triggering a bank run. To understand how this low-rate environment affects banking regulation, I develop a tractable dynamic equilibrium model with a strongly micro-founded core, that builds on an established theoretical banking literature. In the model, forward-looking banks compete imperfectly for deposit funding, and choose the risk of their loans trading off the gains from shifting risk on depositors against the risk of loss of franchise value.

Two core positive results emerge. First, the ZLB can increase bank risk taking incentives, as falling asset returns eat into bank interest margins and induce a search for yield when banks are constrained from passing on low rates to depositors. Second, the ZLB can make capital requirements less effective in reducing these risk taking incentives, exactly during times of low interest rates, when risk taking incentives are already heightened. The reason is that at the ZLB banks cannot lower deposit rates in response to higher capital requirements, such that the cost of capital has to be disproportionately borne by banks, undermining profitability and hence franchise values.

A simulation calibrated to U.S. data reveals what these positive results imply for optimal capital regulation. If deposit rates are occasionally constrained by the ZLB, optimal requirements vary with the level of interest rates, where lower rates motivate weaker requirements despite overall higher risk taking. The model thus highlights a novel rationale for “counter-cyclical” regulation, as well as a novel interaction between monetary and macro-prudential policies. As an alternative policy tool, subsidizing the funding cost of banks helps reducing risk taking incentives at the ZLB, but may have an overall negative effect on welfare as banks grow too larger relative to financial markets in equilibrium.

The second and third chapters are centered around the question how recent technological advances affect firm financial policies and the wider macro-economy as a whole. Advances in ICT technology since the 1980s have had a major effect on the kind of products firms produce, and the inputs they use. In the past, production largely required tangible inputs such as factories and machinery, whereas digital technologies, high-skill human capital and other intangible assets dominate the production process of modern firms.

The second chapter is joint work with Enrico Perotti and Tomislav Ladika. We model how the shift to intangibles affects firm financial structure and employee compensation, and present empirical evidence consistent with the model's predictions. A crucial difference between tangible and intangible assets is that tangibles can be purchased and funded externally, while the creation of intangible assets largely relies on the commitment of high-skill human capital over time. Traditional firms require large outlays to invest in physical assets, and can finance these outlays with debt. On the other hand, the investment process of intangible assets is supported by high-skill employees, and thus requires lower investment outlays by firms. Indeed, U.S. high-intangibles firms have larger free cashflows, lower total investment spending, and less debt, yet do not appear more financially constrained. The main concern of intangible-intensive firms is to retain high-skill employees, which they achieve by offering deferred compensation sensitive to future outside options. A policy to retain cash and favor repurchases helps to insure and protect unvested claims, reducing the cost of human capital compensation. High-intangibles firms also should favor a payout policy of repurchases over dividends to avoid penalizing unvested claims. All these predictions are consistent with empirical evidence from a large sample of U.S. public firms, also for the subset of firms that do not appear financially constrained.

The third chapter is joint work with Enrico Perotti. Related to the second chapter, we analyse the aggregate implications of the rise of intangibles. As intangibles grow in importance over time, firms raise less financing for investment, but promise an increasing share of cashflows to high-skill, innovative employees. As employees capture an increasing share of capital income, the supply of investable assets falls. As corporate leverage falls, the general equilibrium effect is a gradual fall in interest rates and rising asset valuations to absorb excess savings. The concomitant rise in house prices and wage inequality leads to higher household leverage and mortgage default risk. Using a long-run growth model, we show that only a redistributive productivity shift can account for a fall in physical investment in the context of falling interest rates, consistent with major economic and financial trends since 1980. Intuitively, a drop in both quantity of corporate borrowing and price (interest rates), can only be consistent with lower demand from firms.

Chapter 1

Bank Capital in a Zero Interest Environment

1.1 Introduction

During the past decade interest rates have been historically low, increasing the likelihood of more frequently hitting zero in the future. Recent contributions show that low interest rates can induce investors to take more risk in a “search for yield” (e.g. Rajan, 2005; Martinez-Miera and Repullo, 2017), and highlight their consequences for macroeconomic outcomes when monetary policy becomes constrained by the zero lower bound (ZLB) (e.g. Eggertsson and Woodford, 2003; Eggertsson and Krugman, 2012). An open question remains how such a low-rate environment affects banking and financial regulation. This paper tackles this question using a dynamic general equilibrium framework and analyzes how the ZLB affects (optimal) bank capital regulation and risk taking.

The question addressed in this paper is important because the ZLB seems to be a particularly relevant constraint for commercial banks. For example, even with interbank rates below zero, retail deposits have been shielded from negative rates in the Eurozone (Heider et al., 2016).¹ In section 1.2 I present similar evidence for U.S. banks, and argue that fees do not overcome the problem either, as they are not a per-unit price and quantitatively extremely small relative to the growing deposit base of banks.² In sum, low interest rates can undermine the profitability of a banks’ deposit franchise, particularly when the ZLB

¹ While there are some cases of banks charging negative rates, a majority seems hesitant to do so. This seems to be particularly true for retail deposits, which may more easily substitute towards cash. Perhaps behavioral biases play a role too, as retail customers may perceive negative rates as unfair.

² While banks have been increasing fees, low interest rates induce large deposit inflows. Therefore, fees *relative to deposits* have actually been falling.

constrains banks from passing on low asset returns to depositors (see further evidence in section 1.2, as well as Drechsler et al., 2016).

How do banks react to this environment of near-zero interest rates and compressed margins, and what are the implications for the ongoing debate about the optimal level of bank capital requirements (e.g. Van den Heuvel, 2008; Begeau, 2016)? I study these questions in a tractable dynamic equilibrium model with endogenous deposit competition and bank failures, in which the risk taking incentives of forward-looking banks are determined by their franchise value (Hellmann et al., 2000). The model endogenizes several elements relevant to bank capital regulation, yet remains tractable and allows to pin down analytically how the level of interest rates affects risk taking incentives and their interplay with capital requirements. I also calibrate the model to U.S. data and quantify optimal (welfare-maximizing) capital requirements in the presence of an occasionally binding ZLB constraint.

The main take-away from the model is that low interest rates may not only increase bank risk taking per se, but that the ZLB can also make capital requirements less effective in curbing such risk taking incentives. The reason is that tight capital requirements erode franchise value when the ZLB constrains banks in passing on the cost of capital to depositors. As a result, optimal capital requirements vary with the level of interest rates, where low interest rates motivate weaker requirements despite overall higher risk taking. Intuitively, capital requirements are optimally lower when interest rates are near-zero and the ZLB renders them less effective. In contrast, when interest rates are high banks can better absorb tight capital requirements as their market power allows them to pass on the cost of capital to depositors.

In the model, firms produce output using capital as the only input and there are two investment technologies to produce new capital. Households can directly invest in creating new capital, which I interpret as investments in the financial market. Banks can also produce new capital, albeit at a higher cost (perhaps due to the cost of operating a branch network and complying with regulation). The bank's technology can be interpreted as loans to a bank-dependent sector.

Banks take the return on capital as given, but have market power on the funding side, where they set deposit rates under monopolistic competition, subject to a zero lower bound constraint.³ Households are willing to accept a lower return on deposits because deposits carry a liquidity service valued in their utility function.⁴

³ The ZLB constraint is assumed exogenously, but could easily be endogenized by introducing fiat money.

⁴ Since equity carries no convenience yield and bank investments are costlier than in the financial market, bank capital is (socially) costly in the model.

There is a moral hazard problem, because bank risk-taking is not contractible and shareholders enjoy limited liability. At the same time, banks stand to lose rents upon failure because they have market power. In balance, banks trade off the gains from shifting risk on depositors against the risk of loss of franchise value.

The representative household's discount factor moves around stochastically over time, generating variation in the level of interest rates.⁵ There is no other source of aggregate risk.

In a first step, I revisit the question whether low interest rates induce banks to take more risk - a concern that has first been articulated by Rajan (2005) during the run-up to the financial crisis of 2008. In contrast to other contributions in the search for yield literature (e.g. Acharya and Plantin, 2016; Martinez-Miera and Repullo, 2017), a reduction in interest rates has little effect on bank risk taking, so long as deposit rates are not constrained by the ZLB. The reason is that market power allows banks to pass on reductions in interest rates to depositors and maintain relatively stable interest margins. That is, with a slack ZLB banks are not exposed to interest rate risk, in line with recent evidence (Drechsler et al., 2017a; Hoffmann et al., 2017). At the same time, lower discount rates boost franchise values, inducing banks to actually take *less* risk.

This result reverses when deposit rates are constrained by the ZLB, where any reduction in asset returns eats 1-1 into margins, eroding franchise value and hence increasing risk taking incentives. This effect is particularly strong if the yield curve flattens substantially and the ZLB is expected to bind for a long time. Moreover, even if the ZLB is slack in a given period, incentives are affected if it is possible that the economy transitions to a state with a binding ZLB in the future. This dynamic effect highlights that even after a rate “normalization” (e.g. the Fed started raising rates in 2015), the possibility of falling back to the ZLB in the future may still affect incentives.

As a next step, I examine how the ZLB affects (optimal) capital regulation. In the model, capital requirements limit the leverage banks can take, reducing risk taking incentives by increasing a banks' “skin in the game” (Holmstrom and Tirole, 1997). However, at the ZLB a countervailing effect comes into play. When banks cannot pass on the cost of capital to depositors, tight capital requirements erode franchise value, with the perverse effect of increasing risk taking incentives. Via this negative franchise value effect, the ZLB reduces the overall effectiveness of capital requirements exactly during times when bank risk taking incentives are already heightened.

⁵ In particular, the discount factor alternates according to a two-state Markov process. A high-rate state represents “normal” times with interest rates well above zero, such as the period before the crisis in 2008. In the low-rate state deposit rates may be constrained by the ZLB, as from 2009-2015.

The franchise value effect has implications for optimal capital regulation, which trades off the gain from less bank risk taking against the loss of lower liquidity creation by banks. Calibrating the model to U.S. data and allowing for a state-dependent capital requirement, I find an optimal level around 7-8% if the ZLB is slack at all times. In contrast, if the ZLB binds occasionally, optimal capital requirements vary with the level of interest rates. Perhaps surprisingly, optimal requirements are *weaker* whenever the ZLB binds, even though risk taking incentives are already higher at the ZLB. The reason is that the franchise value effect makes capital regulation less effective at the ZLB, motivating a weaker requirement despite overall higher risk taking. At the same time, low *expected* profitability increase risk taking incentives, motivating tighter requirements when interest rates are high but may fall back to the ZLB again in the future.

These findings closely relate to the debate on counter-cyclical capital regulation, where capital requirements optimally vary with the business cycle.⁶ Here, optimal capital requirements also vary with the state of the macro-economy, but they do so with the “interest rate cycle” rather than the business cycle.⁷ Because the model abstracts from business cycle dynamics, it thus delivers a novel rationale for cyclical capital regulation, distinct from the traditional view on counter-cyclical regulation.

The franchise value effect at the ZLB is also relevant for the debate on whether monetary policy should target financial stability. Some commentators argue that monetary policy should focus on targeting inflation, and let macro-prudential policies take care of financial stability (e.g. Bernanke, 2015). However, if very low interest rates undermine the effectiveness of prudential policies, the two cannot be set independently.

I consider as an alternative policy tool a subsidy per unit of deposits, paid to banks whenever the ZLB binds. Such a policy effectively supports interest margins, and restores prudence incentives as it stabilizes profitability.⁸ However, its overall effect on welfare is ambiguous because the taxes raised to fund the subsidy create an additional distortion.

⁶ The case for counter-cyclical requirements is often made in models with welfare-relevant pecuniary externalities or aggregate demand externalities (e.g. Lorenzoni, 2008; Stein, 2012; Korinek and Simsek, 2016). The argument in the policy debate is that buffers built up in good times should be available to be used in bad times (e.g. Goodhart et al., 2008), and relies on frictions to raising equity. In contrast, the rationale here is relevant even absent any frictions to raising equity and welfare-relevant pecuniary externalities.

⁷ In fact, the model abstracts from business cycle dynamics, singling out the effect of the level of interest rate.

⁸ One can think of this policy as broadly resembling policies that subsidize the funding cost of banks, such as the ECB’s targeted long-term refinancing operations or the Bank of England’s Funding for Lending and Term Funding schemes.

1.1.1 Related Literature

This paper relates to several strands of the literature. First, it relates to recent contributions that study optimal capital regulation in dynamic general equilibrium models with banks (Van den Heuvel, 2008; Martinez-Miera and Suarez, 2014; Begenau, 2016; Davydiuk, 2017). None of these papers addresses the main question in this paper, namely how the ZLB affects optimal capital requirements. Some distinct modeling features include bank market power and bank failures. Allowing for bank failure, risk taking is driven by franchise values, as banks stand to lose rents upon failure (Hellmann et al., 2000). Introducing market power ensures that banks have strictly positive margins and franchise values, and allows me to study the effect of weakened profitability at the ZLB.

The notion that franchise value affects risk taking is in line with several contributions in the banking literature (e.g. Hellmann et al., 2000; Perotti and Suarez, 2002; Repullo, 2004; Boyd and De Nicolo, 2005; Martinez-Miera and Repullo, 2010). To the best of my knowledge this paper is the first to incorporate this channel in a dynamic general equilibrium model.

Closely related to this paper, Hellmann et al. (2000) argue that capital requirements should be complemented with interest rate ceilings, since otherwise capital requirements erode franchise value. Effectively, the ZLB has the opposite effect of an interest rate ceiling, imposing a minimum rate banks have to pay to depositors. In contrast to Hellmann et al. (2000), I find that capital requirements erode franchise value only if the ZLB binds, since otherwise market power allows banks to fully pass on the cost of capital.⁹

Also closely related, Brunnermeier and Koby (2016) introduce the concept of a “reversal rate”, below which monetary policy becomes ineffective. While the authors also highlight the negative effect of low interest rates on bank profitability, this paper has a distinct focus on risk taking and novel implications for bank capital regulation.

This paper also relates to the literature on “search for yield”, which argues that low interest rates result in an increase in risk taking (Rajan, 2005; Jiménez et al., 2014; Dell Ariccia et al., 2014; Martinez-Miera and Repullo, 2017; Drechsler et al., 2017b; Acharya and Plantin, 2016). Closely related, Heider et al. (2016) show in a diff-in-diff setting that negative interest rates in the Eurozone have induced banks that rely relatively more on deposit funding to lend to relatively riskier borrowers.

Via the risk taking channel of monetary policy an increase in risk tolerance is an *intended* effect of low interest rates via portfolio rebalancing (Borio and Zhu, 2012; Choi et al., 2016). This paper relates to this literature, but focuses on inefficient risk shifting

⁹ Section 1.5 discusses the differences to Hellmann et al. (2000) in more detail.

as a result of agency problems.

Another recent related strand of literature analyzes how monetary policy affects the market power of banks (Drechsler et al., 2016; Scharfstein and Sunderam, 2015) and shadow banks (Xiao, 2017). Drechsler et al. (2016) present a “Deposits Channel” of monetary policy, in which market power allows banks to pass on increases in the Fed Funds rate less than 1-1 to depositors. Relatedly, Drechsler et al. (2017a) and Hoffmann et al. (2017) show that market power in the deposit market also shields banks from interest rate risk, despite them engaging in maturity transformation. My model builds on these findings. As long as the ZLB is slack, banks can pass on changes in interest rates to depositors and maintain stable margins. The core results rely on the insight that this mechanism breaks down once the zero lower bound distorts deposit pricing. This notion is consistent with event studies around monetary policy announcements which find that falling interest rates negatively affect bank stock prices if and only if the ZLB binds (Ampudia and Van den Heuvel, 2017; English et al., 2012).

Finally, this paper is related to the macroeconomic literature on the zero lower bound and liquidity traps (e.g. Keynes, 1936; Krugman, 1998; Eggertsson and Woodford, 2003; Eggertsson and Krugman, 2012; Guerrieri and Lorenzoni, 2017). While this literature focuses on monetary and fiscal policy, this paper shows that the ZLB may also constrain the effectiveness of prudential regulation. In fact, I study the implications of the ZLB in a real model, in which interest rates clear the savings-investment market. The economy here can therefore be interpreted as one in which the price level and inflation expectations are fixed.

The rest of the paper is organized as follows. Section 1.2 presents motivating evidence. Section 3.3 describes the model setup, equilibrium and calibration. Section 1.4 studies the determinants of bank risk taking in the model. Section 1.6 derives optimal capital regulation, shows how it is affected by the ZLB, and discusses alternative policy options. Finally, section 3.8 concludes.

1.2 Motivating Evidence

This section summarizes three motivating empirical facts: (i) banks are hesitant to pass on negative interest rates to depositors; (ii) fees are too small relative to the deposit base of banks to overcome the problem, and falling; (iii) since the ZLB started binding in 2009, interest margins and bank profitability have shrunk, in particular for banks with a lot of deposit funding.

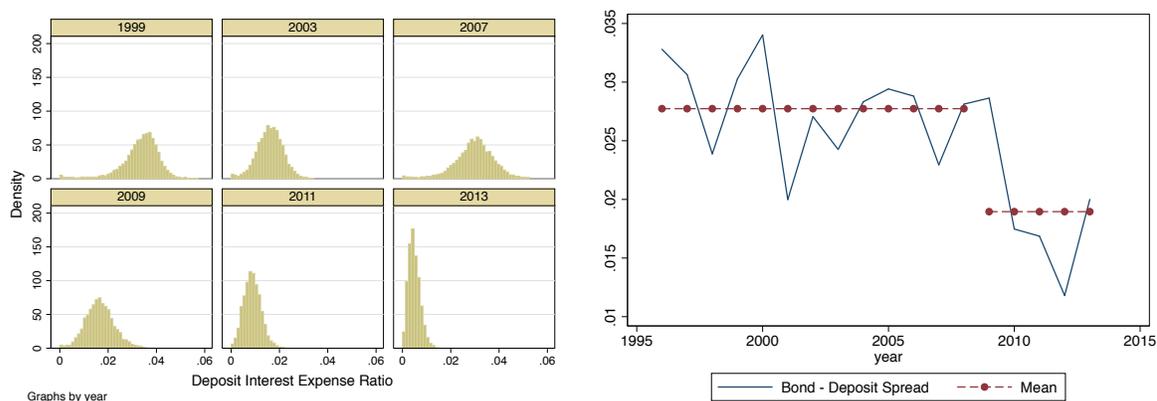


Figure 1.1: For selected years from 1999-2013, the left panel plots the cross-sectional distribution of deposit interest expense per unit of deposit funding across U.S. banks in the Call Reports data. The deposit interest expense ratio is defined as interest expenses per unit of deposits. The right panel plots the spread between the BofA Merrill Lynch US Corporate AAA Effective Yield (retrieved from FRED) and the interest expense per unit of deposit funding of the median U.S. bank.

For selected years, figure 1.1 plots the cross-sectional distribution of U.S. banks' deposit interest expense per unit of deposit funding.¹⁰ Before 2009, the mean shifts around with the level of interest rates, but the shape of the distribution changes little (see appendix 1.10 for additional years). As the ZLB starts binding in 2009 the distribution becomes increasingly right-skewed, suggesting a distortion in deposit pricing as interest rates bunch near zero. This notion is confirmed by FDIC data showing that the average rate on savings accounts has been near zero since 2009 (not reported here, see the FDIC website). Heider et al. (2016) find similar evidence for the Eurozone, suggesting that many banks are unable or unwilling to lower deposit rates into negative territory, even when interbank rates fall below zero.¹¹

When banks cannot pass on falling interest rates to depositors, their margin between asset returns and cost of funding shrinks. This is illustrated in the right panel of figure 1.2, which plots the spread of corporate bond yields over median deposit interest expense.¹² Notwithstanding swings in the level of interest rates, the spread averages around 2.75% until 2008. Thereafter, a clear compression in the spread is visible, as the ZLB starts

¹⁰ Following Drechsler et al. (2016), the interest expense ratio is calculated using Call Reports data (series riad4170 divided by rcon2200). Due to the short maturity of deposits it is a good approximation for the current interest rate a bank offers on deposits.

¹¹ Anecdotal evidence suggests that the reason banks are hesitant to set negative interest rates on retail deposits is that they are concerned about triggering a bank run.

¹² The interest expense ratio is calculated using Call Reports data (series riad4170 divided by rcon2200). Due to the short maturity of deposits it is a good approximation for the current interest rate offered on deposits. The bond yield is the BofA Merrill Lynch US Corporate AAA Effective Yield, retrieved from FRED.

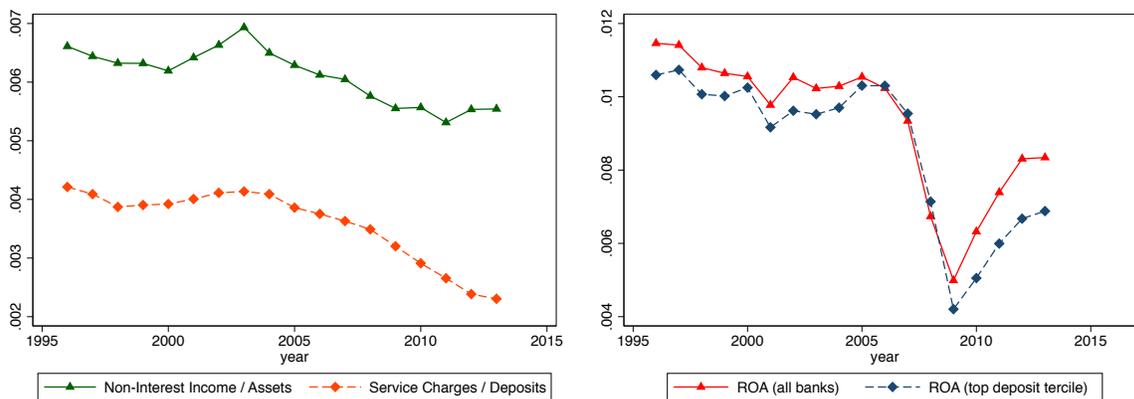


Figure 1.2: The left panel plots non-interest income per unit of assets, as well as service charges per unit of deposits for the median U.S. bank in the Call Reports data. Figure 1.11 in the appendix reports histograms for additional years. The right panel plots the median ROA (defined as net income over assets), separately across all banks and across banks in the top tercile of deposits /assets.

binding in 2009.

This comparison shows that for investments in an asset class with a given level of risk, deposit-funded banks earn relatively less at the ZLB. Relative to bank-level measures of interest income, this measure has the advantage that it is not confounded with endogenous higher risk taking by banks. Still, appendix 1.10 shows that the spread between bank-level interest income and deposit interest expense follows a similar pattern, dropping around 2007 (though to a lesser extent).

Even if banks are unable to set negative interest rates on deposits, they may be able to do so effectively by increasing fees. By revealed preference, if the two were equivalent banks should have charged fees rather than interest rates also away from the ZLB. Arguably, the problem is that unlike interest rates, fees are not proportional to an account's balance. Already on a low level, service charges on deposits earn a small number of around 0.37% relative to deposits before 2008. Perhaps surprisingly, this number has actually been coming down in recent years, dropping below 0.25% (figure 1.2). While banks have been increasing fees (Azar et al., 2016a), more deposits have been flowing into the banking system at the same time. Intuitively, in a low interest environment households gain little from hunting yield in other investment opportunities, and might as well store their savings in deposit accounts that guarantee absolute safety.

Fees and other forms of non-interest income are therefore small and falling, especially relative to the net interest income of banks, which averages around 3.9% over the period 1984-2013. As a consequence, the overall ROA (net income over assets, including all income and expense) of the median U.S. bank has been significantly lower since the ZLB

started binding in 2009, see the right panel of figure 1.2. The figure also shows that the drop in ROA is concentrated among those banks that rely most heavily on deposits funding, which arguably are most exposed to the ZLB constraint.

Overall, the evidence suggests that the zero lower bound on deposit rates binds, and that it has a negative effect on interest margins and bank profitability. Motivated by this evidence, the rest of this paper develops a model to understand how the zero lower bound affects bank risk taking incentives and capital regulation.

1.3 Model Setup

In the model, time runs discretely from $t = 0, \dots, \infty$. A representative household invests in bank deposits and the financial market, where deposits generate additional utility because they provide liquidity services.

Firms produce output using capital as the only input. There are two technologies to produce new capital, one operated by households, and the other by banks. The former technology represents bank-independent finance, where households directly fund investments through the financial market. Capital produced by banks can be interpreted as bank loans that fund the investment of bank-dependent firms or mortgages. In the remainder I adopt these interpretations, and refer to the technologies as the financial market and bank loans, respectively.¹³

Banks compete monopolistically for deposit funding, subject to a zero lower bound on deposit rates.¹⁴ Banks affect the riskiness of their portfolio by choosing the (non-contractible) monitoring intensity, and are subject to a capital requirement that limits the leverage they can take.

The main focus of the paper is on how the level of interest rates affects risk taking and optimal capital regulation, in particular when the ZLB binds. To generate stochastic variation in interest rates, the household's discount factor varies according to a 2-state Markov process.

The flow diagram in figure 1.3 summarizes the timing within a period t . In the beginning of period t (stage A) firms produce output and pay households and banks a return on their investments made at $t - 1$. Banks use the proceeds to repay depositors and pay a

¹³In the real world, banks lend to firms which in turn make physical investments. Leaving out this extra layer of capital producing firms is equivalent to assuming that there are no frictions between them and banks.

¹⁴Here, the ZLB is exogenously assumed, but it can be motivated by the option to hoard cash with a net return of zero. In this paper, the ZLB plays the role as an off-equilibrium outside option, and its exact motivation is irrelevant.

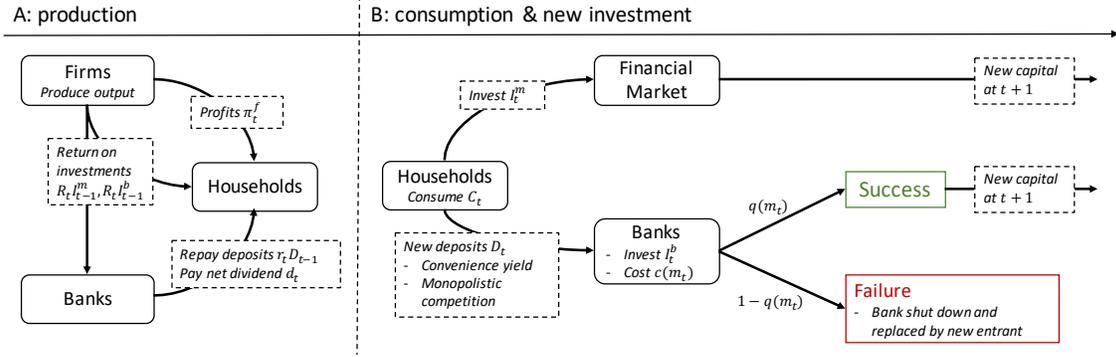


Figure 1.3: Flow diagram summarizing the within-period timing.

dividend, and firms return their profits to households. Afterwards (stage B), households consume and new investments are made.

In the following I describe the individual elements of the model in more detail, solve the problem of firms, households, and banks, define the equilibrium and describe how I calibrate the model.

1.3.1 Firms

A representative firm operates a production technology and produce output using capital K_t as the only input,

$$F(K_t) = K_t^\alpha,$$

where $\alpha < 1$. Capital is owned by firms, which start with an initial capital stock K_0 . In subsequent periods, capital depreciates with a rate δ and firms buy new capital K_t^{new} from households and banks, such that the capital stock evolves according to

$$K_t = (1 - \delta)K_{t-1} + K_t^{new}.$$

Denoting by R_t the return on newly produced capital, firm profits in period t can be written as

$$\pi_t^f = F(K_t) - R_t K_t^{new}.$$

The firm problem is to maximize expected profits, discounted by the household's stochastic discount factor β_t :

$$\max_{K_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t-1} \beta_\tau \right) \pi_t^f. \quad (1.1)$$

The first order condition relates the return on capital to its marginal productivity:

$$R_t[1 - \beta_t(1 - \delta)] = F_K(K_t). \quad (1.2)$$

1.3.2 Household Problem and Liquidity Demand

An infinitely-lived, representative household maximizes her lifetime utility over consumption C_t and liquidity services from deposits D_t . Households have a preference for different varieties of bank deposits indexed by $i \in [0, 1]$. Different varieties could represent a bank specializing in online banking, a big international bank with a prestigious brand, or a local bank with personal relations between clients and advisors. Alternatively, varieties can represent different locations and banks differentiate spatially. Following Dixit and Stiglitz (1977) I model this preference by expressing D_t as a CES composite of varieties $D_{t,i}$,

$$D_t = \left[\int_0^1 D_{t,i}^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}}.$$

Product differentiation gives banks some market power, the degree of which is governed by the elasticity of substitution η .¹⁵ Higher values of η indicate greater ease of substitutability between varieties, implying lower market power. I assume that $\eta > 1$, such that deposits of different banks are substitutes.

A fraction ω of each bank's deposits are insured by the government, which funds the deposit insurance by lump-sum taxes T_t . None of the results in this paper rely on the presence of deposit insurance, and for the most part I set $\omega = 0$ to minimize the number of frictions in the model. Only in the quantitative evaluation of optimal capital requirements in Section 1.6, I calibrate ω to a realistic level to reflect the presence of deposit insurance in the real world.

Next to deposits, households can invest in the financial market I_t^m , to produce capital goods that are sold to firms in the following period. Households are also the owners of firms and banks. Firms rebate their profits π_t^f , and banks make a net dividend payment d_t^b , which may take negative values when raising new equity.

The household's discount factor β_t evolves according to a two-state Markov process. At the beginning of each period, households learn whether $\beta_t = \beta_H$, resulting in high

¹⁵ Arguably, bank market power is not only driven by product differentiation, and for example customer "stickiness" is likely another important determinant. The advantage of the Dixit-Stiglitz model of monopolistic competition is that it is quite tractable in general equilibrium. It is commonly used in the macro literature, and has recently gained popularity in the banking literature (e.g. Drechsler et al., 2016).

interest rates (state $s = H$), or $\beta_t = \beta_L > \beta_H$, resulting in low interest rates (state $s = L$). The probability of transitioning from state s to s' is denoted $P_{ss'}$.

Utility is linear in consumption C_t and concave in deposits D_t ,¹⁶ and the problem of the representative household is given by

$$\begin{aligned}
\max_{C_t, I_t^m, D_{t,i}} \quad & \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t-1} \beta_{\tau} \right) [C_t + \gamma v(D_t)] \\
\text{with} \quad & D_t = \left[\int_0^1 D_{t,i}^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}}, \\
\text{s.t.} \quad & C_t + I_t^m + \int_0^1 D_{t,i} di = R_t I_{t-1}^m + \int_0^1 [\omega + (1-\omega)q_{t-1,i}] r_{t,i} D_{t-1,i} di + d_t^b + \pi_t^f - T_t, \\
& D_{t,i} \geq 0, \forall i.
\end{aligned} \tag{1.3}$$

Here, $\gamma \geq 0$ measures the household's preference for liquidity services, and $v(D_t) = \log(D_t)$ is the ‘‘convenience’’ utility households derive from holding deposits. The deposit rate offered by bank i is denoted $r_{t,i}$, and $q_{t-1,i}$ is the probability that bank i does not fail (chosen by the bank at $t-1$, to be determined below). The first constraint is the household's budget constraint, and the second a non-negativity constraint on deposits.¹⁷ The first-order condition with respect to I_t^m yields the household's Euler equation

$$R_{t+1} \beta_t = 1. \tag{1.4}$$

Since β_t can only take two values, this condition implies that the economy is either in a high-rate environment with $R_{t+1} = 1/\beta_H \equiv R_H$, or a low-rate environment with $R_{t+1} = 1/\beta_L \equiv R_L$. This property highlights the analytical attractiveness of the chosen utility function, namely that the return on capital is a function of the current state only.¹⁸

Next to the financial market, households invest in bank deposits. The demand for

¹⁶The quasi-linear, separable preferences can easily be generalized to a general utility function $U(C_t, D_t)$. This formulation simplifies solving the model, as it implies that the return on capital R_t only depends on the current state.

¹⁷Note that due to log-utility the solution is always interior. I_t^m and C_t can take negative values (as in Brunnermeier and Sannikov, 2014). When $I_t^m < 0$, firms disinvest and return cash to investors. Negative consumption can be interpreted as working.

¹⁸Arguably, variations in discount factors are not the main driver behind movements in interest rates. However, the goal here is not to explain why interest rates are low, and this formulation allows to study the implications of low interest rates while preserving tractability.

deposits of bank i is given by the first-order condition with respect to $D_{t,i}$:

$$D_{t,i}(r_{t+1,i}) = \left[\frac{\gamma v'(D_t)}{1 - [\omega + (1 - \omega)q_{t,i}] \frac{r_{t+1,i}}{R_{t+1}}} \right]^\eta D_t, \quad (1.5)$$

where I use that $\beta_t = 1/R_{t+1}$ by (1.4). Banks can attract more funding, the higher the deposit rate $r_{t+1,i}$ they offer, i.e. the lower the interest margin $R_{t+1}/r_{t+1,i}$. The elasticity of substitution η governs how elastic demand is with respect to deposit rates, as greater substitutability makes it easier for households to switch to competitors. Finally, the demand for deposits increases in the preference for liquidity services γ .

1.3.3 The Bank's Problem

In each period t , bank i sets its gross deposit rate $r_{t+1,i}$, and decides how much equity to contribute per unit of deposit, denoted $e_{t,i}$. Setting deposit rates, banks are subject to a zero lower bound constraint that requires $r_{t+1,i} \geq 1$. Moreover, there is an exogenous capital requirement \bar{e}_t , and regulation requires $e_{t,i} \geq \bar{e}_t$.

Each bank has access to a single project of variable scale $I_{t,i}^b$, interpreted as bank loans. Note that since $e_{t,i}$ is expressed as capital *per unit of deposit*, the total investment scale of the project is $I_{t,i}^b = (1 + e_{t,i})D_{t,i}(r_{t+1,i})$. With probability $q_{t,i} = q(m_{t,i})$, the project succeeds and produces one unit of capital per unit of investment, which can be sold to the representative firm in the following period. Success probabilities are i.i.d. across banks, such that there is no aggregate risk.

In case of failure, the project produces nothing and the bank is in default. Shareholders enjoy limited liability, but failing banks cannot continue operating as they are shut down by the regulator. Each failing bank may be replaced by a new entrant, but the total number of bank licenses is limited by mass 1, such that the total number of banks is constant.¹⁹

Banks that do not fail in a given period pay a net dividend

$$d_{t,i}^b = \underbrace{[R_t(1 + e_{t-1,i}) - r_{t,i}]D_{t-1,i}}_{\text{net interest income}} - \underbrace{[e_{t,i} + (1 + e_{t,i})c(m_{t,i})]D_{t,i}}_{\text{cost of new loans}}, \quad (1.6)$$

which consists of the bank's net interest income (define as the net return on loans, after repaying depositors), net of the monitoring cost and equity it contributes to new loans.

¹⁹Note that it is optimal for new banks to enter, since banks have market power and earn monopolistic rents.

For new entrants, $d_{t,i}^b < 0$, because these banks have no interest income from previous loans and must therefore raise equity externally. Failing banks pay zero dividends as they are shut down.

The project's success probability increases in the monitoring intensity $m_t \geq 0$ chosen by the bank. In principle, $q(m_t)$ can be any function with $q'(m_t) \geq 0$, that is bounded by $\lim_{m_t \rightarrow \infty} q(m_t) \leq 1$, and $\lim_{m_t \rightarrow 0} q(m_t) \geq 0$. For concreteness I use as a functional form the CDF of the Standard Gaussian distribution, $q(m_t) = \Phi(m_t)$.²⁰ Banks incur a cost

$$c(m_t) = \psi_1 + \psi_2 m_t$$

per unit of investment, which consists of two components. The parameter ψ_1 governs the overall cost of operating a bank, such as maintaining a branch network and costs of complying with regulation. The second term depends on the bank's monitoring intensity m_t , and creates a trade-off between risk and return.

Crucially, the bank's monitoring intensity is not contractible, and is chosen after raising deposit funding and choosing their leverage. Banks hence set the level of m_t that maximizes their equity value, which generally does not align with the socially optimal level because shareholders enjoy limited liability.

A central element in the further analysis is the bank's franchise value V_t^b , which generally takes strictly positive values due to the market power of banks.²¹ For the analysis, It turns out to be convenient to define V_t^b as the value of the bank's current and future loans:

$$V_t^b = \max_{m_t, i, e_{t,i}, r_{t+1,i}} \pi_{t,t+1}^b D_{t,i}(r_{t+1,i}, m_{t,i}) + q(m_{t,i}) \beta_t \mathbb{E}_t V_{t+1}^b, \quad (1.7)$$

where $\pi_{t,t+1}^b$ denote discounted expected profits per unit of deposits raised at period t ,

$$\pi_{t,t+1}^b \equiv (q(m_{t,i}) \beta_t [R_{t+1}(1 + e_{t,i}) - r_{t+1,i}] - [e_{t,i} + (1 + e_{t,i})c(m_{t,i})]),$$

²⁰The advantage is that this function is well behaved and bounded between 0 and 1.

²¹When deposit rates are constrained by the ZLB, it may potentially be that the bank's franchise value turns negative. I do not study this case and focus on equilibria with $V_t^b \geq 0$

and the problem is subject to the following constraints:

$$m_{t,i} = \arg \max_{m_{t,i}} \pi_{t,t+1}^b D_{t,i} + q(m_{t,i}) \beta_t \mathbb{E}_t V_{t+1}^b, \quad (1.8)$$

$$D_{t,i}(r_{t+1,i}, m_{t,i}) = \left[\frac{\gamma v'(D_t)}{1 - [\omega + (1 - \omega)q(m_{t,i})]^{\frac{r_{t+1,i}}{R_{t+1}}}} \right]^\eta D_t, \quad (1.9)$$

$$e_{t,i} \geq \bar{e}_t, \quad (1.10)$$

$$r_{t+1,i} \geq 1. \quad (1.11)$$

Equation (1.9) is the demand for deposit variety i derived from the household problem, (1.10) is the regulatory capital requirement, and (1.11) is the ZLB constraint. Eq. (IC) is an incentive-compatibility constraint characterizing the bank's non-contractible monitoring decision.

Since the bank's decides sequentially on its funding and then monitoring, the problem is solved backwards, starting with the optimal monitoring choice *for a given level of* $D_{t,i}$ *and* $e_{t,i}$. The incentive-compatible m_t is characterized by the first order condition to (IC):

$$c'(m_{t,i})(1 + e_{t,i})D_{t,i} = q'(m_{t,i})\beta_t [(1 + e_{t,i})R_{t+1} - r_{t+1,i}] D_{t,i} + \mathbb{E}_t V_{t+1}. \quad (1.12)$$

Intuitively, the bank equates the marginal cost of monitoring on the left-hand side to the marginal benefit on the right-hand side. The higher the bank's profits from current loans, and the higher its expected franchise value $\mathbb{E}_t V_{t+1}^b$, the more intensely it monitors.

Denote by $m_{t,i}^*$ the optimal $m_{t,i}$ that solves (1.12). In the first stage, the bank chooses $e_{t,i}$ and $r_{t+1,i}$ taking into account how its choices may affect $m_{t,i}^*$ in the second stage. The FOC w.r.t. $e_{t,i}$ is as follows:

$$\frac{\partial V_t^b}{\partial e_{t,i}} = \underbrace{q(m_{t,i})\beta_t R_{t+1} - (1 + c(m_{t,i}))}_{<0} + \underbrace{\frac{dm_{t,i}^*}{de_{t,i}} \frac{\partial D_{t,i}(r_{t+1,i}, m_{t,i})}{\partial m_{t,i}} \pi_{t,t+1}^b}_{\text{Incentive effect}} \quad (1.13)$$

The first term in (1.13) reflects the cost of equity and is always negative (because $\beta_t R_{t+1} = 1$, by the household's Euler equation (1.4)). Equity is costly, because equity does not carry any convenience yield, and households can invest in the financial market as an alternative to bank equity, where they can create new physical capital without incurring the bank's operating cost $(1 + c(m_t))$.²²

²²Note, however, that this does *not* imply that households are unwilling to hold bank stock. If bank stocks were traded, they would in fact do so at strictly positive values, reflecting the monopolistic rents banks earn. The subtle difference here is between raising new equity and the value of outstanding

The second term reflects an incentive effect. Equity credibly signals to depositors that banks monitor more intensely in the second stage, allowing banks to attract more deposits. The bank's optimal $e_{t,i}$ can either be at an interior solution to (1.13) where $\frac{\partial V_t^b}{\partial e_{t,i}} = 0$ or at the regulatory capital constraint if $\frac{\partial V_t^b}{\partial e_{t,i}} < 0$ at $e_{t,i} = \bar{e}_t$.

Under full deposit insurance ($\omega = 1$), depositors become insensitive to a bank's risk taking and banks always choose to be at the regulatory constraint.²³ More generally, the empirically plausible case seems to be that banks choose to be at the regulatory capital constraint. Appendix 1.8.3 uses the model's calibration and numerical solution to show that banks indeed endogenously choose to be at the regulatory capital constraint, even in the complete absence of deposit insurance (except for some extreme cases with capital requirements near zero). For that reason, I focus on the corner solution $e_{t,i} = \bar{e}_t$ for all analytical results.

The first-order conditions with respect to the deposit rate implicitly defines the interior solution $r_{t+1,i}^*$:

$$\frac{r_{t+1,i}}{R_{t+1}} = \frac{\rho_2}{\rho_1} \left[\frac{\eta - 1/\rho_2}{\eta - 1} - \frac{\eta}{\eta - 1} \frac{(1 - q(m_{t,i}))e_{t,i} + (1 + e_{t,i})c(m_{t,i})}{q(m_{t,i})} \right], \quad (1.14)$$

where

$$\begin{aligned} \rho_1 &\equiv \omega + (1 - \omega) \left(q(m_t) + \frac{\eta}{\eta - 1} q'(m_t) r_{t+1} \frac{dm_t^*}{dr_{t+1}} \right), \\ \rho_2 &\equiv \omega + (1 - \omega) \left(q(m_t) + q'(m_t) r_{t+1} \frac{dm_t^*}{dr_{t+1}} \right). \end{aligned}$$

The deposit rate is either at the interior solution to (1.14), or at the corner $r_{t+1,i} = 1$ if the ZLB binds. For illustration, it is useful to consider the case of full deposit insurance ($\omega = 1$), in which case $\rho_1 = \rho_2 = 1$, and hence

$$r_{t+1,i} = \max \left\{ R_{t+1} \left[1 - \frac{\eta}{\eta - 1} \frac{(1 - q(m_{t,i}))e_{t,i} + (1 + e_{t,i})c(m_{t,i})}{q(m_{t,i})} \right], 1 \right\}.$$

In the first case in the max-function, banks set the deposit rate at an interior solution, proportional to the return on capital. Deposit rates are below R_{t+1} , as banks pass on their costs and charge a mark-up that depends on the elasticity of substitution between deposits η (a higher level of η implies less market power and hence higher deposit rates). If this

equity. While outstanding stocks are valuable, bank management would never voluntarily raise new equity funding.

²³It is easily verified that with $\omega = 1$, $\frac{\partial D_{t,i}(r_{t+1,i}, m_{t,i})}{\partial m_{t,i}} = 0$, such that the incentive effect vanishes.

interior solution is smaller than 1, the ZLB binds and the second case in the max-function applies.

In the more general case with $\omega < 1$, the terms ρ_1 and ρ_2 capture that banks have to compensate depositors for the risk they take, and that banks take into account that their deposit rate affects their optimal monitoring decision m_t^* in the second stage.

1.3.4 Government

To close the model, the government runs a balanced budget to finance the deposit insurance. In the remainder I will focus on symmetric equilibria, such that each period a fraction $(1 - q(m_{t-1}))$ of banks fail, and the government needs to raise taxes of

$$T_t = \omega(1 - q(m_{t-1}))r_t D_{t-1} \quad (1.15)$$

to repay depositors of failing banks. The capital requirement \bar{e}_t is taken as exogenously given for now, and Section 1.6 derives the welfare-maximizing level of \bar{e}_t .

1.3.5 Equilibrium

The only state variables of the model are the capital stock K_t and the realization of the discount factor β_t . Both are known at the beginning of the period, and decisions are made subsequently. In the following equilibrium definition and the remainder of the paper I focus on symmetric equilibria, in which all banks choose the same deposit rate and monitoring intensity.

Definition. *Given capital requirements $\{\bar{e}_t\}_{t=0}^{t=\infty}$, transition probabilities $P_{ss'}$, an initial state $s_0 \in \{H, L\}$, and an initial capital stock K_0 , a symmetric competitive equilibrium is a set of prices $\{R_t, r_t\}_{t=0}^{t=\infty}$ and allocations $\{K_{t+1}, I_t^m, I_t^b, C_t, D_t, e_t, m_t, T_t\}_{t=0}^{t=\infty}$, such that*

(a) *Given an initial capital stock K_0 and prices $\{R_t\}_{t=0}^{t=\infty}$, firms maximize profits (3.4).*

(b) *Given prices $\{R_t, r_t\}_{t=0}^{t=\infty}$, households maximize lifetime utility solving (3.2).*

(c) *Given prices $\{R_t\}_{t=0}^{t=\infty}$, banks maximize net dividends solving (1.7).*

(d) *Market clearing is satisfied at any time $t \geq 0$*

- *aggregate resource constraint:*

$$C_t + I_t^m + I_t^b(1 + c(m_t)) = F(K_t),$$

- *capital*:

$$K_t = (1 - \delta)K_{t-1} + K_t^{new},$$

with

$$K_t^{new} = I_{t-1}^m + q(m_t) \underbrace{(1 + e_{t-1})D_{t-1}}_{=I_{t-1}^b}.$$

The set of equations describing the equilibrium is summarized in Appendix 1.8.1. The forward-looking nature of the bank’s problem and the occasionally binding ZLB constraint potentially complicate solving the model. However, owing to the simple stochastic structure and linear utility function, the equilibrium values of all variables relevant for the bank’s forward-looking problem (R_t , e_t and D_t) depend on the current state only, i.e. they are memory-less and independent of the time period t .²⁴ This property simplifies solving the forward-looking bank problem, as it allows to express the expected franchise value as

$$\mathbb{E}_s V_{t+1} = P_{ss'} V_s + (1 - P_{ss'}) V_{s'}.$$

Therefore, the bank’s value function can be solved as a simple system of non-linear equations. For ease of notation I denote the value of a memory-less variable x_t in state s simply as x_s , and the expectations given state s as $\mathbb{E}_s x_{t+1} \equiv \mathbb{E}_t[x_{t+1}|s]$.²⁵

1.3.6 Calibration

I derive as many results as possible analytically, but also rely on a numerical solution when analytics are ambiguous, as well as for the quantification of optimal capital requirements in Section 1.6. For this purpose, I calibrate the model to U.S. data. The calibration also allows me to get a sense for the magnitude of analytical results.

The high-rate state represents “normal times”, with safe, short term rates away from the ZLB, such as the period from the 1990s until the financial crisis in 2008. Accordingly, I set $\beta_H = 0.95$ to generate a return on capital of around 5.5%, which is equal to the average yield on AAA corporate bonds over the period 1996-2008, as reported in FRED.²⁶ The level of rates in the low-rate state is one of the main comparative statics of interest. In the baseline calibration, $\beta_L = 0.975$ to target the average AAA corporate bond yield

²⁴In fact, the equilibrium values of all variables except for I_t^m and C_t are memory-less.

²⁵With non-linear utility, the model can be solved globally by value function iteration. This would require iterating back and forth between the household problem and the bank problem, taking into account equilibrium conditions.

²⁶BofA Merrill Lynch US Corporate AAA Effective Yield© [BAMLC0A1CAAAY], retrieved from FRED, Federal Reserve Bank of St. Louis; <https://fred.stlouisfed.org/series/BAMLC0A1CAAAY>.

over 2009-2013 at around 2.5%.

Regarding aggregate Macro moments, I set $\delta = 0.065$, equal to the average depreciation rate of the U.S. capital stock from 1970-2016, computed using the BEA's Fixed Assets Tables 1.1 and 1.3. Using the same data and period, I compute an average capital-output ratio of 3.25. Accordingly, I set $\alpha = 0.38$, such that $K_H/Y_H = 3.25$ in the high-rate state.

Next, I set the capital requirement s.t. $\bar{e}_t/(1 + \bar{e}_t) = 0.085$, equal to the minimum requirement for the Tier 1 capital ratio in the Basel III framework. I also set $\omega = 0.57$, equal to the aggregate amount of deposits insured by the FDIC, divided by the aggregate amount of deposits of regulated U.S. banks in 2017. Note that for all analytical results in Section 1.4 I set $\omega = 0$, to highlight the main mechanisms under a minimal number of frictions. Only for the quantification of optimal capital requirements in Section 1.6 I use $\omega = 0.57$.

The cost function parameters ψ_1 and ψ_2 are set to reflect the average net non-interest expense of banks in the Call Reports data over 1984-2013, at around 2.3% of assets. The parameter ψ_2 reflects the cost of monitoring, and hence governs a bank's failure probability ($1 - q(m_H)$). Hence, I also target the the average annual proportion of banks failing in the U.S. of around 0.76% (computed by Davydiuk (2017) using the Failed Bank List issued by the FDIC). This yields $\psi_1 = 0.011$ and $\psi_2 = 0.018$.

The elasticity of substitution η affects bank market power and hence interest margin $R_H - r_H$. Following Drechsler et al. (2016) I use Call Reports data to proxy deposit rates as the deposit interest expense per unit of deposits. Similarly, I calculate the interest income rate as the ratio of interest income over total assets, and the interest margin as the difference between interest income and expense ratio. The average interest margin over the period 1996-2008 is 3.5%, consistent with a value of $\eta = 4.5$.

Given the calibration of the bank variables I set the parameter γ , which governs the preference for liquidity. Doing so, I target the ratio of aggregate deposit liabilities of U.S. chartered institutions to the aggregate debt liabilities of non-financial corporates using data from the Flow of Funds. Setting $\gamma = 0.005$ results in a ratio ratio of $D_H/(D_H + K_H^m) = 0.02$, consistent with Flow of Funds data.

Finally, in the baseline calibration I set the transition probabilities equal to $P_{HH} = 0.9$ and $P_{LL} = 0.8$. This implies an expected duration of 10 years spent in the high-rate state, and 5 years in the low-rate state. For comparison, the Federal Funds Rate target range was at 0% for seven years, from December 2008 to December 2015. All parameter values are summarized in Table 1.2 in Appendix 1.8.2.

1.3.7 Discussion of the Framework

This section discusses the assumptions in the model.

Convenience yield. The money in the utility approach assumes a social value of bank debt. While a shortcut, the banking literature has identified several micro-foundations that motivate this assumption. Because bank debt is information-insensitive, it protects depositors from better informed traders (Gorton and Pennacchi, 1990; Dang et al., 2017). Its demandability may incentivize monitoring (Diamond, 1984), and facilitates the transformation of risky long-term assets into liquid and safe claims (Diamond and Dybvig, 1983; Ahnert and Perotti, 2017). Moreover, banks invest into ATM networks and electronic payment infrastructure that make deposits a convenient medium of exchange.

Bank costlier than the financial market. It is costlier for banks to produce new capital goods than it is via the financial market. This assumption ensures that it is socially costly to provide equity to banks, as the financial market provides a superior outside option, i.e. that the banks' FOC w.r.t. equity (1.13) is negative. It ensures a meaningful trade-off between overcoming moral hazard and the cost of bank equity, and can be interpreted as operating costs such as the costs of operating a branch network and complying with regulation.

One might expect that the convenience yield of deposits already makes bank equity costly. This would only hold in a model in which the balance sheet size of a bank is fixed and the relevant opportunity cost is the interest paid on deposits. If instead banks can expand the size of their balance sheet, the relevant opportunity cost is the required return of shareholders, which in this model is given by the financial market.²⁷

Riskless financial market. Taken literally, in the model banks are riskier than the financial market. However, one could easily introduce risk in the financial market. In fact, because households are risk-neutral one may simply re-interpret the return in the financial market as a risky return that pays R_{t+1} *in expectation*. What matters is that there is some risk in the bank's investment, to open the possibility of bank failure and introduce the risk-shifting moral hazard I am interested in.

²⁷To see this, consider a version of the model in which the total investment size $I_t^b = (1 + e)D_t$ is fixed at $I_t^b = 1$, s.t. $D_t = \frac{1}{1+e_t}$. In this case, the banks' FOC w.r.t. e_t is negative if and only if $r_{t+1} < \frac{R_{t+1}}{q(m_t)}$. Given risk-neutrality, the required return on deposits would indeed be less than $R_{t+1}/q(m_t)$ if there is a convenience yield.

Market power on the lending side. While banks have market power in deposit markets, in the model they are price takers on the lending side. In the real world, banks have some market power over borrowers that cannot easily substitute bank funding for other sources of finance, such as small businesses and households. Market power on the lending side could potentially alleviate some of the pressure on profitability at the ZLB, and instead result in a misallocation of finance between bank-dependent and bank-independent borrowers. However, at the margin some borrowers can substitute to other sources of finance. While market power may support margins to some extent, it would thus not fully overcome the problem.

1.3.8 First Best and Inefficiencies

Before proceeding, it is useful to understand what market failures lead to inefficiencies in this economy. The non-contractability of monitoring in combination with limited liability for shareholders imply that the incentives of bank shareholders may not be aligned with the social optimum. Moreover, households receive less than the competitive return on deposits because banks have market power.

To see how these market failures affect equilibrium outcomes, it is useful to characterize the first best allocation (FB) and contrast it to the competitive equilibrium (CE). The first best allocation is the solution to a planner's problem, who directly chooses risk taking, consumption and investment subject to aggregate resource constraints:

$$\begin{aligned}
& \max_{C_t, I_t^m, D_{t,i}, m_t, e_t} && \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t-1} \beta_{\tau} \right) [C_t + \gamma v(D_t)] \\
& \text{with} && D_t = \left[\int_0^1 D_{t,i}^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}}, \\
& \text{s.t.} && C_t + I_t^m + \int_0^1 (1 + e_{t,i}) D_{t,i} (1 + c(m_{t,i})) = F(K_t), \\
& && K_t = (1 - \delta) K_{t-1} + I_{t-1}^m + q(m_t) (1 + e_t) D_t
\end{aligned} \tag{1.16}$$

From the CES aggregator it follows immediately that the planner allocates the same amount of deposit funding to each bank, $D_{t,i} = D_t$. Moreover, since the bank's investment technology is costlier than the financial market, investments into banks can only be socially useful if they are in the form of deposits, and hence $e_t = 0$. The remaining variables are

chosen according to the first-order conditions w.r.t. I_t^m , m_t and D_t :

$$\beta_t R_{t+1} = 1 \tag{1.17}$$

$$c'(m_t) = q'(m_t) \tag{1.18}$$

$$D_t = \frac{\gamma}{1 - q(m_t) + c(m_t)} \tag{1.19}$$

These three conditions are readily compared to their counterparts in the competitive equilibrium. First, (1.17) is equivalent to the household's Euler equation (3.2), implying that the overall level of capital accumulation is not distorted.

In contrast, condition (1.18) differs from its counterparts in the CE. In the FB allocation, $\frac{c'(m_t)}{q'(m_t)} = 1$. This is not generally true in the CE, as revealed by the bank's FOC w.r.t monitoring (1.12).

Similarly, condition (1.19) can be compared to the demand for deposits by households (1.19), after rewriting it as

$$D_t = \frac{\gamma}{1 - [\omega + (1 - \omega)q(m_t)] \frac{r_{t+1}}{R_{t+1}}}. \tag{1.20}$$

Clearly, the quantity of deposits in the CE is only equal to its FB level if $\frac{r_{t+1}}{R_{t+1}} = 1 - \frac{c(m_t)}{q(m_t)}$. However, this is not generally true, see (1.14).

These two comparisons show that misallocations arise because banks do not choose the optimal amount of risk taking, and do not provide the optimal amount of liquidity via deposits. These inefficiencies are a result of the two frictions in the model. Limited liability gives bank shareholders an option-like payoff, as they do not fully internalize losses incurred in case of failure. This convex payoff structure induces excessive risk taking. On the other hand, monopolistic competition implies that banks may take *less* risk relative to the FB. The reason is that the bank's franchise value reflects rents due to market power, which are of private value to bank shareholders but do not add to welfare. Overall, bank shareholders trade off the gains from shifting risk on depositors against the risk of loss of franchise value. In the baseline calibration, banks take excessive risk relative to the first best (failure probability of 0.76% vs 0.17% in the first best).

While market power may reduce those excessive risk-taking incentives, it also reduces the liquidity provision by banks. Low deposit rates weaken the demand for deposits by households, resulting in an inefficiently low quantity of liquidity production in equilibrium.

1.4 Risk Taking and Capital Regulation at the Zero Lower Bound

The analysis in this section is of positive nature, to understand how risk taking incentives are affected by the level of interest rates and capital regulation, and how the two interact. The answer depends on whether the ZLB binds occasionally in the low-rate state, so a first step is to show under what conditions deposit rates do become constrained.

1.4.1 Zero Lower Bound

Banks set their deposit rate according to the first-order condition (1.14). This may either be at an interior solution if the return on capital is sufficiently high, and at the corner solution $r_{t+1} = 1$ if the ZLB binds.

Lemma 1. *At any time t , in state s the ZLB is slack (i.e. banks set an interior deposit rate $r_s \geq 1$) if and only if*

$$\beta_t \leq \beta_t^{ZLB}, \quad (1.21)$$

where β_t^{ZLB} is implicitly defined as the β_t that solves (1.14) at $r_{t+1} = 1$.

Lemma 1 defines a threshold β_t^{ZLB} , below which the ZLB binds. In the baseline calibration, this threshold is around 0.9669, such that deposit rates hit the ZLB when the return on capital drops below 3.5% ($= 1/\beta_t^{ZLB} - 1$). The return on capital is above this threshold in the high-rate state (5.5%), while in the low-rate state $R_L - 1 = 2.5\%$ and the ZLB binds.

1.4.2 Do Low Interest Rates Spur Risk Taking?

To answer this question, consider a marginal increase in the discount factor β_t . By the household's Euler Equation (1.4) the direct effect of an increase in β_t is to push down R_{t+1} . To understand how this affects risk taking, rewrite the bank's FOC w.r.t. monitoring (1.12) as

$$\frac{c'(m_t)}{q'(m_t)} = 1 - \underbrace{\frac{1}{(1+e_t)} \frac{r_{t+1}}{R_{t+1}}}_{\text{Margin on current loans}} + \underbrace{\frac{\mathbb{E}_t V_{t+1}}{I_t^b R_{t+1}}}_{\text{Discounted franchise value}}. \quad (1.22)$$

The left-hand side increases in m_t ,²⁸ and the right-hand side reveals that falling R_{t+1} affects monitoring via a *margin channel* and a *discounting channel*. When R_{t+1} falls,

²⁸This is easy to verify because $c'(m_t) = \psi_2$ and $q'(m_t)$ is the PDF of the Standard Gaussian Distribution and hence decreases for any $m_t \geq 0$.

banks discount their continuation value less, boosting overall franchise value. Via this discounting channel, lower interest rates induce banks to monitor more intensely, i.e. take less risk. On the other hand, a low investment return may harm interest margins and thereby induce higher risk taking. Hence, the overall effect on risk taking depends on the balance between the discounting and margin channel.

The following proposition shows that at the ZLB the margin channel dominates:

Proposition 1. *Hold $\beta_{t+1}, \beta_{t+2}, \dots$ fixed, and consider the comparative statics of monitoring m_t with respect to the discount factor β_t . If $\beta_t > \beta_t^{ZLB}$ (binding ZLB), a necessary condition for*

$$\frac{dm_t}{d\beta_t} \leq 0$$

is that $\beta_t \geq \frac{1}{2[\omega+(1-\omega)q(m_t^*)]}$.

Note that the necessary condition in Proposition 1 only fails for very unrealistic parameterizations. For example, with $\omega = 0$ (no deposit insurance), at $\beta_t = 0.95$ the condition holds for $q(m_t) > 0.526$, i.e. for annual failure rates below 47.4%. The baseline calibration in Section 3.6 targets a failure rate below 1%, in line with the actual failure rate of U.S. banks in the data. Appendix 1.8.4 gives the proof to Proposition 1 and derives a sufficient condition that is satisfied for an even wider parameter space. Intuitively, when the ZLB binds,

$$\frac{r_{t+1}}{R_{t+1}} = \frac{1}{R_{t+1}}, \tag{1.23}$$

and any reduction in R_{t+1} eats one for one into interest margins, such that the margin effect dominates.

In contrast, away from the ZLB it is less clear which effect dominates. As long as banks set deposit rates according to the interior solution in (1.14), the relevant equilibrium ratio $\frac{r_{t+1}}{R_{t+1}}$ is quite stable as banks can pass on a reduction in R_{t+1} to depositors (see Eq. (1.22)). Therefore, the discounting channel tends to dominate when the ZLB is slack, and lower interest rates induce less risk taking. Even though this result is difficult to prove analytically, Appendix 1.8.4 shows it for the case $\omega = 1$.

While the comparative statics in Proposition 1 refer to a marginal change in β_t , keeping $\beta_{t+1}, \beta_{t+2}, \dots$ fixed, Figure 1.4 uses the numerical solution to verify that the same results obtain when changing β_L along the entire equilibrium path. The left panel of Figure 1.4 shows that as long as $\beta_L \leq \beta_L^{ZLB}$, banks can decrease deposit rates proportionately, guaranteeing a stable interest margin. In contrast, when $\beta_L > \beta_L^{ZLB}$ the ZLB binds and margins shrink.

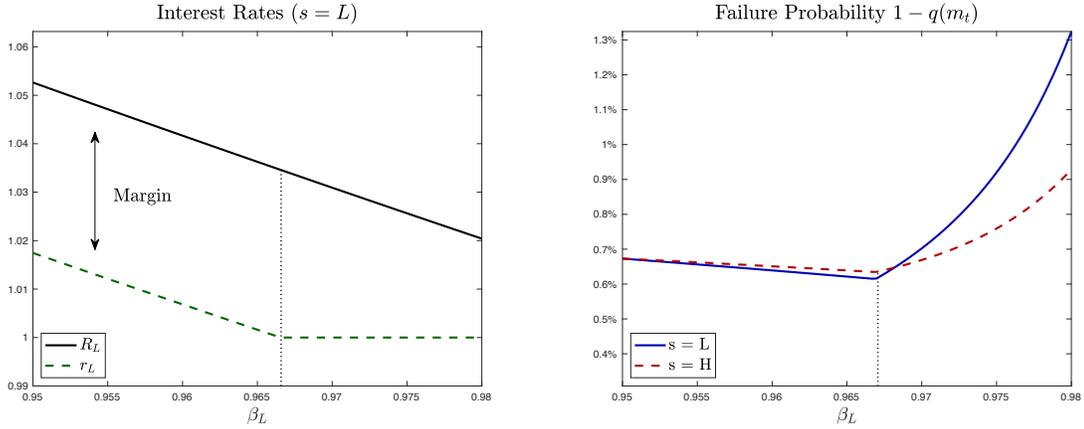


Figure 1.4: This figure plots equilibrium interest rates in the low-rate state ($s = L$), and equilibrium bank risk taking in both the low- and high-rate states, against the discount factor in the low-rate state β_L . Parameters are calibrated as described in section 3.6.

The right panel of Figure 1.4 plots the equilibrium failure probability $1 - q(m_t)$ against the discount factor β_L . The discounting effect dominates as long as the ZLB is slack ($\beta_L \leq \beta_L^{ZLB}$), even though the magnitude of the effect is quite modest. Failure probabilities fall by a few basis points as the return on capital falls from above 5% (at $\beta = 0.95$) to around 3.5% (at $\beta = \beta_L^{ZLB}$). In contrast, when the ZLB binds the margin channel dominates and falling interest rates result in a sizable increase in risk taking. The annual probability of failure more than doubles from around 0.6% to above 1.3%, as the return on capital falls from 3.5% (at $\beta_L = \beta_L^{ZLB}$) to 2% (at $\beta_L = 0.98$).

Figure 1.4 also reveals that a binding ZLB in the low-rate state affects risk taking in the high-rate state, even though the ZLB is slack in the high-rate state ($s = H$, see the dashed red line). The reason is that incentives are not only affected by current profits, but also expected profitability going forward.

1.4.3 Expectations Matter

Because expected profitability affects franchise value, it matters for how long the economy is expected to remain at the ZLB:

Proposition 2. *Suppose that $\beta_H < \beta_H^{ZLB}$ and $\beta_L > \beta_L^{ZLB}$ (ZLB slack in the high-rate state, and binding in the low-rate state). There exists a threshold $\hat{\beta} \leq \beta_L^{ZLB}$, s.t. if*

$$\beta_L \geq \hat{\beta}, \tag{1.24}$$

then $V_H^b > V_L^b$. In this case, equilibrium monitoring in states $s = H, L$ decreases the more

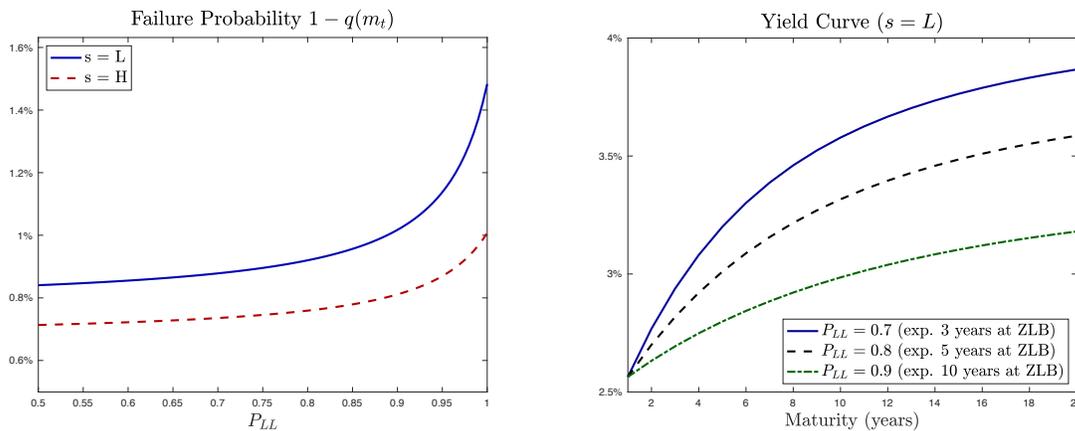


Figure 1.5: This figure plots bank risk taking in both the low- and high-rate states, against the probability of staying in the low-rate state (left panel). The right panel illustrates how an increase in the probability of remaining in the low-rate state P_{LL} translates into a flattening of the yield curve.

Parameters are calibrated as described in section 3.6.

time the economy is expected to spend at the ZLB:

$$\frac{dm_t}{dP_{LL}} \leq 0, \frac{dm_t}{dP_{HL}} \leq 0$$

When $\beta_L > \hat{\beta}$, the ZLB binds and intermediation margins are sufficiently compressed, such that the bank's franchise value in the high-rate state exceeds that in the low-rate state ($V_H^b > V_L^b$). In this case, the overall value of banks is lower, the more time the economy spends in the low-rate state. Low expected profitability erodes franchise value and boosts risk taking incentives.

The left panel in Figure 1.5 illustrates the result of Proposition 2. It plots the equilibrium failure probability $1 - q(m_s)$ for $s = H, L$, against the likelihood of remaining in the low-rate state P_{LL} . In the baseline calibration indeed $V_H^b > V_L^b$, such that Condition (1.24) is satisfied and an increase in P_{LL} results in more risk taking (lower success probability $q(m_s)$).

The right panel in Figure 1.5 connects this result to the yield curve, here computed assuming the expectations hypothesis holds.²⁹ A zero interest environment may be particularly problematic if the yield curve flattens substantially and rates are expected to be at the ZLB for long. The target range for the Fed Funds rate was lowered to 0% in December 2008, where it remained for seven years until the Fed started lifting rates in December 2015. An expected duration of seven years corresponds to a probability of staying in the

²⁹I.e. the forward rate from date t to $t + \tau$ is calculated as $R_{t,t+\tau} = (R_{t+1} \times R_{t+2} \cdots \times R_{t+\tau})^{1/\tau}$.

low-rates state of around $P_{LL} \approx 0.85$. In the Eurozone rates are expected to remain near-zero for an even longer time. The ECB lowered its deposit facility rate close to zero by the beginning of 2009, and did not start the process of increasing rates by end 2018.

Even with rates in the U.S. rising, the overall level of interest rates is expected to remain low (perhaps due to demographic change and weak demand for finance by corporations). This increases the likelihood that upon the next monetary policy loosening cycle rates will hit the ZLB again. Proposition 2 shows that even when banks are not currently constrained by the ZLB, the prospect of a binding ZLB in the future affects incentives. The more likely the economy transitions from the high-rate to the low-rate state (higher P_{HL}), the higher the chance that banks face weak profitability in the future, and hence the more risk they take.

1.4.4 Discussion of the Mechanism

In the model, risk taking is driven by bank franchise value, consistent with previous literature and several empirical studies. For example, Jiang et al. (2017) exploit the differential process of bank deregulation across U.S. states to show that a deregulation-induced increase in competition increases risk taking through reduced profits and bank franchise values. Similarly, Beck et al. (2013) find support for a positive relation between bank competition and fragility across a large set of countries, while Craig and Dinger (2013) find a positive relation between bank risk taking and deposit market competition.

Franchise value, in turn, is driven by interest margins and bank competition. As long as the ZLB is slack, interest margins are determined by market power. At the ZLB, bank competition is distorted, as depositors are unwilling to accept negative interest rates. Drechsler et al. (2016) argue more generally that the closer interest rates are to zero, the more bank deposits compete with cash and hence the lower bank market power. With a more general substitutability between cash and deposits, a reduction in interest rates would undermine bank market power even above zero. Consequently, the margin channel described in Proposition 1 might already be more strongly at play with a slack ZLB, and a reduction in interest rates might increase risk taking incentives even when the ZLB is slack. Still, franchise value and hence incentives would be disproportionately affected once the ZLB binds, consistent with high-frequency studies of bank stock price reactions to monetary policy announcements. English et al. (2012) and Ampudia and Van den Heuvel (2017) find that interest rate decreases boost bank stock prices if and only if the ZLB is slack.

The overall mechanism closely mirrors evidence in Heider et al. (2016). In a diff-in-diff

setting, the authors show that negative policy rates in the Eurozone have eaten relatively more into the interest margin of banks with more deposit relative to wholesale funding. Consistent with the notion that tight margins spur risk taking, these banks are shown to increase their lending to riskier borrowers as interbank rates fall below zero.

Competition-stability framework? Contrary to this paper, other contributions in the literature show that higher bank competition may actually decrease risk taking incentives. For example, Boyd and De Nicrolo (2005) place the risk shifting problem at the firm rather than the bank level. By charging lower lending rates, a more competitive banking sector then increases the “margin” of firms (between asset returns and borrowing rates), thereby increasing firm franchise value and hence lowering risk taking. Interestingly, the main result in this section is robust to whether the moral hazard problem is placed with banks or with firms.

To see this, consider a variation of the model, in which the risk taking decision is done by firms, which earn a margin between final asset returns and lending rates, which in turn depend on the competitiveness of the banking sector. When the ZLB constrains deposit rates, falling returns inevitably reduce the margin between final asset returns and deposit rates. Some of that squeeze in margins would have to be borne by firms, inducing them to take more risk.

1.5 The Effectiveness of Capital Requirements at the ZLB

In the model, the main policy tool to curb risk taking incentives are capital requirements:

Proposition 3. *An increase in the capital requirement induces banks to monitor more intensely in equilibrium:*

$$\frac{dm_t}{d\bar{e}_t} \geq 0.$$

Intuitively, higher capital increase a bank’s “skin in the game”. As shareholders put more of their own funds at stake, their payoff becomes less convex, inducing more prudent investment (Holmstrom and Tirole, 1997). However, at the ZLB a countervailing effect comes into play. When banks are unable to pass on the cost of capital to depositors, tight capital requirements eat into bank profitability and erode franchise value:

Lemma 2 (Franchise Value Effect). *For a given level of monitoring m_t (but taking into account how banks optimally set deposit rates in (1.14)), bank profits as a function of capital requirements \bar{e}_t are given by*

$$\pi_s^b(\bar{e}_t; m_t) = \begin{cases} q(m_t) \left(1 - \frac{\rho_2 - 1}{\rho_1(\eta - 1)}\right) + \left(\frac{\rho_2}{\rho_1} \frac{\eta}{\eta - 1} - 1\right) [(1 - q(m_t))\bar{e}_t + (1 + \bar{e}_t)c(m_t)], & \text{if } \beta_t \leq \beta_t^{ZLB} \\ q(m_t)(1 - \beta_t) - c(m_t) - \bar{e}_t[1 + c(m_t) - q(m_t)], & \text{if } \beta_t > \beta_t^{ZLB} \end{cases}$$

Profits decrease in \bar{e}_t if and only if the ZLB binds:

- $\frac{\partial \pi_s^b(\bar{e}_t; m_t)}{\partial \bar{e}_t} \geq 0$ if $\beta_t \leq \beta_t^{ZLB}$ (ZLB slack)
- and $\frac{\partial \pi_s^b(\bar{e}_t; m_t)}{\partial \bar{e}_t} \leq 0$ otherwise.

Lemma 2 shows in partial equilibrium that bank profitability is negatively affected by higher capital requirements if the ZLB binds. The reason is that with a slack ZLB, banks can fully pass on the cost of capital to depositors. This can be seen when differentiating the deposit rate r_{t+1} in (1.14) w.r.t. e_t (setting $\omega = 1$ for ease of illustration):

$$\frac{\partial r_{t+1}}{\partial e_t} = -\frac{\eta}{\eta - 1} \left[\frac{(1 - q(m_t)) + c(m_t)}{q(m_t)} \right] R_{t+1} < 0$$

Banks set lower deposit rates, the higher capital requirements are. The term in square brackets reflects the cost of equity. Relative to the financial market, bank equity is expensive because banks incur operating costs $c(m_t)$, and fail with prob. $(1 - q(m_t))$, while investing via the financial market does not carry any cost, and produces physical capital with certainty. Under perfect competition, $\eta \rightarrow \infty$, and banks just pass on the cost of capital. The more market power banks have (smaller η , larger $\frac{\eta}{\eta - 1}$), the more aggressively they pass on the cost of capital to depositors.

Figure 1.6 confirms the partial equilibrium result of Lemma 1 in general equilibrium. The left panel plots the equilibrium franchise value in the low-rate state V_L against the capital requirement \bar{e}_L (keeping \bar{e}_H fixed), for different levels of β_L and likelihood of remaining in the low-rate state P_{LL} .

With $\beta_L = 0.95$ the ZLB is slack at all times, and capital requirements actually have an overall positive effect on V_L , consistent with Lemma 1. In contrast, with $\beta_L = 0.975$ the ZLB binds and higher capital requirements erode profitability. This adverse effect is particularly strong the higher P_{LL} , i.e. the longer the economy remains at the ZLB in expectation.

The right panel of Figure 1.6 shows the implications for equilibrium monitoring. The more the capital requirement depresses franchise values, the less it curbs risk shifting

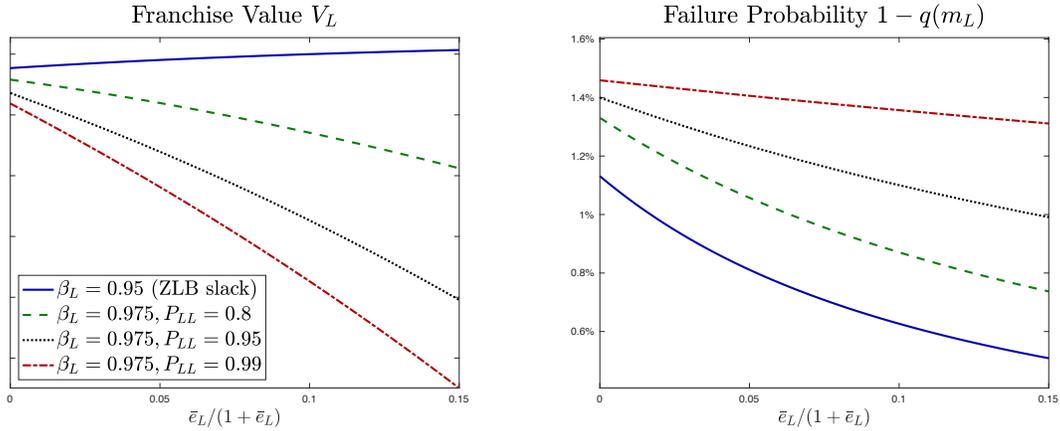


Figure 1.6: This figure plots franchise values (left panel) and risk taking (right panel) in the low-rate state, against the capital requirement \bar{e}_L . Different lines represent different levels of interest rates and probability of remaining in the low-rate state. Parameters are calibrated as described in section 3.6.

incentives. For example, franchise values drop much more with $\beta_L = 0.975$ and $P_{LL} = 0.99$ than in the baseline calibration with $\beta_L = 0.975$ and $P_{LL} = 0.8$ (representing an expected duration of 5 years at the ZLB). Accordingly, the line representing $P_{LL} = 0.99$ in the right panel is much flatter, i.e. a marginal increase in capital requirements reduces risk shifting incentives relatively less.

Via the skin-in-the-game effect, higher capital requirements always reduce risk taking (Proposition 3), but the franchise value effect works some way against the skin-in-the-game effect, rendering capital requirements overall less effective. In the limiting case $P_{LL} = 1$, the franchise value effect completely overrules the skin-in-the-game effect, such that capital regulation no longer has any effect on risk taking incentives. This result can be shown analytically:³⁰

Proposition 4. *Suppose $\beta_L > \beta_L^{ZLB}$ (ZLB binds in the low-rate state). In the limiting case $P_{LL} = 1$ (the ZLB binds forever), equilibrium monitoring m_L is unaffected by the level of capital requirements,*

$$\frac{dm_L}{d\bar{e}_L} = 0.$$

Capital requirements and franchise value. Using a Monti-Klein model of bank competition, Hellmann et al. (2000) show that higher capital requirements may more generally undermine bank franchise value. This is in contrast to the monopolistic competition setup

³⁰To see that the capital requirement becomes ineffective, evaluate (1.22) at $s = L$ and $r_L = 1$, using D_L from (1.20) and V_L from (1.27). After some algebra, it can be seen that in the limiting case $P_{LL} = 1$ all \bar{e}_L drop out from the right hand side of (1.22), implying that m_L is unaffected by \bar{e}_L .

here, where banks can fully pass on the cost of capital to depositors as long as the ZLB remains slack.³¹ Hence, whether capital requirements do or do not reduce franchise value away from the ZLB depends on modeling choices. However, this is besides the main point. The general result here is that at the ZLB higher capital requirements *disproportionately* affect franchise values. Clearly, the ZLB eliminates one margin of adjustment, such that higher capital requirements must inevitably have a more negative effect on bank profitability when the ZLB binds.

1.6 Optimal Capital Regulation

The previous analysis highlights two key positive insights: one, the ZLB can increase bank risk taking incentives. And two, the ZLB can make capital requirements less effective in reducing risk taking incentives, exactly during times when they are already high. The natural follow-up question is what this means for optimal capital regulation.

1.6.1 Welfare Benchmark

To answer this question, I calculate the welfare-maximizing, state-dependent levels of the capital requirement $\{e_H^*, e_L^*\}$. A strength of the general equilibrium approach here is that the representative household's lifetime utility delivers a clear welfare benchmark. To calculate welfare, I simulate the model for 100,000 random paths of length of 200 years, starting in the low-rate state. I then pick the combination of capital requirements that maximizes the average lifetime utility across the 100,000 draws. To be very clear about the constrained efficiency exercise here, the approach takes as given the level of competition and deposit insurance, i.e. they are not part of the policy choice set. I also do not consider policies that directly alleviate the ZLB constraint.³²

While deposit insurance was is not a critical element for the analytical results in Section 1.4, I realistically set $\omega = 0.57$ for the quantitative exercise here, in line with U.S. data. I further introduce a social cost of bank failures $\chi[1 - q(m_{t-1})]^2$. Realistically, re-

³¹ Another modeling difference to Hellmann et al. (2000) is the general equilibrium approach taken in this paper. In Hellmann et al. (2000) equity is priced by the opportunity cost of funds of bank owners, and banks face an exogenous demand for deposits as well as a choice between two investment opportunities with exogenously given returns. Here, households price the required return on equity and assets (via financial market investments), and the demand for deposits is also derived from household optimization. This equilibrium approach is useful when studying the effect of changing interest rates, as shifts in the household's discount factor affect the entire spectrum of required returns and interest rates.

³² Such policies could include abolishing paper money, or a higher inflation target, but are beyond the scope of this paper.

solving banks can be quite costly, especially if many institutions fail together. This failure cost is borne by the government, such that lump-sum taxes reflect both the cost of deposit insurance as well as failure costs:

$$T_t = \omega r_t D_{t-1} + \chi [1 - q(m_{t-1})]^2$$

Since the cost enters the model via lump sum taxes, agents do not internalize the social cost of bank failures, and hence all other equilibrium conditions are unaffected.³³

To calibrate the cost of bank failures χ I use budget figures from FDIC’s 2017 Annual Report.³⁴ In 2017, the FDIC spent \$430 million on their Receivership Management program, reflecting costs of managing resolved assets, and which amounts to 0.0022% of GDP. Solving $\frac{\chi[1-q(m_{t-1})]^2}{Y_t} = 0.000022$ for χ , yields $\chi = 0.75$.

While these two elements help to get a realistic assessment of the optimal level of capital requirements in the model, I also report robustness of the results to varying ω and χ (including $\omega = \chi = 0$).

1.6.2 Results

Figure 1.7 plots the welfare-maximizing capital requirements for different levels of the household’s discount factor in the low-rate state β_L . When $\beta_L < \beta_L^{ZLB}$ interest rates are high and the ZLB is slack. In this region, the optimal capital requirement is around 10%-11% in both the low-rate and high-rate state, somewhat above the level currently required according to the Basel III regulatory framework.³⁵ In contrast, when the ZLB binds in the low-rate state ($\beta_L > \beta_L^{ZLB}$), the optimal capital requirement in the low-rate state drops significantly, while that in the high-rate state increases. That is, if the ZLB binds occasionally, optimal capital requirements are positively correlated with the level of interest rates.

What explains these results? The benefit of tighter capital requirements is that they

³³While the failure cost is not internalized by any agents in the competitive equilibrium, it does affect the first best allocation, as shown in Appendix 1.9.

³⁴<https://www.fdic.gov/about/strategic/report/index.html>

³⁵In the model, the capital requirement is expressed as a fraction of non risk-weighted assets, more closely resembling the Leverage Ratio requirement. At the same time, in the model banks only invest in risky loans, which tend to carry relatively high regulatory risk-weights. The model capital requirement can therefore be interpreted as a leverage requirement on risky loans, somewhere between a leverage and a capital requirement. According to Basel III regulation, banks are required to hold Tier 1 plus Additional Tier 1 capital of 6%, plus an additional 2.5% in the “Capital Conversation Buffer”, all as a fraction of risk-weighted assets (BIS, 2011). Moreover, Basel III requires a “Leverage Ratio” of at least 3% of Tier 1 capital over total (non risk-weighted) assets.

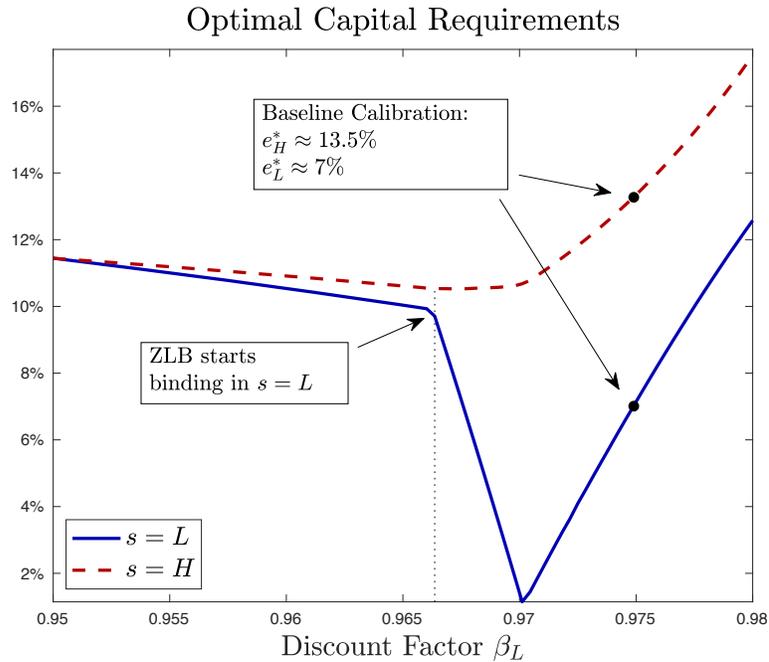


Figure 1.7: This figure plots the optimal state-dependent capital requirement, for different levels of the discount factor in the low-rate state. Capital requirements are expressed as a fraction of total assets ($e_t/(1 + e_t)$). Parameters are calibrated as described in Section 3.6.

induce banks to take less risk, and their cost is lower liquidity provision. As higher capital requirements induce banks to lower deposit rates, households demand less deposits in equilibrium. Figure 1.8 reveals that banks take too much risk and provide too little liquidity relative to the first best, as long as the ZLB is slack in both states ($\beta_L \leq \beta_L^{ZLB}$). In this region, optimal capital requirement trade off a reduction in risk taking against lower liquidity provision, resulting in an optimal level around 10%.³⁶

When the ZLB binds occasionally ($\beta_L > \beta_L^{ZLB}$) two new effects come into play. First, the franchise value effect described in Section 1.5 renders capital requirements less effective in curbing risk taking at the ZLB. Because capital requirements have a cost, this effect motivates a weaker use in the low-rate state, explaining the drop in e_L^* for $\beta_L > \beta_L^{ZLB}$ in Figure 1.7.³⁷

³⁶Recall from Proposition 1 that lower discount rates induce banks to take less risk. This explains that the optimal capital requirement decreases slightly in β_L , allowing for a higher level of liquidity provision while keeping equilibrium failure rates at a stable level.

³⁷What explains the U-shaped pattern of the optimal capital requirement e_L^* in Figure 1.7? The marginal return to monitoring is higher at lower levels of m_t , i.e. $q(m_t) - c(m_t)$ is concave. While the franchise value effect initially motivates a lower level of e_L^* , for very high levels of β_L bank risk taking is so strong that the marginal return to monitoring is very high and it becomes optimal to again increase the capital requirement as β_L increases further. In the baseline calibration with $\beta_L = 0.975$, the optimal capital requirement is still substantially lower than compared to when the ZLB is slack at all times ($e_L^* \approx 7\%$).

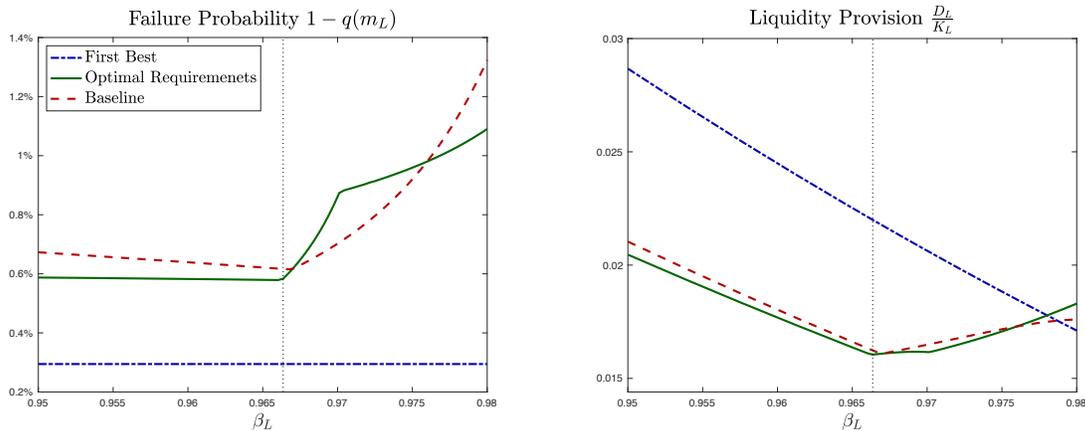


Figure 1.8: These graphs plot failure probabilities and liquidity provision for the first best, the competitive equilibrium with optimal capital requirements, and for the baseline with capital requirements of 8.5%. The vertical dotted line marks the threshold β_L^{ZLB} , beyond which the ZLB binds in the low-rate state. Parameters are calibrated as described in section 3.6.

At the same time, the binding ZLB in the low-rate state motivates a tighter capital requirement in the high-rate state, as evident by the increasing e_H^* in Figure 1.7. In the high-rate state, the effectiveness of capital requirements is not undermined because the ZLB is slack. Yet, risk taking incentives are heightened because banks anticipate that they may be constrained by the ZLB in the future, and hence have low expected profitability. To tame these higher risk taking incentives, optimal capital requirements in the high-rate state are unambiguously tighter .

The ZLB motivates lower capital requirements, even though risk taking incentives are already heightened at the ZLB (Proposition 1). In fact, at the ZLB equilibrium failure probabilities may be even higher under optimal capital requirements than in the baseline with $e_H/(1 + e_H) = e_L/(1 + e_L) = 8.5\%$ (left panel of Figure 1.8). The reason for this is that preventing risk taking becomes costlier at the ZLB, due to the franchise value effect described above (Section 1.5).

Regarding liquidity provision, at the ZLB the equilibrium quantity of deposits grows relative to the financial market, and may even exceed the first best level (right panel of Figure 1.8). Intuitively, from the perspective of households deposits become quite attractive when the ZLB binds, inducing a substitution from the financial market towards deposits.

Discussion The results in this section relate to the debate on counter-cyclical capital regulation. Recent contributions show that counter-cyclical leverage limits may be moti-

at $\beta_L = 0.975$, down from $e_L^* \approx 10\%$ at $\beta_L = \beta_L^{ZLB}$).

vated in models with welfare-relevant pecuniary externalities (e.g. Lorenzoni, 2008; Stein, 2012; Korinek and Simsek, 2016). In the policy debate, a common rationale is that buffers built up in good times should be available to be used in bad times (e.g. Goodhart et al., 2008).

None of these channels are active in this model, as there are no fire sale or aggregate demand externalities, nor frictions in raising equity that would motivate dynamically adjusting optimal capital requirements. Yet, capital requirements optimally vary with the level of interest rates. The argument here is based purely on how the level of interest rates affects the ability of banks to set deposit rates. To the extent that interest rates are low in bad times, the model thus delivers a novel rationale for counter-cyclical regulation.

Another implication of the franchise value effect is that monetary- and macro-prudential policy may not be seen in isolation. In the policy debate it is sometimes argued that monetary policy should focus on targeting inflation, while macro-prudential policies should target financial stability (e.g. Bernanke, 2015). This argument sees monetary policy as an independent, alternative tool to macro-prudential regulation. However, if near-zero interest rates undermine the effectiveness of prudential policies, monetary- and macro-prudential policy cannot be set in isolation as their inter-dependencies need to be taken into account.

1.6.3 Sensitivity Analysis

Table 1.1 reports how optimal capital requirements vary with the bankruptcy cost χ and the fraction of insured deposits ω , for $\beta_L = 0.96$ (so the ZLB is slack at all times) and $\beta_L = 0.975$ (baseline, ZLB binds occasionally).

As expected, optimal capital requirements are higher as bankruptcy costs increase, though the magnitude of the impact is modest. For example, at the baseline $\beta_L = 0.975$ optimal capital requirements vary between 12.8% and 13.86% in the high-rate state, as χ increases between 0 to 1.5 (= +/- 100% of its baseline level 0.75). A more generous deposit insurance also motivates tighter optimal capital requirements. For example, at $\beta_L = 0.975$ optimal requirements vary between 9.29% and 16.71% in the high-rate state, as the fraction of insured deposits varies from 30% to 80%. Intuitively, deposit insurance is a strong distortion that make the pricing of deposits unresponsive to a bank's risk.

Importantly, in each of the columns, the distance between e_H^* and e_L^* is much wider at $\beta_L = 0.96$ (slack ZLB), compared to $\beta_L = 0.975$ (ZLB binds occasionally). Hence, the key result that optimal capital requirements vary with the level of interest rates if the ZLB binds occasionally is robust to changing χ and ω .

		(ω, χ)				
		(0.57,0.75)	(0.57, 1.5)	(0.57, 0)	(0.8,0.75)	(0.3,0.75)
$\beta_L = 0.96$	e_H^*	10.90%	11.29%	10.51%	13.83%	7.24%
	e_L^*	10.53%	10.92%	6.81%	13.46%	6.84%
$\beta_L = 0.975$	e_H^*	13.34%	13.86%	12.80%	16.71%	9.29%
	e_L^*	7.13%	7.82%	6.37%	10.66%	3.20%

Table 1.1: This table reports optimal capital requirements for different values of β_L, ω and χ . Capital requirements are reported as a ratio of total assets ($e_t/(1 + e_t)$). At $\beta_L = 0.96$ the ZLB is slack at all times, and at $\beta_L = 0.975$ it binds whenever the economy is in the low-rate state.

1.6.4 An Alternative Policy

Is there a better policy response than merely adjusting capital requirements at the ZLB? One way to alleviate the ZLB constraint is to pay a subsidy whenever the ZLB binds. I consider a subsidy τ_t per unit of deposits, to replicate whatever negative rate banks would want to set if there was no ZLB constraint. That is, if \tilde{r}_{t+1} denotes the equilibrium deposit rate banks would want to set in an economy without a ZLB constraint, then the subsidy is given by

$$\tau_t = \min \{1 - \tilde{r}_{t+1}, 0\}.$$

To finance the subsidy, the government raises lump sum taxes of $\tau_t D_t$.

The subsidy effectively eliminates the ZLB constraint for banks. Accordingly, it restores bank profitability and hence incentives, as illustrated in the top left panel of Figure 1.9. The figure highlights the difference between the competitive equilibrium under optimal capital requirements, with and without the subsidy, as well as a counter-factual economy absent the ZLB friction. With the subsidy, the risk taking of banks is much lower than without, and comes close to the level in an economy without the ZLB friction.

However, the overall welfare effect of the subsidy is ambiguous. The bottom left panel plots a welfare gap, defined as the relative deviation of the representative household's lifetime utility from the first best. When rates are quite low (β_L high), the subsidy result in a higher level of welfare, but for smaller values of β_L the subsidy can actually worsen welfare. The reason is that the subsidy results in an inefficiently high quantity of deposits supplied in equilibrium, as banks grow relative to the financial market (see the top right panel, which plots the relative deviation of D_L from the first best). This effect is stronger, the more sensitive depositors are to bank risk taking, i.e. the lower the level of deposit insurance ω . For example, with $\omega = 0.3$ the lower risk taking induced by the subsidy results in an even stronger inflow into deposits than in the baseline $\omega = 0.57$, and accordingly the subsidy has a negative impact on welfare for a wider range of values β_L

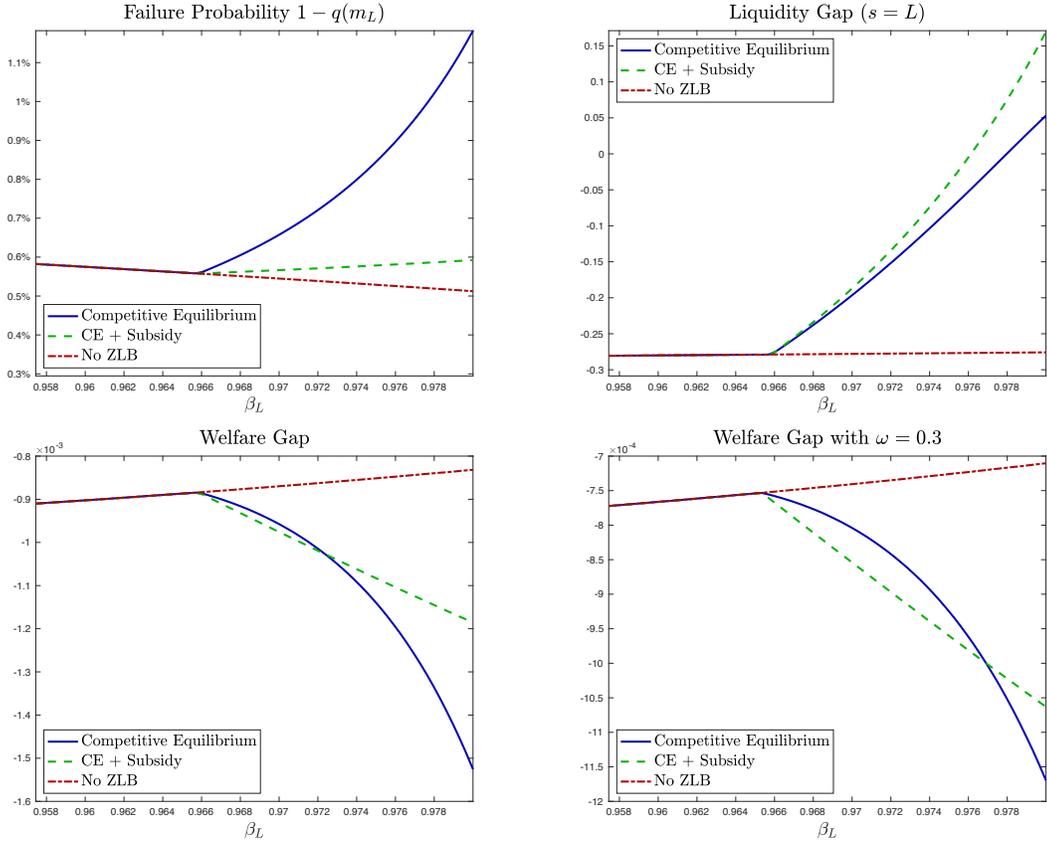


Figure 1.9: Risk taking (top left panel), liquidity gap (top right panel), and welfare gap relative to the first best equilibrium (bottom panels), for different levels of β_L , under the competitive equilibrium with optimal capital requirements, the equilibrium with a subsidy on deposits, and the equilibrium absent the ZLB friction. Other parameters are calibrated as described in Section 3.6.

(bottom left panel).

Another distortion may be that taxes raised to fund the subsidy may be distortionary (outside the model, as here taxes are lump-sum). Overall, the welfare effects of the subsidy are thus ambiguous.

1.7 Conclusion

Since the 1980s real interest rates across advanced economies have followed a steady downward trend. Low rates are likely here to stay (Summers, 2014), increasing the likelihood that short-term rates frequently hit zero in the future. This new environment of near-zero interest rates requires re-thinking some fundamental questions across macro- and financial economics. This paper highlights potential consequences for banking regulation and risk taking.

The ZLB may increase risk taking incentives of banks, as low margins induce a search for yield when banks cannot pass on low asset returns to depositors. These effects are particularly strong if the ZLB is expected to bind for a long time. And even after monetary policy “normalization”, incentives are affected if the ZLB is expected to bind again in the future.

While the ZLB has often been discussed as a constraint to monetary policy, I show that it can also impede the effectiveness of bank capital regulation. Hence, the ZLB not only increases risk taking incentives per se, it can also makes the typical regulatory tools employed to curb risk taking less effective.

A result of these effects is that they provide an independent motivation to adjust capital requirements to the level of interest rates. Perhaps surprisingly, even though there is already more risk taking at the ZLB, via these channels optimal requirements should be lower whenever the ZLB binds. These channels also motivate tighter capital regulation whenever the ZLB is slack but there is a chance of it binding in the future, providing a novel rationale for cyclically adjust regulation.

These points are also relevant for the debate on the interaction between monetary and macro-prudential policies. It is sometimes argued that monetary policy should focus on inflation, while macro-prudential policies should focus on financial stability. However, if there is an interaction between the two, they cannot be seen in isolation. Given that low policy rates may undermine the effectiveness of prudential regulation, an interesting avenue for future research is to study their joint determination.

1.8 Paper Appendix

1.8.1 Equilibrium conditions

All equilibrium conditions can be summarized as follows:

- Firms

$$\begin{aligned} F(K_t) &= K_t^\alpha, \\ K_t &= (1 - \delta)K_{t-1} + I_{t-1}^m + q(m_t)I_{t-1}^b, \\ \alpha K_t^{(\alpha-1)} &= R_t - (1 - \delta). \end{aligned}$$

- Households

$$\begin{aligned} R_{t+1}\beta_t &= 1, \\ D_t &= \left(\frac{\gamma}{1 - [\omega + (1 - \omega)q(m_t)]\frac{r_{t+1}}{R_{t+1}}} \right), \\ C_t &= F(K_t) - I_t^m - I_t^b(1 + c(m_t)). \end{aligned}$$

- Banks

$$\begin{aligned} \frac{c'(m_t)}{q'(m_t)} &= \frac{\beta_t \mathbb{E}_t V_{t+1}^b}{(1 + e_t)D_t} \\ V_t &= d_t^b + q(m_t)\beta_t \mathbb{E}_t V_{t+1}, \\ d_t^b &= [R_t(1 + e_{t-1}) - r_t]D_{t-1} - [e_t + (1 + e_t)c(m_t)]D_t(r_{t+1}), \\ r_{t+1} &= \max \left\{ R_{t+1} \left[\frac{\eta - 1/q_t}{\eta - 1} - \frac{\eta}{\eta - 1} \frac{(1 - q(m_t))e_t + (1 + e_t)c(m_t)}{q(m_t)} \right], 1 \right\}, \\ I_t^b &= (1 + e_t)D_t. \end{aligned}$$

1.8.2 Calibration

The following table summarizes the calibration of the model and data sources.

Table 1.2: Calibration

Parameter	Target Moment	Data Source
$\beta_H = 0.95$	Average corporate bond yield 1996 - 2008, $R_H = 1.055$	FRED
$\beta_L = 0.975$	Average corporate bond yield 2009 - 2013, $R_L = 1.025$	FRED
$\delta = 0.065$	Average depreciation rate of U.S. capital stock 1970 - 2016	BEA Fixed Assets Tables
$\alpha = 0.38$	Average U.S. capital-output ratio 1970-2016, $K_H/Y_H = 3.25$	BEA Fixed Assets Tables
$\bar{e}_s = 0.0929$	Basel III bank capital requirement, $\bar{e}_s/(1+\bar{e}_s) = 0.085$	BIS
$\psi_1 = 0.017$	Median U.S. bank's net non-interest expense / assets 1984 - 2013, $c(m_H) = 0.023$	Call Reports (obtained through WRDS)
$\psi_2 = 0.0017$	Average annual failure rate of U.S. banks, $1-q(m_H) = 0.0076$	Davydiuk (2017)
$\eta = 4.5$	Average interest margin of U.S. banks from 1996-2013 $R_H - r_H = 3.5\%$	Call Reports (obtained through WRDS)
$\gamma = 0.005$	Deposit liabilities of U.S. chartered institutions / debt instruments of non-financial corporates, $D_H/(D_H + I_H^m) = 0.2$	Flow of Funds
$P_H = 0.9$	Expected duration in high-rate state of 10 years	N/A
$P_L = 0.8$	Expected duration in low-rate state of 5 years	N/A

1.8.3 Bank Problem

Detailed Derivation

This appendix provides some more detail on solving the bank's problem. To arrive at the FOC w.r.t. deposit rates (1.14), differentiating V_t w.r.t. r_{t+1} gives (dropping i subscripts to minimize notation):

$$\frac{\partial V_t}{\partial r_{t+1}} = -q(m_t)\beta_t D_t + \pi_{t,t+1} \frac{\partial D_t}{\partial r_{t+1}} + \dots$$

$$\frac{dm_t^*}{dr_{t+1}} \left(\underbrace{q'(m_t)\beta_t [(R_{t+1}(1+e_t) - r_{t+1})D_t + \mathbb{E}_t V_{t+1}] - (1+e_t)D_t c'(m_t)}_{=0 \text{ by FOC w.r.t. } m_t \text{ (1.12)}} + \pi_{t,t+1} \frac{\partial D_t}{\partial m_t} \right).$$

The partial derivatives of D_t w.r.t. r_{t+1} and m_t are obtained by differentiating (1.5):

$$\frac{\partial D_t}{\partial r_{t+1}} = \eta[\omega + (1-\omega)q(m_t)] \frac{1}{R_{t+1}} D_t \left(1 - [\omega + (1-\omega)q(m_t)] \frac{r_{t+1}}{R_{t+1}} \right)^{-1}$$

$$\frac{\partial D_t}{\partial m_t} = \eta[(1-\omega)q'(m_t) \frac{r_{t+1}}{R_{t+1}}] D_t \left(1 - [\omega + (1-\omega)q(m_t)] \frac{r_{t+1}}{R_{t+1}} \right)^{-1}.$$

Setting $\frac{\partial V_t}{\partial r_{t+1}} = 0$, and rearranging gives (1.14).

The FOCs w.r.t. e_t and r_{t+1} depend on how the optimal monitoring in the second stage reacts to these two variable, i.e. on $\frac{dm_t^*}{dr_{t+1}}$ and $\frac{dm_t^*}{de_t}$, respectively. These two derivatives can be derived using the Implicit Function Theorem, by first defining the FOC w.r.t. m_t (1.12) as a function

$$g(m_t, e_t, r_{t+1}) = \frac{q'(m_t)}{c'(m_t)} \frac{\beta_t}{(1+e_t)D_t} ((1+e_t)R_{t+1} - r_{t+1})D_t + \mathbb{E}_t V_{t+1} - 1. \quad (1.25)$$

The derivatives can be derived analytically as

$$\frac{dm_t^*}{dr_{t+1}} = - \frac{\partial g(m_t, e_t, r_{t+1}) / \partial r_{t+1}}{\partial g(m_t, e_t, r_{t+1}) / \partial m_t}$$

$$\frac{dm_t^*}{de_t} = - \frac{\partial g(m_t, e_t, r_{t+1}) / \partial e_t}{\partial g(m_t, e_t, r_{t+1}) / \partial m_t}.$$

Binding Capital Requirement

Does the regulatory capital requirement bind, or do banks set equity at an interior solution to (1.13)? Table 1.3 reports the leverage chosen by banks if there were not capital

	ω					
	0	0.2	0.4	0.6	0.8	1
e_H	4.94%	3.46%	1.81%	0%	0%	0%
e_L	0%	0%	0%	0%	0%	0%

Table 1.3: This table reports interior capital choices by banks, according to (1.13), for different levels of deposit insurance ω . The numbers are reported as a fraction of total assets, $e_t/(1 + e_t)$. All other parameters are calibrated as described in Section 3.6.

requirements ($\bar{e}_t = 0$). Banks contribute less equity if there is more deposit insurance (higher ω). Intuitively, the more depositors are insured, the less sensitive they are to the bank's risk taking, and the less value there is for banks to signal lower risk taking with more equity.

Even in the complete absence of deposit insurance banks choose to contribute less than 5% equity, below the 8.5% in the baseline calibration. With a binding ZLB in the low-rate state, banks always choose $e_L = 0$.

1.8.4 Proof of Proposition 1

A marginal increase in β_t results in a decrease in R_{t+1} , by the Euler Equation (1.4). To see how a marginal decrease in R_{t+1} affects equilibrium monitoring, re-write the FOC (1.22) as a function $g(m_t, r_{t+1}, R_{t+1}) = 0$:

$$g(m_t, r_{t+1}, R_{t+1}) = \frac{q'(m_t)}{c'(m_t)} \frac{1}{(1 + e_t)} \left((1 + e_t) - \frac{r_{t+1}}{R_{t+1}} + \frac{\mathbb{E}_t V_{t+1}}{D_t R_{t+1}} \right) - 1. \quad (1.26)$$

with D_t given by (1.5):

$$D_t = \frac{\gamma}{1 - [\omega + (1 - \omega)q(m_t)] \frac{r_{t+1}}{R_{t+1}}}.$$

Note that $\mathbb{E}_t V_{t+1}$ is unaffected by a change in β_t , since the comparative statics keep $\beta_{t+1}, \beta_{t+2}, \dots$ fixed. Using the Implicit Function Theorem:

$$\frac{dm_t}{dR_{t+1}} = - \frac{\partial g(\cdot)/\partial R_{t+1}}{\partial g(\cdot)/\partial m_t}.$$

It is easy to see that $\partial g(m_t, R_{t+1})/\partial m_t \leq 0$. Hence, $\frac{dm_t}{dR_{t+1}} \geq 0$ has the same sign as $\partial g(\cdot)/\partial R_{t+1}$. If the ZLB binds, $r_{t+1} = 1$, and the partial derivative is given by

$$\partial g(\cdot)/\partial R_{t+1} = \frac{q'(m_t)}{c'(m_t)} \frac{1}{(1 + e_t)} \left(-\frac{1}{R_{t+1}^2} - \frac{\mathbb{E}_t V_{t+1}}{D_t^2 R_{t+1}^2} \frac{\partial(D_t R_{t+1})}{\partial R_{t+1}} \right),$$

Evaluating when $\partial g(\cdot)/\partial R_{t+1} \leq 0$ defines a necessary and sufficient condition for $\frac{dm_t}{dR_{t+1}} \leq 0$. Proposition 1 gives an even weaker necessary condition

$$\frac{\partial(D_t R_{t+1})}{\partial R_{t+1}} \geq 0 \Leftrightarrow \beta_t \geq \frac{1}{2[\omega + (1 - \omega)q(m_t)]}.$$

□

With a slack ZLB, r_{t+1} is given by (1.14). In the case of $\omega = 1$, the ratio $\frac{r_{t+1}}{R_{t+1}}$ can be expressed as a function of m_t and e_t only. Hence, in this case R_{t+1} only enters the function $g(m_t, r_{t+1}, R_{t+1})$ via the denominator in the term $\frac{\mathbb{E}_t V_{t+1}}{D_t R_{t+1}}$, reflecting the discounting effect. Hence, with a slack ZLB and $\omega = 1$, an increase in β_t (= a decrease in R_{t+1}), always results in an increase in m_t^* .

1.8.5 Proof of Proposition 2

This appendix shows (i) that $V_H > V_L$ when $\beta_L < \hat{\beta}$, and (ii) that in this case equilibrium monitoring increases in P_{HH} and decreases in P_{LL} .

(i) Use the definition of V_t and $\pi_{t,t+1}$ from (1.7), and that $\mathbb{E}_s V_{t+1} = P_{ss}V_s + P_{ss'}V_{s'}$, to find the franchise value of the bank in state $s \in \{H, L\}$:

$$V_s = \frac{1}{\Lambda} [(1 - q(m_{s'}))\beta_{s'}P_{s's'}\pi_s D(r_s) + q(m_s)\beta_s P_{ss'}\pi_{s'} D(r_{s'})], \quad (1.27)$$

with

$$\Lambda \equiv (1 - q(m_H)\beta_H P_{HH})(1 - q(m_L)\beta_L P_{LL}) - (q(m_H)\beta_H P_{HL})(q(m_L)\beta_L P_{LH}),$$

and $D(r_s)$ is defined in (1.20). By lemma 1, if $\beta_L > \beta_L^{ZLB}$, the ZLB binds. In this case, one can write π_L as

$$\pi_L = q(m_L) \left[(1 + \bar{e}_L) - \frac{1}{R_L} \right] - [\bar{e}_L + (1 + \bar{e}_L)c(m_L)]. \quad (1.28)$$

Moreover, with a binding ZLB at $r_L = 1$,

$$D(1) = \left(\frac{\gamma}{1 - [\omega + (1 - \omega)q(m_L)]/R_L} \right).$$

Clearly, $\lim_{R_L \rightarrow 1} \pi_L < 0$, and $\lim_{R_L \rightarrow [\omega + (1-\omega)q(m_L)]} D(1) = \infty$. Hence,

$$\lim_{R_L \rightarrow 1} \pi_L D(1) = -\infty.$$

Inspecting (1.27), it is clear that the term $\pi_L D(r_L)$ has a greater weight on V_L than V_H (since $(1 - q(m_H)\beta_H P_{HH}) > q(m_H)\beta_H P_{HL}$). Hence, V_L tends faster to $-\infty$ as β_L increases and there is a threshold $\hat{\beta}$ s.t. for $\beta_L > \hat{\beta}$ it must be that $V_H > V_L$.

(ii) From (1.22), monitoring increases in $\mathbb{E}_t V_{t+1}$. With $V_H > V_L$ it follow immediately that $\mathbb{E}_s V_{t+1} = P_{ss} V_s + P_{ss'} V_{s'}$ decreases in P_{sL} . \square

1.8.6 Proof of Propositions 3 and 4

Proposition 4 states that if the ZLB binds forever ($P_{LL} = 1$), then $dm_t/de_t = 0$. Equilibrium risk taking is defined by $g(m_t, e_t, r_{t+1}) = 0$, with $g(\cdot)$ defined in (1.25), and

$$\frac{dm_t}{de_t} = -\frac{\partial g(m_t, e_t, r_{t+1})/\partial e_t}{\partial g(m_t, e_t, r_{t+1})/\partial m_t}.$$

However, evaluating $g(m_t, e_t, r_{t+1} = 1)$ with $P_{LL} = 1$, also using (1.27) and (1.28), after some algebra all e_t drop out from $g(\cdot)$ and m_t is a function of β_t and other exogenous parameters only. This proves Proposition 4. \square

Proposition 3 follows from the proof of Proposition 4. If in the extreme case $P_{LL} = 1$ capital requirements have exactly zero effect on risk taking, they must have a weakly positive impact on equilibrium monitoring overall. The reason is that with $P_{LL} < 1$ there is at least some chance that at some point the bank is not constrained by the ZLB. With a slack ZLB, capital requirements have a less negative impact on bank profitability and franchise values, as banks can pass on the cost of capital on depositors (Lemma 2). \square

1.9 First Best with Bank Failure Cost

This appendix solves the first best when bank failures generate a cost $(1 - q_t)^2\chi$. While the failure cost of banks is not internalized by any agents in the competitive equilibrium, it does affect the first best allocation as the budget constraint in the planner's problem is now given by

$$C_t + I_t^m + (1 + e_t)D_t(1 + c(m_t)) + \chi(1 - q(m_t))^2 = F(K_t). \quad (1.29)$$

Consequently, the first order condition w.r.t. m_t (1.18) takes into account the cost of bank failures:

$$c'(m_t) = q'(m_t) \left[1 + \frac{2\beta_t\chi(1 - q(m_t))}{(1 + e_t)D_t} \right].$$

The FOC's w.r.t. I_t^m and D_t are unaffected and still given by (1.17) and (1.19), respectively.

1.10 Additional Evidence

1.10.1 Interest Margins and Deposit Rates at the ZLB

Figure 1.2 from the introduction shows that the spread between safe corporate bonds and the deposit expense ratio has declined since 2009. The left panel of figure 1.10 complements this data by showing the spread between interest income and deposit interest expense ratio of the median U.S. bank in the Call Reports data. Analogously to the interest expense ratio, the income ratio is defined as total interest income (riad4107) divided by total assets (rcfd2170).

As in figure 1.2, a compression in spreads is visible in these series too, though the magnitude of the drop is smaller and occurs slightly earlier - perhaps because non-performing loans started pushing down bank interest income already in 2007.

That interest income ratios are somewhat more stable than the return on safe bonds in figure 1.2 is consistent with the notion that banks start lending to riskier borrowers (since riskier borrowers pay higher interest rates). It is also driven by the fact that bank assets have relatively long maturity, so that margins only come under pressure once their long-term assets roll off. Drechsler et al. (2017a) show that banks in the U.S. lengthened the duration of their balance sheets during the zero-lower-bound period, which has limited the compression of their net interest margins.

In my model I cannot study these gradual effects as loans are re-priced every period. Nevertheless, the comparison to highly rated corporate bonds in figure 1.2 shows that for a given level of risk margins on new business are significantly compressed since 2009.

The right panel of figure 1.10 shows for a longer horizon the spread between the rate on 30 year mortgages (as reported in FRED), and the median deposit interest expense ratio. I calculate the mean of this spread for three phases: 1985 - 1995, 1996 - 2007, and 2007 - 2013.

In 1994 the Riegle-Neal Interstate Banking and Branching Efficiency Act removed several obstacles to banks opening branches in other states and provided a uniform set of rules regarding banking in each state. This act increased competition, with an evident negative effect on interest margins. In 2008 the ZLB starts binding, explaining the second drop in margins, analogous to the left panel and figure 1.2.

This pattern of interest margins is consistent with the model. Away from the ZLB, margins are determined by the level of competition (parameter η in the model). When the ZLB binds, the market power of banks breaks as depositors face cash as an attractive outside option. Accordingly, a further compression in margins occurs.

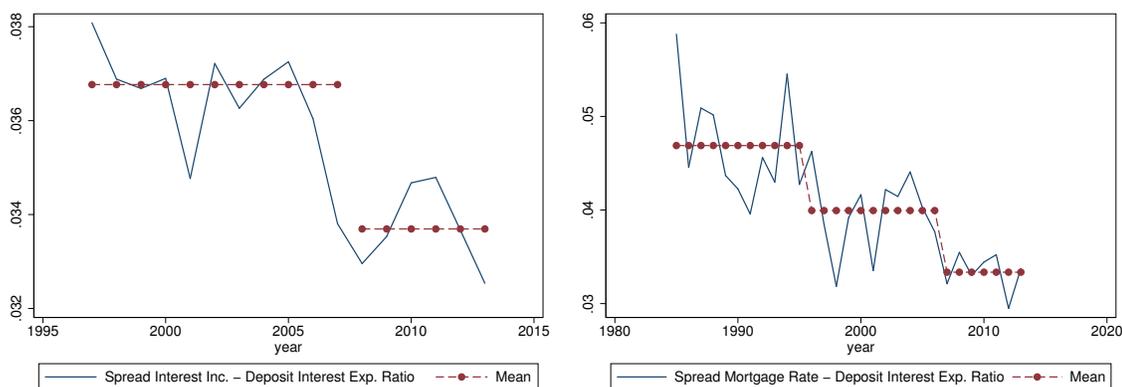


Figure 1.10: The left panel plots the median spread between interest income and deposit interest expense ratio, among all U.S. banks in the Call Reports data. The right panel plots the spread between the rate on 30 year mortgages and the median deposit expense ratio.

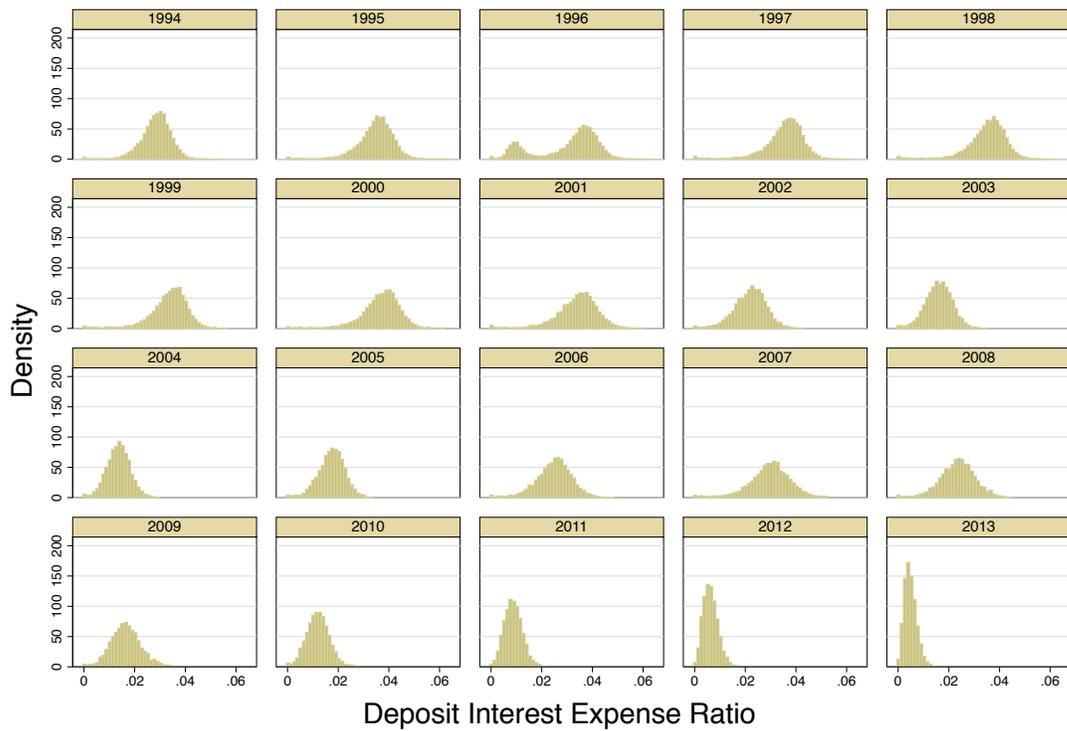
Deposit Rates Figure 1.11 expands on figure 1.1 in the introduction. This more comprehensive perspective shows that the skewness and concentration of the distribution is a phenomenon particular to the ZLB period after 2009. This is despite substantial swings in the Federal Funds rate over the relevant period.

1.10.2 Evolution of Bank Concentration

A central prediction of the model is that the ZLB distorts bank competition, as cash provides an attractive alternative source of liquidity for households. In the light of weakening profitability, one may expect the industry to consolidate.

Figure 1.12 presents evidence of the evolution of bank concentration since 1994, using branch-level data on deposit holdings from the FDIC. The left panel shows that the aggregate number of banks has been steadily decreasing since 1994. In contrast, the average number of banks per county increases from around 13 in 1994 to almost 14.5 in 2008. These trends are consistent with the interpretation that after 1994 competition *between* banks increased. In 1994 the Riegle-Neal Interstate Banking and Branching Efficiency Act removed several obstacles to interstate-banking. This allowed the most efficient banks to venture into other states, explaining the increase in the average number of banks per county. At the same time, less efficient banks leave the market, explaining the decrease in the number of banks on the national level.

As the ZLB starts binding in 2008, banks again face fiercer competition. However, this time tighter competition is not the result of fiercer competition with each other, but a result of the fact that depositors have cash as an alternative source of liquidity with zero



Graphs by year

Figure 1.11: For the years 1994-2013, this figure plots the cross-sectional distribution of deposit interest expense ratios across U.S. banks in the Call Reports data. The deposit interest expense ratio is defined as interest expenses per unit of deposits.

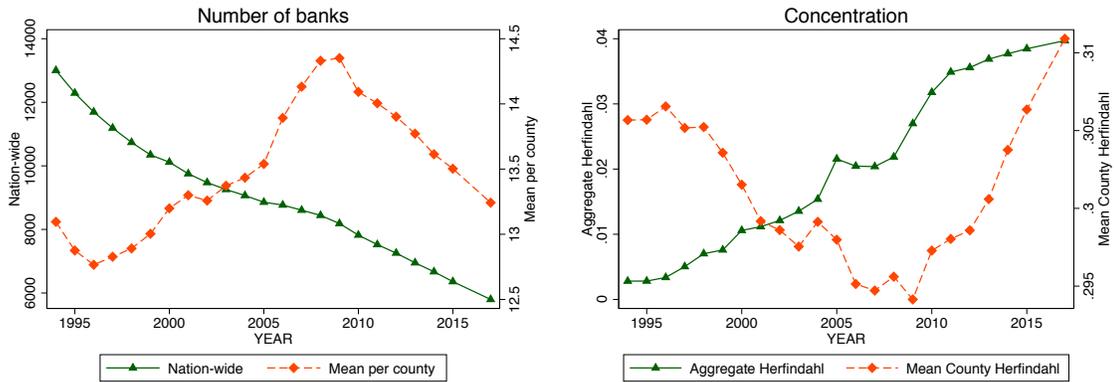


Figure 1.12: The left panel plots the number of banks on a nation-wide level (left axis), and the mean number of banks per county (right axis). Analogously, the right panel plots Herfindahl based on bank-level deposits on a nation-wide level, and per county.

net return. Accordingly, the growth in the number of banks per county reverses, falling in tandem with the aggregate number of banks, and almost all the way back to its 1994 level. Likely other drivers behind the fall in the number of banks are the emergence of online banking and fintech, as well as bank failures triggered by the financial crisis.

The right panel of figure 1.12 further supports this interpretation by plotting deposit Herfindahls on a national and the country level. Following Drechsler et al. (2016), I calculate the county-level Herfindahl by summing the deposit holdings across all branches of a bank in a given county, and then calculating the Herfindahl as the sum of squared deposit market shares of all banks in a county. Analogously, I calculate the aggregate Herfindahl by summing the deposit holdings across all branches of a bank in the entire U.S.

Unsurprisingly, the Herfindahls have an inverse relationship to the number of banks, confirming that county-level concentration decreases from 1994-2008, but then starts increasing again as the ZLB binds from 2009 onwards. Interestingly, by 2015 the mean County Herfindahl surpasses its 1994 level.

Chapter 2

The (Self-)Funding of Intangibles

2.1 Introduction

Progress in information technology since 1980 has transformed corporate investment. Firms' investment into intangible capital has risen progressively relative to physical plant and other tangible assets (Corrado and Hulten, 2010a). Such a major shift in capital asset composition can be expected to alter corporate finance practices, and may help explain falling financial leverage and rising corporate cash holdings (Bates et al., 2009; Falato et al., 2013), (see Figure 2.1).

A natural interpretation is that more intangible assets imply a reduced debt capacity, as raising external financing depends on the ability to offer collateral. Moreover, innovative firms may face higher costs of financial distress (Opler et al., 1999; Froot et al., 1993). By holding more cash, firms with high intangibles to total assets (henceforth HINT firms) can reduce the risk of becoming financially constrained. This view is supported by evidence that increased corporate cash holdings are highly correlated with R&D investment and cashflow volatility (Bates et al., 2009; Pinkowitz et al., 2016; Graham and Leary, 2016).

This paper models and tests how the composition of investment affects corporate funding and payout policy. While lower asset tangibility necessitates more precautionary savings (e.g., Almeida and Campello, 2007), a careful framing of the process of creating intangible capital yields some novel insights. Since intangible investment relies largely on the commitment of human capital over time, it requires lower upfront cash outlays than the acquisition of tangible assets. Indeed, on average HINT firms have lower investment expenditures for a given level of profitability (see Figure 2.5). Yet since firms cannot own talented employees' human capital (Hart and Moore, 1994), they need to share the value created so as to match their outside options to move to or start another firm (Eisfeldt

and Papanikolaou, 2013). This compensation must be deferred to ensure retention, either explicitly by unvested grants or implicitly via career prospects.

We formalize these insights with a simple model in which firms differ in their technological profile and the composition of their investment. Innovative HINT firms require less upfront cash outlays than traditional firms that operate with more tangible assets. On the other hand, these firms need to reward human capital by promising more future earnings via deferred compensation over time. These rewards are due once revenues are realized.

All firms may face some shock at the interim date that requires additional investment. While low-intangibles (LINT) firms can pledge assets to raise financing, HINT firms need to self-finance more expenditures. On the other hand, some intangible investment is supported by human capital, so it requires lower cash outlays. Overall, innovative firms may or may not face greater financial constraints, depending on the balance between the two effects.

HINT firms' need to reward their human capital creates a conflict quite distinct from the classic agency problem associated with external financing of conventional investment. Because critical employees can leave with the intangible capital created, they must be promised adequate and reliable compensation conditional on their commitment. We show how an efficient reward and retention policy requires pledging future revenues to match the value of employees' external options. Established firms here take advantage of the fact that changing jobs or starting a new firm incurs costs and exposes the employee to more risk.

This insight suggests a second reason for HINT firms' prudent financial policy: They need to retain internal resources until deferred compensation vests (Acharya et al., 2011). Insufficient resource retention can lead to financial distress, which prompts innovative employees to exit and start their own firm (Babina, 2017). Retaining cash has the additional benefit of decreasing future share price volatility, which increases the utility value of deferred pay (whether it comes in the form of share grants or fixed promises), thus reducing the corporate cost of human capital.

For the same reason, firms with more intangibles should choose a payout policy that avoids dividends to vested equity and favors repurchases, in order to protect unvested share values. A generous dividend policy would hurt the firm's reputation for rewarding skilled human capital, thereby increasing future retention costs. Holding more cash and repurchasing shares reduces the deferred equity compensation needed for retention, limiting ex ante dilution for shareholders. Thus the model suggests a retention rationale for HINT firms' prudent financial policy next to the traditional precautionary motive.

Overall, our model makes clear predictions on HINT firms' optimal financing, compen-

sation and payout policies, particularly when employees are exposed to more firm risk.

We test these predictions using a large sample of Compustat firms over the period 1970 through 2010. Following Peters and Taylor (2016), we measure intangible asset values by capitalizing annual investment into the production of knowledge, brand quality, and organizational culture. Interestingly, most of these expenditures reflect salaries, illustrating how intangible assets are created and maintained by the human capital investment of highly skilled employees.

We use two empirical approaches to test how intangibles affect firms' financial policies. First, we use pooled OLS regressions to study all of the cross-sectional and time-series variation in intangibles usage. Second, we examine how policies change following large, sectoral shifts from tangible to intangible investment. These technological transitions are staggered across time, reflecting how IT and the Internet have transformed corporate strategies at different speeds across industries.¹ To further highlight the broad adoption of intangibles across sectors and firms' life cycle stages, we report all results separately after excluding young or high-tech firms.

We start our analysis by showing that HINT firms have higher cashflows *and* lower up-front investment outlays than LINT firms. Across all years, HINT firms invest 80% of operating (pre-investment) cashflows, while LINT firms' outlays often exceed their cashflows. We further show that free cashflows rise sharply by 60% after industry-level technological transitions, concurrent with a steep decline in tangible investment.

In part because HINT firms have lower investment needs, they do not appear to have been more frequently financial constrained than LINT firms during our sample period. We find that HINT firms' operating cashflows are more frequently sufficient to fully cover their typical investment outlays, which appear less volatile than those of LINT firms. This suggests that some of HINT firms' large liquidity may be held for reasons other than hedging sudden investment needs.

The data further show that firms use different sources of financing to produce tangible and intangible assets. HINT firms have significantly lower net leverage, and raise larger amounts of internal funding by granting employees more unvested stock options and restricted stock. The value of these grants rises by 40% following technological transitions, and amounts to an annual transfer of 0.7% of firms' market capitalizations to employees.

The evidence indicates that firms retain cash to support the value of these deferred grants, as well as for standard precautionary reasons. First, we find that while HINT

¹ We use Andrews (1993)'s procedure to identify major structural breaks in each industries' time-series of investment composition. These breaks range from 1974 to 2002.

firms' payments to shareholders are similar to LINT firms', they retain a larger fraction of their free cashflows.

Second, HINT firms' cash holdings are larger when their employees are more exposed to firm risk. The positive association between intangibles usage and cash holdings is larger among firms that have higher stock price volatility, and that grant more equity to employees. HINT firms overall hold 3.4% more cash as a fraction of total assets than LINT firms, but high-volatility HINT firms hold 8.7% more cash, and high-equity-grant firms hold 7.4% more cash.² These effects are robust to controlling for commonly used measures of financial constraints, which are also positively associated with HINT firms' cash holdings. Thus, the evidence suggests both a precautionary and retention motive for holding cash, as predicted by the model.

To further rule out that financial constraints fully explain the results, we analyze a subset of firms with lines of credit that are partially or fully undrawn. Credit lines provide an ample buffer against future constraints as they cover 144% of typical investment outlays on average, yet they cannot be pledged to unvested employees. Accordingly, we find that HINT firms hold more cash even among this subset of unconstrained firms.

Finally, we show that intangibles usage is also associated with a preference for share repurchases over dividends. The ratio of repurchases to total payouts rises from 0.28 to 0.39 following a technological transition.

2.1.1 Related literature

An extensive literature examines the asset determinants of corporate leverage. Firms tend to fund tangible assets with debt, not least for tax reasons, and often adjust net leverage by their cash holdings.

The classic view is that firms hold cash to buffer against future financing constraints (Kim et al., 1998; Almeida et al., 2004; Harford et al., 2014); see Almeida et al. (2014) for a survey. We include this first-order cause in our model, balanced against associated agency costs of managerial discretion (Jensen, 1986; Pinkowitz et al., 2006; Dittmar and Mahrt-Smith, 2007; Harford et al., 2008).³ Our approach is close to Acharya et al. (2011), who show that maintaining resources in the firm is necessary to motivate managerial human capital. More generally, skilled human capital has direct and indirect claims on profits via deferred compensation, career advancement, share and option grants (Eisfeldt

² These magnitudes correspond to a 0.31 increase in the ratio of intangible to total assets, which is how much the median firm's intangible usage rose from 1970 to 2010. High-volatility (equity-grant) firms are those with stock volatility (equity grant) values in the top tercile of the sample distribution.

³ The conflict is less acute when profitability reflects quasi-rents that require investment to be maintained.

and Papanikolaou, 2013). Accordingly, the amount and safety of corporate assets net of leverage are critical determinants to the return to human capital.

Cash holdings by U.S. companies have been on a long-term rise, as documented by Bates et al. (2009).⁴ Our explanation is related to the spread of information technology since the early 1980s and its impact on the productivity of skilled human capital. Chapter 3 of this thesis offers a general equilibrium model of technological progress where rising intangible value can account for major financial trends such as declining interest rates and a reallocation of credit from productive to asset finance. Graham and Leary (2016) and Begenau and Palazzo (2017) find that the recent increase in cash is largely associated with listings of high tech firms.

While U.S. tax rules on global profitability encourages firms to retain cash abroad (Foley et al., 2007; Harford et al., 2016), Pinkowitz et al. (2016) find that U.S. Firms' cash holdings are no higher than their foreign counterparts' once properly controlled for their greater R&D intensity. Thus their higher cash holdings appear to reflect more intangible assets, in line with our approach.

Other rationales for high corporate cash holdings reflect transaction costs of raising new funding (Miller and Orr, 1966; Mulligan, 1997) or variations in the opportunity cost of holding cash (Azar et al. (2016b)).

One of our contributions is to show that HINT firms simply have lower tangible investment needs, which fits with several recent documented facts. The relationship between external fund flows and growth opportunities has decreased over time (Lee et al., 2016), and capital expenditures of U.S. public firms more than halved from 1980 to 2012 (Fu et al., 2015), while stock prices rose. High-intangibles firms appear to invest less not only in the U.S., but also in Europe (Döttling et al., 2017). Philippon and Gutiérrez (2016) also find evidence for a decrease in competition, as well as weakening corporate governance.

Several papers highlight how technological progress has boosted the role of human capital and induced changes in funding and employee compensation choices.⁵ Lustig et al. (2011) recognize the impact of technology on the productivity of organizational capital, and are able to explain the rising role and dispersion of managers' pay for performance in large firms.⁶ Thakor and Lo (2015) show that cash holdings are essential in a competitive environment where success in R&D is critical.

⁴ Graham and Leary (2016) point out how a similar pattern occurred earlier in the twentieth century.

⁵ This process is believed to account for a drastic rise in the skill premium since 1980 (see, e.g., Katz and Murphy (1992) and Autor et al. (1998)).

⁶ Their estimates suggest managers may be able to claim as much as half of total value of organizational capacity they create. As in our approach, employee risk aversion enables firms to retain more of the value created.

Our paper also relates to a nascent literature showing that firms choose their leverage ratios in part to offer insurance to risk-averse employees (Berk et al., 2009; Agarwal and Matsa, 2013; Kim et al., 2016). Graham et al. (2016) measure the decline in employees' income following bankruptcy and show that firms grant higher ex-ante wages to compensate for distress risk. We contribute to this literature by showing that even in the absence of bankruptcy or distress costs, innovative firms may hold more cash and use less leverage in order to insure employees with large equity stakes. Our results do not depend on whether deferred compensation takes the form of debt or equity, though in practice firms overwhelmingly grant unvested equity rather than deferred cash, either by individual contracts or through broader employee stock ownership plans (ESOPs). The choice of equity over fixed compensation may be due to fiscal advantages (Babenko and Tserlukevich, 2009; Hanlon and Shevlin, 2002) or the need to index compensation to the ex-post value of the employee's outside option (Oyer and Schaefer, 2005a). It may also be due to the greater credibility of a property grant over a nominal contractual promise.

Our work is closely related to two recent papers. Bolton et al. (2016) develop a theory linking corporate liquidity policies to inalienable human capital. In their model, firms retain risk-averse employees by granting them deferred compensation, and hold cash or credit lines to increase the credibility of these claims. Sun and Zhang (2017) also offer a related theory in which firms investing in intangible capital grant deferred compensation to retain innovative employees. Their model studies under what conditions compensating human capital crowds out external debt financing. Our complementary theory proposes that firms that rely largely on human capital investment also spend less upfront on tangible capital, and hence may have a lower *need* for external funding. Our approach yields unique predictions that associate intangible capital with greater cash holdings and a preference for repurchases over dividends, even in the absence of financial constraints.

The rest of the paper is organized as follows. Section 2 develops a model of intangible investment, generating predictions for capital structure, cash holdings, and payouts. Section 3 describes our sampling procedure, key empirical measures, and regression models. Section 4 presents empirical tests linking intangibles usage to corporate financing policies. Section 5 concludes. Proofs are in Appendix A, and variable definitions are in Appendix B.

2.2 Model

We model how corporate investment strategy affects firm funding and liquidity policy. Besides recognizing that tangible and intangible assets differ in their pledgeability, we

investment $H = \eta I$ into intangible assets and $K = (1 - \eta)I$ into tangible assets.⁷

There are two key differences between tangible and intangible assets. First, intangible capital is not pledgeable, so the firm must fully self-finance any re-investment of intangible assets when the liquidity shock hits at $t = 1$, lest all its value is lost. In contrast, tangible capital retains a liquidation value equal to a share $(1 - \theta)$ of its initial cost, with $\theta \in [0, 1]$.⁸ Hence, a fraction $(1 - \theta)$ of tangible investment can be collateralized, and the firm must self-finance only a fraction θ . We realistically assume that in liquidation employees have a comparative disadvantage to extract value from corporate tangible assets relative to external investors. Consequently, the liquidation value of physical capital is best assigned to financial investors.⁹

Second, the creation of intangible capital depends on joint investment of corporate resources and the contribution over time of human capital by the skilled employee. A fraction $(1 - \alpha)$ of intangible investment is created by the employee's effort, assumed costless for simplicity.¹⁰ The firm's contribution requires funding the residual amount $\alpha < 1$ of the investment into intangible assets.

While more intangible investment reduces upfront funding needs, it requires ensuring the commitment of the employee's human capital. The inalienability of the employee's human capital (Hart and Moore, 1994) creates a potential conflict. After observing the firm's re-investment and cash retention decisions at $t = 1$, the employee can leave and use the developed intangible capital to start an own firm, which would produce a stochastic payoff $(1 - \alpha)H\tilde{R}$ proportional to the share of intangible capital created. Because the project's cashflows are not verifiable, she cannot sell her stake or insure its underlying risk. For simplicity, we assume that the firm generates no return if the employee departs.

The firm can ensure retention by granting deferred compensation that the employee receives only if she stays at the firm until $t = 2$. Motivated by firms' observed choices, we assume that this compensation takes the form of an unvested equity stake ω that vests after the project's cashflow is realized at $t = 2$.¹¹ Importantly, our results also obtain were

⁷ The fixed tangible-intangible investment ratio can be motivated by a Leontief production function, where the total return at $t = 2$ is given by $\tilde{R}\mathcal{I}$, with $\mathcal{I} = \min\left\{\frac{H}{\eta}, \frac{K}{1-\eta}, I\right\}$. If the project has positive NPV for the firm, it will always choose $H = \eta I$ and $K = (1 - \eta)I$.

⁸ Thus if the firm has to re-invest at $t = 1$, the liquidation value increases to $(1 - \theta)(1 + \rho)K$.

⁹ Under this assumption, the firm realistically uses external funding to finance tangible investments. An alternative rationale for some leverage is a managerial agency conflict over the capture or proper maintenance of tangible assets, which requires posting them as collateral to monitoring creditors. Likewise, a fiscal advantage of debt would induce the firm to take on leverage.

¹⁰ We abstract from incentive issues arising with a continuous effort choice.

¹¹ The choice of equity over fixed compensation may be due to fiscal advantages (Babenko and Tserlukovich, 2009; Hanlon and Shevlin, 2002) or the need to index compensation to the ex-post value of the

the firm to offer a deferred cash payment (see Appendix 2.6.2). Unvested equity create an incentive to remain, as employees departing voluntarily forfeit their claim.

We assume that the employee has CRRA preferences over time-2 consumption x ,

$$U(x) = \frac{x^{1-\gamma}}{1-\gamma}, \quad (2.1)$$

where $\gamma > 0$ reflects her relative risk aversion. Further, to ensure that the project has positive NPV, we assume

Assumption 1. $\mathbb{E}\tilde{R} \geq (1 + \lambda\rho)$.

Thus the firm has two motives for holding cash. The classic precautionary motive suggests that enough liquidity is retained to ensure reinvestment at $t = 1$. Second, some resources need to be retained by the firm to support the value of the deferred reward for human capital (Acharya et al., 2011). Cash is an ideal choice for this retention motive, as it reduces overall payout uncertainty and reduces the volatility of the employee's equity stake ω . This increases the certainty equivalent value of the deferred equity claim at $t = 0$, and reduces the overall cost of compensation. As other claimants are better diversified than the employee, they value risky equity more, and prefer to retain a larger stake at the cost of leaving more cash in the firm.¹²

2.2.2 Precautionary cash holdings

We proceed to solve the firm's decision problem, starting with the demand for precautionary savings.

If the firm is hit by a shock at $t = 1$, the total re-investment need is $\rho I = \rho(H + K)$. In this case, the firm must invest $\rho(\alpha H + K)$, while the employee contributes the remaining $\rho(1 - \alpha)H$ using her human capital. The amount $\rho(1 - \theta)K$ can be financed externally by pledging tangible assets as collateral, so the firm requires liquidity of $\rho(\alpha H + K) - \rho(1 - \theta)K$ to withstand the shock. These precautionary cash holdings can be expressed as

$$\begin{aligned} C_p &= \rho[\alpha H + \theta K] \\ &= \rho I[\theta + \eta(\alpha - \theta)] \end{aligned} \quad (2.2)$$

Note how C_p depends on the technology parameter η . A LINT firm (small η) incurs a

employee's outside option (Oyer and Schaefer, 2005a).

¹²This might not be the case in a currently financially constrained firm, since retaining cash would reduce investment in some valuable projects.

larger expenditure but can obtain external financing, while a HINT firm (large η) requires a smaller cash outlay but must self-finance all intangible investment.

Whether retained cash increases in η therefore depends on whether the fraction of intangible capital that must be self-financed exceeds the fraction of tangible capital that is non-collateralizable ($\alpha > \theta$). While it is not a priori clear whether HINT firms face a greater future funding risk, they may suffer larger losses in distress. The evidence in any case clearly indicates that they engage in greater precautionary savings (Bates et al., 2009; Falato et al., 2013).

2.2.3 Cash holdings and employee compensation

An employee who starts an own firm at $t = 1$ gains $(1 - \alpha)H\tilde{R} = (1 - \alpha)\eta I\tilde{R}$. Therefore she will choose to remain at the firm if

$$\int U(\omega[RI + (1 - \chi)C_1])dF(R) \geq \int U((1 - \alpha)\eta RI)dF(R). \quad (\text{IC})$$

Note that (IC) always holds when the firm sets $\omega = (1 - \alpha)\eta$ and $C_1 = 0$. In this case the employee's equity stake (and risk exposure) is the same as her outside option, so she will stay even if the firm holds no cash. Retaining cash allows the firm to commit to partially insure the employee, providing higher utility than she could receive from self-employment. As a result, choosing $C_1 > 0$ allows the firm to reduce the optimal equity grant to $\omega^* < (1 - \alpha)\eta$. Hence, the firm's choice of cash at $t = 1$ refers only to the retention issue, and we will henceforth use $C_1 = C_R$. This observation yields the following result:

Lemma 3. *Under Assumption 1, it is optimal for the firm to invest in the project at $t = 0$, and to retain cash $C_0 \geq C_p$.*

Proof. With $C_0 \geq C_p$, the firm will invest if

$$(1 - \omega)[\mathbb{E}RI + (1 - \chi)C_R] \geq (1 + \lambda\rho)(\alpha H + \theta K) + C_R. \quad (2.3)$$

Since (IC) is always satisfied when $\omega = (1 - \alpha)\eta$ and $C_R = 0$, evaluating Eq. (2.3) at these values yields a necessary condition for firm participation. Using that $H = \eta I$ and $K = (1 - \eta)I$, shows that Assumption 1 (Eq. 2.3) is satisfied for any $\eta \in [0, 1]$. Note that since $\rho \leq 1$, the fact that the firm wants to invest at $t = 0$ also implies that it is optimal to re-invest after the liquidity shock. Therefore, the firm retains cash $C_0 \geq C_p$. \square

Lemma 3 implies that the firm's retained cash at $t = 0$ equals

$$C_0 = C_p + C_R^*,$$

where C_R^* denotes the period-1 level of cash holdings that optimally trades off the moral hazard cost χ against a reduction in ω .

If the firm is hit by a shock at $t = 1$, it re-invests its precautionary savings C_p . Otherwise, the firm can pay out the excess cash C_p as a dividend to its external shareholders. Note that since the employee holds unvested equity she does not receive any dividends, so whether or not a shock occurs the firm can reach its target cash level C_R^* without sharing any of the excess cash with the employee.

It follows that the firm's choice of C_0 and ω can be reduced to choosing C_R and ω . We now consider this optimization problem, which can be written as

$$\begin{aligned} \max_{C_R, \omega} \quad & V(\omega, C_R) = (1 - \omega)[\mathbb{E}\tilde{R} + (1 - \chi)C_R] - (1 + \lambda\rho)(\alpha H + \theta K) - C_R, \\ \text{s.t.} \quad & (IC), \\ & C_R, \omega \geq 0. \end{aligned}$$

The firm's objective function is decreasing in the employee's equity stake, because higher values of ω lead to greater dilution of shareholders. Therefore the firm sets ω to the lowest value that satisfies (IC), i.e., (IC) always binds. Thus we can derive ω as a function of C_R :

$$\omega(C_R) = \eta(1 - \alpha)S(C_R), \tag{2.4}$$

where

$$S(C_R) = \left[\frac{\int (RI)^{1-\gamma} dF(R)}{\int [RI + (1 - \chi)C_R]^{1-\gamma} dF(R)} \right]^{\frac{1}{1-\gamma}}.$$

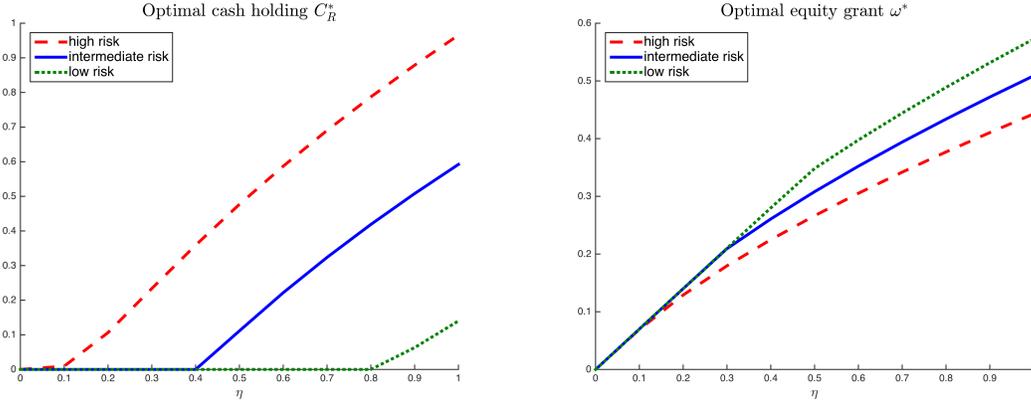
Eq. (2.4) shows that ω is proportional to $\eta(1 - \alpha)$, scaled down by an insurance premium $S(C_R) \leq 1$. Because $S'(C_R) < 0$, the required equity payment is decreasing in the amount of cash that the firm retains until $t = 2$. Furthermore, the sensitivity of ω to cash holdings depends on the employee's risk aversion γ and the underlying risk in the distribution of \tilde{R} .

Substituting Eq. (2.4) into the firm's objective function, the first-order condition w.r.t. C_R implicitly defines optimal cash holdings C_R^* :

$$(1 - \chi)[1 - \omega(C_R^*)] - \omega'(C_R^*)[\mathbb{E}R + (1 - \chi)C_R^*] = 1. \tag{2.5}$$

The left-hand side is the firm's marginal benefit from retaining an additional unit of cash. This benefit consists of two terms: 1) the per-unit return on cash net of the moral

Figure 2.2: Optimal Cash Holding and Employee Compensation Policies



Numerical solutions for C_R^* and ω^* for different risk level of \tilde{R} .

hazard cost, weighted by the share of cash $1 - \omega(C_R^*)$ that accrues to the firm; and 2) the marginal reduction in the share grant ω . The right-hand side is the marginal cost of holding cash, equal to 1.

The following proposition describes how equilibrium cash holdings at $t = 1$ (thus net of precautionary holdings) vary with technology η .

Proposition 5. *The firm's optimal cash holdings for retention purposes are increasing in η : $\frac{dC_R^*}{d\eta} \geq 0$.*

The proof is in Appendix 2.6.1. To interpret the result, note that the employee's human capital contribution increases with η . To match the value of the employee's outside option, a firm with a higher η offers a greater share grant, and holds more cash than what it needs for traditional precautionary reasons.¹³

It is easy to show that retention cash holdings C_R will increase in the employee's risk aversion γ and the underlying risk in the distribution of \tilde{R} , as both increase the required insurance premium $S(C_R)$. These results are confirmed in the numerical example plotted in Figure 2.2, where the choice of cash holdings C_R^* as well as the equity stake ω^* increase with η . The interesting result is that firms with a more volatile return \tilde{R} will further increase their cash holdings while reducing the equity grant, essentially providing more insurance.

To summarize, the firm's cash holdings at $t = 0$ are composed of a precautionary and a retention component, $C_0 = C_p + C_R^*$. The precautionary motive may induce higher

¹³In the figure we set $\chi = 0.1$, $I = 1$, $\alpha = 0.3$, $\gamma = 0.9$, while $\tilde{R} \sim U[a, b]$, where $(a, b) = (0, 5)$, $(0.4, 4.6)$ and $(0.8, 4.2)$ describe the high, intermediate and low risk case.

holdings for intangible firms if shocks requires more internal funding, while their retention motive will always induce them to hold more cash holdings to reduce their cost of funding human capital. The setup thus offers a simple rationale for why HINT firms may hold more cash than LINT firms even in the absence of financial constraints. Their greater use of unvested equity grants and other forms of self-financed deferred compensation (e.g., career promises) to employees implies further cash holdings to retain safe resources to insure their employees, all the more so when earnings are more volatile. However, as higher volatility of cash flows also increase precautionary cash holdings, the ability to identify empirically the retention motive depends on the subtler implication that the sensitivity of cash holdings to intangibles should be higher for firms with more human capital and deferred compensation.

2.2.4 Payout policy

We next consider the implications of intangible investment for corporate payout policy. Dividend policy creates a second internal conflict in the firm: As dividends are only paid out to vested shareholders, they reduce the value of the employee's unvested equity.¹⁴

In our setup, an innovative firm will avoid paying too large a dividend at $t = 1$ as the employee will depart if the value of ω^* falls below its outside option. Thus dividend payments reduce shareholder value whenever the project's present value exceeds the agency cost of retaining cash until $t = 2$.

A more interesting possibility arises when the firm can pay a dividend at $t = 2$, just before the employee's shares vest. By this date the employee has contributed her human capital to production and cannot depart to start an own firm. A dividend payment thus transfers value from the employee to shareholders, without affecting the project's return. Anticipating this possibility, highly-skilled employees would leave the firm at $t = 1$.

Thus the creation of intangible assets via the commitment of human capital over time has to resolve a double-sided moral hazard problem. Co-investment at $t = 0$ will occur only if the firm can build a reputation for refraining from large dividends before deferred equity grants vest.

A payout policy that favors repurchases over dividends reduces moral hazard cost while supporting the value of unvested shares. Let the firm's total shares be normalized to 1, and denote the market values of the firm prior to and after a repurchase as V_{NR} and V_R , respectively. Repurchasing a fraction x of shares at fair market value requires the firm to spend xV_{NR} of its cash. This reduces the firm's value to $V_R = (1 - x)V_{NR}$, but the employee's unvested equity stake concurrently rises to $\omega' = \omega/(1 - x)$. For a risk-neutral

¹⁴While dividend protected grants may be an option, they are very uncommon, and in any case less safe.

agent the value of the stake would remain constant ($\omega'V_R = \omega V_{NR}$). The risk-averse employee however suffers some utility loss from holding a larger claim on a riskier pool of assets. Nevertheless, the negative effect is much smaller than from a dividend payout.

Firms may seek various solutions to the commitment problem. We do not explicitly model how it may be solved by building reputation via an appropriate payout policy in a dynamic setting, and simply note how it would require significant cash retention and a preference for repurchases in payout policy.¹⁵

2.2.5 Empirical Implications

Our model predicts that relative to firms using few intangible assets, HINT firms:

1. have lower upfront cash outlays and higher free cashflows, for a given level of profitability
2. are not necessarily more frequently financially constrained
3. have lower net leverage and pledge a larger fraction of equity to employees
4. retain more cash, increasing in both share price volatility and size of equity grants
5. maintain a payout policy that favors repurchases over dividends

2.3 Empirical Methodology

This section describes our sample, and our measurement of intangible assets and corporate investment, financing, and payout policies. We also describe our pooled regressions and our time-series analysis of industry-level transitions to predominantly intangible investment strategies.

2.3.1 Sampling procedure

We follow the sampling criteria adopted by Bates et al. (2009) and Falato et al. (2013). Starting from all firms in Compustat between 1970 and 2010, we exclude 8,677 financial and utilities firms (SIC codes 6000–6999 and 4900–4999, respectively); 3,815 firms with asset data missing or below \$5 million, or with zero or negative sales; 3,695 firms incorporated outside the United States; and 4,800 firms with less than five years of data. Our final sample contains 12,242 firms. Some tests further restrict the sample to 2,435 firms that are in Compustat ExecuComp between 1992 and 2010.

¹⁵Here there is no reason for an innovative firm to prefer dividends, while in reality there are valid reasons (e.g. related to fiscal rules or control issues) to favor them over repurchases.

2.3.2 Empirical measures

Intangibles

Firms do not report the value of most intangible assets in their financial statements. Instead, U.S. accounting rules require firms to classify spending on intangibles as an on-going business expense, and to deduct it from operating earnings.¹⁶ As do most other researchers and practitioners, we estimate the value of intangible assets by capitalizing annual investment into intangibles with an appropriate depreciation schedule.

Our procedure follows Peters and Taylor (2016) by computing the value of knowledge acquired through research, the firm's brand recognition, and the quality of its organizational culture. The creation and maintenance of these assets relies largely on the human capital contribution of highly skilled employees, such as research scientists and marketing professionals. The ideas that creative employees formulate over time matter more for intangible asset values than upfront cash invested by the firm. Prior work measures intangible assets similarly and finds that they are associated with reliance on skilled labor, greater emphasis on employee retention, and usage of information technology (Lev and Radhakrishnan (2005), Eisfeldt and Papanikolaou (2013)).¹⁷

The procedure capitalizes past years' R&D spending using the perpetual inventory method. Missing R&D values are set to 0 after 1977. R&D depreciation rates are from the Bureau of Economic Analysis, and range across industries from 10% to 40% (see Li (2012)). Similarly, we capitalize a portion of Selling, General, and Administrative expenses (SG&A), as these include investment to enhance organizational capital (e.g., marketing or employee training expenses, see Eisfeldt and Papanikolaou (2013)). We subtract annual R&D spending from SG&A, because Compustat almost always combines the two expenditures. We then capitalize 20% of remaining SG&A as investment into organizational capital. We use a lower weight on SG&A than the 30% in Peters and Taylor (2016), because the data show an economy-wide decrease in SG&A expenditure after 2001 that could be due to cost-cutting efficiency gains rather than reduced investment. We follow the literature by setting the depreciation rate for organizational capital to 20%.

We calculate firms' total intangible assets as the sum of capitalized investments into

¹⁶ Among the exceptions, the purchase price of externally acquired intangible assets is included in Goodwill. Also, some internally produced intangibles are reported as Other Intangible Assets, including legal and consulting fees incurred when developing a patent, and spending on software that has reached commercial viability.

¹⁷ Bellstam et al. (2017) propose a different measure of corporate innovation, based on textual analysis of analyst reports, and find that it is associated with growth opportunities and the operation of innovative systems.

R&D and organizational capital, plus the book value of Other Intangible Assets. Our measure excludes Goodwill as it partly reflects a market premium paid to acquire tangible assets, but our results are robust to including it and to using a range of different weights on SG&A (see I.A. Table ??). *Intangibles Ratio* equals the stock of intangible assets divided by total assets. Throughout the paper, we measure total assets as the sum of intangible assets and Property, Plant, and Equipment net of depreciation (PP&E).

In addition to using a continuous measure of intangibles, we present some descriptive patterns separately for HINT and LINT firms. HINT (LINT) firms are those with *Intangibles Ratio* values in the highest (lowest) tercile of the sample distribution. We calculate the distribution across all sample years, but our results do not change when using annual terciles to classify firms.

Table 2.1 reports a selection of industries that experienced the largest and smallest change in *Intangibles Ratio* during our sample period. While intangibles usage is highest among firms that produce pharmaceuticals (0.96) and computers (0.90), numerous other industries such as Healthcare, Communication, and Apparel have also experienced dramatic increases. At the other end of the spectrum, firms in the Transportation, Agriculture and resource extraction industries use the fewest intangible assets.

TABLE 2.1 ABOUT HERE

Investment and Cashflows

To confirm that intangible capital creation requires lower outlays, we measure the amount of cash that firms spend each year on different types of investment. We measure *Tangible Investment* as the annual change in net PP&E. The change in physical plant reflects annual capital expenditures, and also encompasses the cost of acquiring tangible assets as well as purchases recorded under other accounting items. *Intangible Investment*, as described above, is annual spending on R&D and 20% of SG&A, plus external acquisitions of intangible assets. This measures firms' cash outlays—for example, R&D consists mostly of cash wages paid to researchers and the cost of materials—but not the human capital investment of employees.

We scale both variables by operating cashflows, measured as earnings prior to depreciation and investment, minus taxes and interest payments. This is the amount of cash inflows from business operations, which the firm can invest, pay out to shareholders, or retain. Scaling by cashflows is an intuitive way to analyze how much a firm invests out of each dollar of cash that it earns, yet results are robust to scaling by total assets (see I.A.

Table ??). Moreover, as Peters and Taylor (2016) explain, operating cashflows more accurately measure the performance of HINT firms than profitability metrics such as EBITDA or ROA, which are calculated after deducting intangible investment.

Free Cashflows is the fraction of operating cashflows that remain after total investment outlays. Thus firms with higher free cashflows spend proportionally less upfront on investment. *Retained Cash* measured the fraction of *Free Cashflows* that the firm retains, with the remainder paid out to shareholders. The accumulation of retained free cashflows over time is reflected in a firm's stock of cash. We measure *Cash Holdings* as the sum of cash and marketable securities, divided by total assets.

Financing

We use *Net Leverage* to measure firms' reliance on external financing. This variable equals the book value of debt minus cash holdings, divided by total assets.

Our primary measure of inside financing, *Equity Grants*, equals the total dollar value of annual stock option and restricted stock grants to employees, divided by market capitalization. This variable reflects the fraction of total equity value that the firm pledges to employees each year.

One challenge is that firms historically did not report detailed data on inside ownership by employees. Prior work (e.g., Aldatmaz et al. (2017)) commonly uses the procedure developed by Bergman and Jenter (2007). The procedure uses data from ExecuComp on the fraction of stock options granted to top executives each year, and infers the Black-Scholes value of total option grants to all employees. We measure *Equity Grants* as the sum of this number plus the annual value of stock grants to all employees, which firms report in their financial statements. Because the procedure relies on data from ExecuComp, *Equity Grants* is only measured for the firms in that database (which are in the S&P 1500) starting from 1992. We include equity grants to top executives, as their human capital contribution likely supports the value of intangible assets (e.g., some C-Suites include a chief technology or marketing officer); we obtain similar results when excluding them.

We also constructed a second measure, *Reserved Shares*, which equals the number of deferred shares and stock options that firms have granted to employees, divided by this number plus publicly traded shares. This approximates employees' maximum equity stake in the firm, as it equals the amount of shares they would receive if all stock options were exercised and all restricted stock vested. However, Compustat stops reporting this variable after 1995. Because much of the growth in intangibles usage has come in recent years, we relegate results using *Reserved Shares* to the Internet Appendix.

Payouts

Total payouts are the sum of common dividends and share repurchases. Because our model’s implications are for payouts to external shareholders, we measure repurchases following Fama and French’s (2001) procedure, which excludes share buybacks that are immediately used to fulfill employees’ option exercises. The composition of annual payouts, $Repurchases/Payouts$, is measured as stock repurchases divided by total payouts.

2.3.3 Empirical specifications

Pooled OLS regressions

We use two empirical models throughout the paper. First, we estimate pooled OLS regressions across our entire sample, to analyze all of the cross-sectional and time-series variation in intangibles usage. We use the following model, for firm i and fiscal year t :

$$\begin{aligned} Corporate\ Policy_{i,t} = & \alpha + \beta Intangibles\ Ratio_{i,t} + \phi Tobin's\ Q_{i,t} + \zeta Log\ Total\ Assets_{i,t} \\ & + \delta X_{i,t-1} + \mu_j + \mu_t + \epsilon_{i,t} \end{aligned} \tag{2.6}$$

The dependent variables in this model are the various corporate policies described in Section 2.3.2. Our control variables are based on Bates et al. (2009). We use *Tobin’s Q* in all regressions to control for investment opportunities, and *Log Total Assets* to control for differences in firm size. We follow Peters and Taylor (2016) by including intangible assets in the denominator of Q , as this better explains intangible investment.

Some regressions further include a vector of additional variables X that partly measure financial constraints. These include *Operating Cashflows*, *Cashflow Volatility* measured as the standard deviation of operating cashflows from the previous 10 years, and *Book Leverage*. Firms with higher cash inflows, less risky cashflows, and lower leverage may have a lower need for precautionary savings.

All regressions include fixed effects μ_j for the Fama-French 48 industries and μ_t for the fiscal year. We cluster all standard errors at the firm level, to account for possible serial correlation due to interdependence of firms’ observations across time. We obtain similar results when using firm fixed effects in Eq. (2.6) to analyze how corporate policies change within the same firm as its intangible capital evolves over time (see I.A. Table ??).

We estimate Eq. (2.6) using all sample firms, and also after excluding firms that produce computers, software, and related products. The tech sector, and startup firms in general, certainly rely largely on employees’ human capital contributions and do not need

to use many tangible assets. Importantly, however, technological innovation is thought to affect the production process and increase the importance of human capital across a wide range of economic sectors. We test this theoretical view by re-estimating all results without computers firms. We separately report results after excluding any firm that recently completed an IPO (see I.A. Table ??).

Staggered technological transitions

Our second model studies how corporate policies evolve across time following large changes in intangibles usage. We analyze rapid, structural shifts from tangible to intangible investment at the industry level. The data show that these transitions were staggered across time, as technological innovation increased the return on human capital earlier in some industries than others. This setting thus provides significant time-series variation that is not fully explained by macroeconomic shocks.

To identify transitions, we first calculate the time series of *Intangible/Total Investment* using the median firm in each Fama-French 48 industry. We then use Andrews (1993)'s procedure to test for a single structural break in each industry's time series.¹⁸ We find structural breaks for 37 of the 48 industries. We omit eight industries whose break dates have a confidence interval wider than five years. We also exclude nine industries with intangible investment rates that level off in the 2000s after an earlier period of rapid growth, as our model's implications are for firms that switch from tangible capital-intensive to human capital-intensive production.

We identify that two industries transitioned in the 1970s, seven in the 1980s, four in the 1990s, and seven in the 2000s. Industries that transitioned by the early 1980s include Apparel, Pharmaceuticals, and Business Services (this category includes advertising, software, and data processing). Industries that transitioned after 2000 include Transportation, Wholesale and Entertainment. In our theoretical view, this time-series variation is explained by technological innovations becoming commercially applicable in some industries earlier than in others. Nascent computer systems of the 1980s boosted the productivity of a drug researcher or software developer, while other industries such as wholesale trading were transformed only after the widespread adoption of the Internet.

We estimate the following regression for each firm i in one of the 20 transitioning

¹⁸This procedure is commonly applied when the date of a possible break is unknown. We partition each industry's time series into two parts, regress *Intangible/Total Investment* on two separate time trends, and calculate the difference in explanatory power between the time trends. We use 1973 as the first candidate break, and repeat the process for each year through 2007. The break is the year with the largest change in explanatory power.

industries, using a five-year (two-sided) window around each transition:

$$\begin{aligned} \text{Corporate Policy}_{i,t} = & \alpha + \beta \text{Post Transition}_{i,t} + \phi \text{Tobin's } Q_{i,t} + \zeta \text{Log Total Assets}_{i,t} \\ & + \delta X_{i,t-1} + \mu_j + \epsilon_{i,t} \end{aligned} \tag{2.7}$$

In this model, *Post Transition*_{*i,t*} equals 1 for years that follow a technological transition, and 0 for years that precede it. Other variables are the same as in Eq. (2.6), except that we do not use year fixed effects; otherwise the analysis would exclude years containing only industries that have already transitioned, such as in the late 2000s. (Results are robust to use fixed effects for five-year periods.) To account for possible changes in the composition of firms within an industry, we estimate Eq. (2.7) only for firms that were present before and after the transition.

Figure 2.4 plots intangible and tangible investment rates around the technological transitions. Investment rates are similar before the break. Intangible investment then rises in the year of the break, while tangible investment falls sharply and continues to decrease in subsequent years. As a result, the *Intangible/Total Investment* ratio increases by a third, from 0.51 to 0.69. These plots confirm that these time trend breaks are structural shifts, and correspond to dramatic, one-time changes in the composition of firms' investment.

FIGURE 2.4 ABOUT HERE

2.3.4 Summary statistics

Table 2.2 presents summary statistics for all of the variables used in our analysis, separately for HINT and LINT firms. It also presents the difference in means across the two groups.

TABLE 2.2 ABOUT HERE

The table shows that HINT firms spend significantly less on tangible investment and have higher free cashflows. Their cash holdings are substantially higher at 21% of assets for the median firm, compared to 7.2% for LINT firms. Furthermore, HINT firms are less levered, pledge more equity to employees, retain more cash, and favor share repurchases over dividends.

Interestingly, Table 2.2 shows that HINT firms have significantly higher operating cashflows of 30% of assets, compared to 19% for LINT firms. This finding, together with HINT firms' lower total investment outlays, suggests that these firms can cover a greater portion

of their investment needs from cash inflows. We study this in more detail in Section 2.4.3.

2.4 Empirical Tests

This section presents our results on the relation between intangible assets and cashflows, corporate financial policy, employee compensation, and shareholder payouts.

2.4.1 Investment outlays and free cashflows

Our key insight is that the creation of intangible assets requires lower upfront cash outlays than tangible assets, as it relies on the human capital contribution of skilled employees. We start by verifying this critical modeling assumption.

Figure 2.5, Panel A compares the cash outlays of HINT and LINT firms over time. It plots the fraction of operating cashflows spent on tangible and intangible investment, as well as the free cashflows left after investment. Across our sample period, the median HINT firm spends less than 20% of operating cashflows on the production of tangible assets. While its intangible investment rate is significantly higher, free cashflows are about 20% of operating cashflows. In contrast, the median LINT firm's free cashflows were frequently negative prior to 2000, reflecting a reliance on external finance for tangible investment. LINT firms' investment outlays decreased in the 2000s, resulting in a free cashflow that was positive yet half as high as that of HINT firms.

FIGURE 2.5 ABOUT HERE

Panel B plots the evolution of free cashflows around industry-level technological transitions. Free cashflows appear stable in the years preceding a transition, but rise sharply afterward. This increase is concurrent with a large decline in tangible investment (see Figure 2.4), indicating that firms' outlays fall quickly after a shift to human capital-intensive production, allowing for greater resource retention.

Table 2.3 analyzes these relationships in a regression framework. Columns (1) through (6) report estimates from pooled OLS regressions based on Eq. (2.6). They offer further evidence that intangible assets are associated with significantly lower investment outlays and higher free cashflows, as a fraction of operating cashflows. Column (2) indicates that a 0.31 increase in *Intangibles Ratio*—equal to the median firm's rise in intangibles usage from 1970 to 2010—corresponds to a 0.45 ($= -1.44 \times 0.31$) decline in the tangible investment rate. This equals 92% of the variable's interquartile range of 0.49. Column (5)

indicates that this rise also leads to 0.11 ($= 0.34 \times 0.31$) higher free cashflows, or 20% of the interquartile range.

The results do not change after excluding computers firms in columns (3) and (6). They are also robust to different variations in the empirical specification, such as measuring tangible investment as the sum of capital expenditures and acquisitions (I.A. Table ??) or scaling investment and free cashflows by total assets (I.A. Table ??).

TABLE 2.3 ABOUT HERE

Next, columns (7) through (10) present regressions based on Eq. (2.7), estimated over a five-year window surrounding technological transitions. The estimates indicate that tangible investment indeed declines significantly, from 0.39 prior to the transition to 0.22 afterward, while free cashflows rise from 0.15 to 0.24. The 60% increase in free cashflows shows that large shifts in intangibles production lead to dramatic decreases in investment spending.

2.4.2 Corporate financing

Next we test the model's prediction that firms use different sources of finance to create intangible and tangible assets. LINT firms are able to raise external financing because they can pledge more of their assets as collateral. In contrast, HINT firms grant employees a (deferred) share of the value that their human capital creates, in order to match their outside opportunities. Intangibles usage thus should be associated with lower leverage and larger equity grants to employees.

The results in Table 2.4 support this prediction. Column (2) indicates that the historical 0.31 rise in *Intangibles Ratio* leads to a 0.17 ($= -0.55 \times 0.31$) decline in net leverage, equal to 28% of the variable's interquartile range. Low leverage is often associated with high tech firms, yet we obtain similar results after excluding all computers firms.

Next, columns (4) through (6) show that firms with more intangibles also grant employees more equity each year, as a fraction of their market capitalization. Column (5) indicates that the historical increase in *Intangibles Ratio* is associated with an annual transfer of 0.4% ($= 0.013 \times 0.31$) of the firm's equity. For comparison, the median *Equity Grants* value across the entire sample is 0.8% of market capitalization. These tests are estimated across the subsample of ExecuComp firms for which compensation data is readily available, yet we obtain similar results using the alternative variable *Reserved Shares* that

measures the size of employees' equity stakes across a different set of firms (I.A. Table ??).

TABLE 2.4 ABOUT HERE

Next, columns (7) through (10) examine changes to funding policies around technological transitions. The results imply that the median leverage ratio fell from 0.32 in the five years preceding a transition to 0.27 in the five years afterward. The median amount of equity pledged annually rose from 0.5% to 0.7% of market capitalization, a 40% increase.

Taken together, these results support our model's prediction that the evolution of investment in recent decades has led to a shift from external to internal financing.

2.4.3 Are HINT firms more financially constrained?

HINT firms' lower investment spending and leverage, as well as their higher cash holdings, could be explained as precautionary steps to avoid the possibility of becoming financially constrained in the future. The model offers an alternative view that HINT firms are not necessarily *more* financially constrained than LINT firms. Instead, their cash holdings consist of two components: 1) precautionary savings C_p that are sufficient to cover future investment outlays in the event of financial constraints; and 2) additional cash C_R^* that supports the value of employees' equity claims. We next document that HINT firms' resources seem to exceed the required precautionary component.

Figure 2.6 compares HINT and LINT firms' investment coverage. Panel A plots the median firm's cash holdings at the start of the year, divided by annual total investment spending averaged over the three previous years. In the absence of detailed data on anticipated future spending, we examine whether firms' cash holdings are sufficient to maintain recent investment outlays. Naturally, future investment needs may exceed past spending, but it is worth noting that HINT's firms total investment outlays vary less over our sample period than LINT firms' outlays (Table 2 shows a lower standard deviation of *Avg. Total Investment* among HINT firms).

The plots show that in all years, HINT firms' cash covered a larger portion of total investment spending. Moreover, in recent years the median HINT firm's cash has been sufficient to entirely fund annual investment; in contrast, LINT firms' cash equaled less than half of recent expenditures.

FIGURE 2.6 ABOUT HERE

These differences reflect HINT firms' lower investment outlays, yet they also may be due to the cumulative effect of precautionary savings over time. To provide further evidence, Panel B plots the ratio of current-year operating (pre-investment) cashflows to previous years' total investment. Firms can become financially constrained when they do not earn enough cash to cover annual investment needs. However, the plots show that across time, HINT firms earn similar or higher cashflows relative to recent investment than LINT firms. Additionally, in many years the median HINT firms' cashflows alone were large enough to maintain investment levels.

Next, Panel C analyzes how often each firm's liquid resources are sufficient to preserve investment spending. For each firm, we calculate the fraction of sample years in which current operating cashflows and start-of-year cash holdings exceed previous investment outlays. The plots show that 30% of HINT firms had sufficient investment coverage in all sample years, and another 29% had sufficient coverage at least two-thirds of the time. Only 19% of HINT firms lacked resources in most or all years to cover recent investment levels.

The evidence that HINT firms' cash holdings and cashflows are usually more than sufficient to maintain investment spending offers some perspective to the precautionary savings view. Naturally, some cash retention allows firms to reduce the likelihood of financial constraints. Even if innovative firms are less frequently constrained, their opportunity costs are likely higher. Yet because HINT firms have lower investment outlays, they do not seem to be *more* financially constrained overall than LINT firms. The data suggest they hold cash for reasons other than precautionary savings. We now turn to examining two reasons suggested by our model.

2.4.4 Cash Holdings

Resource Retention

HINT firms grant deferred compensation to promote critical employees' retention, thereby ensuring that the capital they create stays within the firm. The model predicts that this compensation has higher value when firms hold more resources until the grants vest. This allows firms to support employees' human capital commitment at a lower cost.

Table 2.5 presents evidence supporting this prediction, by regressing *Retained Cash* on *Intangibles Ratio*. The results show a positive and highly significant relationship, indicating that intangible firms hold onto more of the free cashflows left after investment, instead of paying them out to external shareholders. Column (2) shows that a firm with a 0.31 higher *Intangibles Ratio* retains an additional 12.7% ($= 0.41 \times 0.31$) of its free cashflows;

the median across the entire sample is 76.8%. Similarly, Column (5) shows that the fraction of free cashflows that firms retain rises from 0.65 to 0.82 (a 26% increase) following a technological transition.

TABLE 2.5 ABOUT HERE

Employee Insurance

Holding significant cash balances offers the additional benefit of reducing future stock price volatility. This boosts the value that risk-averse employees assign to deferred compensation, as large pledged equity grants expose them to idiosyncratic firm risk. The model thus puts forward an insurance benefit of cash holdings, which is increasing in share price volatility and the amount of equity pledged to employees.

We test these predictions using a modified version of our pooled OLS regressions:

$$\begin{aligned} \text{Cash Holdings}_{i,t} = & \alpha + \gamma_1 \text{Intangibles Ratio}_{i,t} + \gamma_2 \text{High Volatility}_{i,t-1} \\ & + \gamma_3 \text{Intangibles Ratio}_{i,t} \times \text{High Volatility}_{i,t-1} \\ & + \phi \text{Tobin's } Q_{i,t} + \zeta \text{Log Total Assets}_{i,t} + \delta X_{i,t-1} + \mu_j + \mu_t + \epsilon_{i,t} \end{aligned} \quad (2.8)$$

In Eq. (2.8), $\gamma_3 > 0$ would indicate that HINT firms hold more cash when their employees are exposed to more stock price risk. *High Volatility* equals 1 for firms with above-median stock volatility, measured as the standard deviation of stock returns from the previous 48 months. It equals 0 for firms with below-median volatility. We use an indicator as the coefficient estimates are easier to interpret, but obtain similar results using continuous volatility (see I.A. Table ??).

We also estimate Eq. (2.8) by interacting *Intangibles Ratio* with *High Equity Grants*, which equals 1 for firms with above-median values of *Equity Grants*, and 0 for firms with below-median values. In these regressions, a positive γ_3 would indicate that HINT firms hold more cash when they have pledged a larger equity stake to employees.

Table 2.6 reports the results. For consistency, we estimate all regressions using the sample of ExecuComp firms over which *Equity Grants* can be measured. Column (1) shows that the effect of intangibles on cash holdings is 2.5 times stronger at high-volatility firms. The coefficient on *Intangibles Ratio* indicates that among low-volatility firms, a 0.31 rise in intangibles usage leads to a 0.034 ($= 0.11 \times 0.31$) higher cash balance (relative to the sample median of 0.14). For high-volatility firms, the same rise leads to a 0.087 ($= (0.11 + 0.17) \times 0.31$) increase in cash holdings. Column (2) shows that the size of equity grants has a similar impact on the intangibles-cash holdings relationship. Among firms

that pledge little equity, the historical rise in intangibles leads to a 0.028 ($= 0.09 \times 0.31$) increase in cash holdings, compared to an increase of 0.074 ($= (0.09 + 0.15) \times 0.31$) at firms that pledge significant equity.

TABLE 2.6 ABOUT HERE

Next, columns (3) and (4) show that both interaction terms have positive and significant coefficients when included together in the same regression. This shows that stock volatility leads to higher cash holdings at both intangible-high equity grant firms and intangible-low equity grant firms. Column (5) further shows that stock volatility and equity grants similarly influence the effect of intangibles usage on cash holdings within the same firm over time.

One possible concern with this analysis is that firms with high stock volatility are at greater risk of financial constraints, and thus hold more cash for precautionary reasons. Similarly, firms with limited free cash may prefer to compensate employees using equity. Table 2.7 accounts for this possibility in two ways. First, Panel A re-estimates the model from Column (3) of Table 2.6, with additional controls for the interaction of *Intangibles Ratio* and commonly used measures of financial constraints (see Farre-Mensa and Ljungqvist (2016)). Columns (1) through (3) use the indexes of Hadlock and Pierce (2010), Whited and Wu (2006), and Kaplan and Zingales (1997).¹⁹ Columns (4) and (5) identify constrained firms as those without a credit rating or that do not pay dividends. We omit *Log Total Assets* from these regressions as the constraint measures are highly correlated with firm size.

TABLE 2.7 ABOUT HERE

Four of the five coefficients on the interaction *Intangibles Ratio* \times *High Constraints* are positive and significant, consistent with HINT firms that face a greater risk of becoming constrained holding more cash. (The fifth measure, the Whited-Wu index, shows that firms generally hold more cash when constrained regardless of intangibles usage.) Yet alongside this precautionary motive, stock volatility and the amount of equity pledged to employees continue to explain intangible firms' cash holdings. The magnitudes of these effects are just slightly smaller than those from Table 2.6.

Next, Panel B re-estimates results using a subset of ExecuComp firms that do not appear to be financially constrained. Column (6) contains only firms with lines of credit

¹⁹We use the KZ index as measured by Lamont et al. (2001). Following convention, we classify firms with index values in the top tercile as financially constrained, and apply the index estimates directly to our sample without re-estimating the underlying models.

that are partially or fully undrawn.²⁰ The average (median) undrawn credit line covers 144% (109%) of annual average total investment spending from the past three years. This provides firms with a precautionary buffer against future constraints, yet firms cannot pledge credit lines to unvested employees and must still hold cash to reward them. The results indeed show that riskier HINT firms or those with larger equity grants hold more cash. Column (7) reports similar results among firms that pay out cash to shareholders; firms that have sufficient cash to buy back stock or pay dividends are likely unconstrained.

Overall, these results support the model’s prediction that firms have a retention motive for holding cash, next to a need to maintain precautionary liquidity.

2.4.5 Payouts to external shareholders

Finally, we examine the model’s prediction that HINT firms favor paying out cash using share repurchases rather than dividends, as this better supports the value of employees’ deferred equity grants. Table 2.8 regresses *Repurchases/Payouts* on *Intangibles Ratio*, among the firms that pay out some amount of cash to shareholders. The results shows that firms with more intangibles indeed pay out cash primarily by repurchasing shares. Column (2) indicates that a 0.31 increase in *Intangibles Ratio* is associated with a 0.08 ($= 0.25 \times 0.31$) higher payout ratio, compared to the sample mean of 0.31. Columns (4) and (5) further show that firms shift the composition of payouts toward more repurchases after their industries experience technological transitions; the payout ratio rises from 0.28 to 0.39 after a transition.

TABLE 2.8 ABOUT HERE

2.5 Conclusions

The paper has studied empirically the effect of evolving technology on funding and payout policy through the lens of a simple model of corporate investment.

Our main contribution is an analysis of the impact of human capital on corporate financing, risk management and payout policy. Our simple investment model distinguishes firms in terms of their adoption of intangible investment. We show that the specific nature of intangible capital implies two key differences.

First, while traditional firms rely on upfront purchases of physical capital, intangible capital needs to be developed and innovated by creative employees contributing their hu-

²⁰Data on the amount of undrawn credit lines is provided by Erasmo Giambona, and were hand-collected from firm financial statements.

man capital, which cannot be purchased. As a result, HINT firms have lower investment and financing needs. Empirically, innovating firms indeed tend to have higher free cash-flows and pledge more equity to skilled employees. They are on average less likely to be ex-post constrained, although some of their cash is likely held for precautionary reasons, reflecting a higher opportunity cost of financial constraints and distress.

Moreover, the setup suggests a second motive for prudent financial policy next to this classic precautionary motive. As intangible investment requires cooperation of skilled labor in developing intangible capital, it needs to be rewarded by deferred compensation. Reducing the cost of skilled human capital requires lower leverage, higher cash holdings and a preference for share repurchases over dividends in the corporate payout policy. This strategy supports the commitment of risk-averse human capital to the development of corporate intangible assets, and reduces the cost of skilled human capital. Our empirical analysis confirms the importance of such a complementary motive for prudent corporate financing and payout policies. Firms with more intangibles appear to hold even more cash, in particular when their stock volatility is high or their employees hold large equity stakes, and favor repurchases over dividends.

In conclusion, this paper contributes to an emerging literature that extends classic insights on corporate financial structure to the growing use of a special class of assets. The traditional motives of risk management and minimization of the cost of capital are here restated in a world where innovation is paired with skilled human capital, and where innovators and top talent have improved outside options. Much work needs to be still done to fully appreciate the implication of this transformation.

2.6 Proofs and Extensions of the Model

2.6.1 Proof of Proposition 5

This appendix proves the result of Proposition 5, that optimal period-1 cash holdings increase in the firm's technological reliance on intangibles, i.e. that $\frac{dC_1^*}{d\eta} \geq 0$. To prove the proposition, we first derive the following intermediate result:

Lemma 4. *Consider two pairs (ω', C_1') and (ω'', C_1'') that are the firm's optimal choice given two different parameter values $\eta' \neq \eta''$. If $\omega'' > \omega'$ then it must also be that $C_1'' \geq C_1'$.*

Proof. Suppose the contrary. We will show that this is inconsistent with the firm's optimization. To see this, use (2.4) to write the firm's first order condition (2.5) as

$$[\mathbb{E}R + (1 - \chi)C_1] \frac{S'(C_1)}{S(C_1)} = \frac{(1 - \omega)(1 - \chi) - 1}{\omega}$$

Since (ω', C_1') and (ω'', C_1'') are both optimal choices, the first order condition must be satisfied for each pair.

Clearly, the RHS increases in ω . Similarly, the LHS can be written as

$$-(1 - \chi) \frac{\int (R + (1 - \chi)C_1) dF(R)}{\int (R + (1 - \chi)C_1)^{1-\gamma} dF(R)},$$

which increases in C_1 for $\gamma \geq 0$. However, this implies that if $\omega'' > \omega'$ and $C_1'' < C_1'$, (2.5) cannot be satisfied for both (ω', C_1') and (ω'', C_1'') , thus contradicting that both can be optimal choices by the firm. \square

Next, observe that a higher η increases the bargaining power of the employee. If $\eta'' > \eta'$, the incentive compatibility constraint (IC) requires that $\omega'' > \omega'$, or $C_1'' > C_1'$, or both. The only way an increase in η can possibly decrease cash holdings is therefore if $\omega'' > \omega'$ and $C_1'' < C_1'$. However, this is ruled out by the result in lemma 4, completing the proof of Proposition 5. \square

2.6.2 Deferred cash compensation

This appendix shows that when the employee is compensated with a deferred cash payment instead of unvested equity, the firm still optimally retains cash to reduce retention costs. Suppose that at $t = 0$, the firm grants the employee a cash payment w that vests after returns are realized at $t = 2$. The crucial insight is that if the firm does not retain enough

cash, it may default on the promised compensation.²¹ In particular, the firm's effective payment to the employee is

$$\min \{RI + (1 - \chi)C_1, w\}.$$

The cash grant is therefore riskless if and only if $C_1 \geq \frac{w}{(1-\chi)}$. Essentially, deferred cash compensation has a debt-like payout structure, and cash holdings shrink the default region.

Now, denote by

$$\hat{R}(C_1) = \frac{w - (1 - \chi)C_1}{I}$$

the threshold such that for realizations of $R < \hat{R}(C_1)$ the firm defaults on the employee's compensation. The incentive compatibility constraint to prevent the employee from leaving can be re-expressed as

$$\int_{\hat{R}(C_1)}^{\bar{R}} U(w) + \int_0^{\hat{R}(C_1)} U([RI + (1 - \chi)C_1])dF(R) \geq \int U((1 - \alpha)\eta RI)dF(R). \quad (\text{IC}')$$

The first term on the left-hand side is the employee's utility from the deferred cash payment, and the second term is the expected utility upon default. As in the model with unvested equity, this must exceed the expected utility from starting an own firm.

The firm's problem is now to choose a level of period-1 cash holdings C_1 and deferred cash payment w to maximize

$$\begin{aligned} \max_{C_1, w} \quad & V(w, C_1) = \Pr[R \geq \hat{R}(C_1)][\mathbb{E}\tilde{R} + (1 - \chi)C_1 - w] - (\alpha H + K + \lambda C_p + C_1), \\ \text{s.t.} \quad & (\text{IC}), \\ & C_1, w \geq 0. \end{aligned}$$

We return to denote C_1 by C_R , as the choice relates to retention. Clearly, the firm's objective function is decreasing in w , so that it chooses the minimum level consistent with (IC'), implicitly defining $w(C_R)$. Condition (IC') shows that the employee's utility from staying inside the firm (the left-hand-side of the condition) is increasing in both w and C_R . This implies that $w'(C_R) \leq 0$, i.e., holding cash reduces the size of the deferred cash grant necessary to retain the employee.

There are now two cases to consider. First, the firm may choose to fully insure the

²¹Recall that the support of \tilde{R} is $[0, \bar{R}]$.

worker by setting $w = \underline{w}$ and $C_R = \frac{\underline{w}}{(1-\chi)}$, where

$$\underline{w} = \eta(1 - \alpha) \left[\int (R)^{1-\gamma} dF(R) \right]^{\frac{1}{1-\gamma}} .$$

Note that the firm will never hold more cash than $\frac{\underline{w}}{(1-\chi)}$, since the employee is already fully insured and additional cash holdings have a moral hazard cost χ . Second, the firm may choose an interior solution $C_R^* \in \left[0, \frac{\underline{w}}{(1-\chi)}\right)$ and $w^* > \underline{w}$ that maximizes $V(w, C_R)$.

Importantly, under deferred cash compensation the same motive to hold cash prevails. Since the firm is risk-neutral, it may choose to hold some cash to insure the risk-averse employee against defaulting on the promised payment, decreasing the overall cost of employee retention.

2.7 Paper Appendix

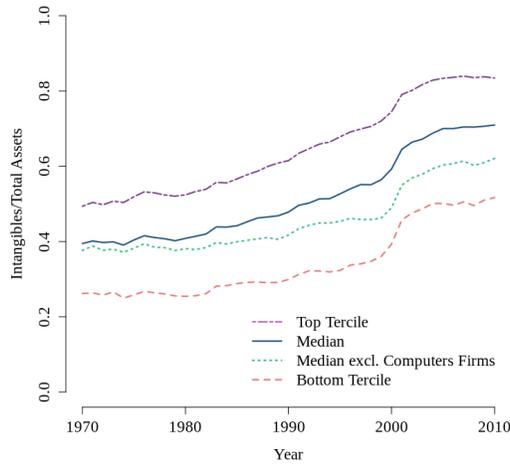
Variable	Definition
<i>Intangibles Ratio</i>	The value of the firm's stock of intangible assets, divided by total assets. The stock of intangible assets is measured as in Peters and Taylor (2016), by summing up the capitalized value of spending on R&D, investment into organizational capital, and acquisition of externally produced intangible assets. Two differences between our procedure and that of Peters and Taylor (2016) is that we measure investment into organizational capital as 20% of SG&A instead of 30%, and we exclude Goodwill from the acquisition of externally produced intangible assets. Throughout this appendix, total assets is defined as the sum of intangible assets and PP&E (data item PPENT).
<i>Post Transition</i>	An indicator that is equal to 0 for observations that precede a technological transition, and 1 for observations that follow it. Technological transitions are identified separately for each of the 48 Fama-French industries as a structural break in the time series of <i>Intangible/Total Investment</i> , using the method developed by Andrews (1993).
<i>Tangible Investment</i>	The annual change in PP&E (data item PPENT) net of depreciation (DPACT), divided by <i>Operating Cashflows</i> . This variable is set to missing for firms with negative <i>Operating Cashflows</i> . This variable is winsorized at the 1-99 level.
<i>Intangible Investment</i>	The sum of R&D spending (data item XRD), $0.2 \times$ SG&A expenditures (SGA), and acquisition of externally produced intangibles, divided by <i>Operating Cashflows</i> . Acquisition of externally produced intangibles is measured as the annual change in Other Intangibles (INTANO) plus Amortization of Intangibles (AM). Starting in 2006, we deduct from SG&A the fair-value expense of stock option grants to employees (data item OPTFVGR), as this is not a cash outlay. This variable is set to missing for firms with negative <i>Operating Cashflows</i> . This variable is winsorized at the 1-99 level.
<i>Intangible/Total Investment</i>	<i>Intangible Investment</i> divided by <i>Total Investment</i> . This variable is winsorized at the 1-99 level.
<i>Avg. Total Investment</i>	The average of the sum of <i>Tangible Investment</i> and <i>Intangible Investment</i> from the three previous years. This variable is winsorized at the 1-99 level.
<i>Free Cashflows</i>	<i>Operating Cashflows</i> minus <i>Total Investment</i> , divided by <i>Operating Cashflows</i> . This variable is winsorized at the 1-99 level.
<i>Net Leverage</i>	The sum of total debt (data items DLTT plus DLC) minus cash and marketable securities (data item CHE), divided by total assets. This variable is winsorized at the 1-99 level.
<i>Equity Grants</i>	The sum of the value of annual stock grants (data item STKCO) and the Black-Scholes value of stock option compensation, divided by market capitalization ($PRCC.F \times CSHO$). Prior to 2004, the Black-Scholes value of stock options is inferred using the procedure of (Bergman and Jenter, 2007). Afterward, it is data item OPTFVGR. Prior to 2001, the value of stock grants is set to 0 as Compustat did not collect STKCO in these years, and only 7.5% of firms granted stock in the early 2000s. This variable is measured only for ExecuComp firms, and is winsorized at the 1-99 level.
<i>Retained Cash</i>	<i>Free Cashflows</i> minus total payouts, divided by <i>Free Cashflows</i> . This variable is winsorized at the 1-99 level.
<i>Cash Holdings</i>	The sum of cash and marketable securities (data item CHE), divided by total assets. This variable is winsorized at the 1-99 level.
<i>Repurchases/Payouts</i>	Stock repurchases divided by the sum of stock repurchases and common dividends (data item DVC). Repurchases are the year-on-year change in the number of shares in the corporate treasury (TSTKC). For firms with zero or missing values of treasury shares in the past two years, repurchases equals open-market purchases of common stock (PRSTKC) minus sales of common stock (SSTK). This variable is winsorized at the 1-99 level.
<i>Tobin's Q</i>	Total debt (the sum of data items DLTT and DLC) plus the market value of equity ($PRCC.F \times CSHO$) minus current assets (ACT), all divided by total assets. This variable is winsorized at the 1-99 level.
<i>Log Total Assets</i>	The natural logarithm of total assets. This variable is winsorized at the 1-99 level.
<i>Operating Cashflows</i>	Operating earnings (data item OIDBP) plus intangible investment minus tax payments (TXT) and interest payments (XINT), all divided by total assets. This variable is winsorized at the 1-99 level.
<i>Cashflow Volatility</i>	The standard deviation of <i>Operating Cashflows</i> over the previous 10 years. It is set to missing for firms with fewer than 3 years of data. This variable is winsorized at the 1-99 level.
<i>Book Leverage</i>	Total debt (data items DLTT plus DLC) divided by total assets. This variable is winsorized at the 1-99 level.
<i>Stock Volatility</i>	The standard deviation of the firm's stock returns from the 48 months prior to the start of the year. Monthly stock returns are CRSP data item RET. This variable is winsorized at the 5-95 level.

Variable	Definition
<i>High Volatility</i>	An indicator that is equal to 1 for firm-fiscal years with above-median <i>Stock Volatility</i> , and 0 for firm-years with below-median volatility.
<i>High Equity Grants</i>	An indicator that is equal to 1 for firm-fiscal years with above-median values of <i>Equity Grants</i> , and 0 for firm-years with below-median values.
<i>High Constraints</i>	An indicator that is equal to 1 for firm-fiscal years with Hadlock-Pierce, Whited-Wu, or Kaplan-Zingales index values in the top tercile; 1 for firms without a credit rating (data item SPLTICRM and SPSTICRM); 1 for firms that do not pay any dividends (DVC) during the year; and 0 otherwise. The Kaplan-Zingales index is measured according to Lamont et al. (2001).
<i>Alt. Tangible Investment</i>	The sum of capital expenditures (data item CAPX) and cash spent on acquisitions (AQC), divided by <i>Operating Cashflows</i> .
<i>Alt. Free Cashflows</i>	<i>Operating Cashflows</i> minus <i>Alt. Tangible Investment</i> and <i>Intangible Investment</i> , divided by <i>Operating Cashflows</i> .
<i>Pledged Equity</i>	The number of shares underlying all stock options held by employees, divided by this number plus the number of publicly traded shares (data item CSHO). The number of shares underlying stock options is the total number of shares underlying conversion of all options, preferred stock, and convertible debt (CSHRT) minus shares underlying conversion of preferred stock (CSHRP) minus shares underlying conversion of convertible debt (SHRC). The latter two items are set to 0 if missing. Data used to construct this variable is only available for fiscal years 1970 through 1995. This variable is winsorized at the 1-99 level.

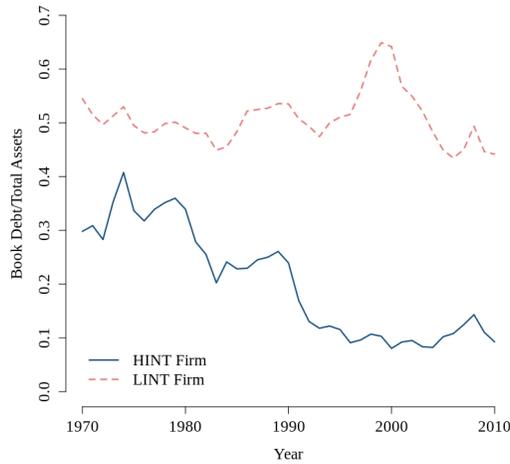
Figure 2.1: Evolution of Intangibles Usage and Corporate Financing

HINT firms have an *Intangibles Ratio* in the highest tercile of the sample distribution, and LINT firms have an *Intangibles Ratio* in the lowest tercile. *Intangibles Ratio* is the firm's stock of intangible assets divided by the sum of intangible assets and net PP&E. Computers firms are those in the Fama-French 48 industries "Computers", "Electronic Equipment", "Measuring and Control Equipment", or "Business Services" (SIC codes 7370-7379 only). Panels B and C plot values for the median HINT and LINT firm.

Panel A. Intangibles Usage



Panel B. Leverage



Panel C. Cash Holdings

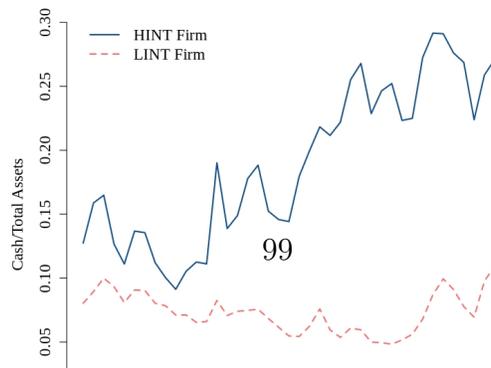


Figure 2.4: Corporate Investment around Technological Transitions

For each Fama-French 48 industry, we measure technological transitions as a structural break in the time series of *Intangible/Total Investment*, following Andrews (1993). Plots show values of *Tangible Investment* and *Intangible Investment* for the median firm, after adjusting for differences in *Log Total Assets* using a regression analysis.

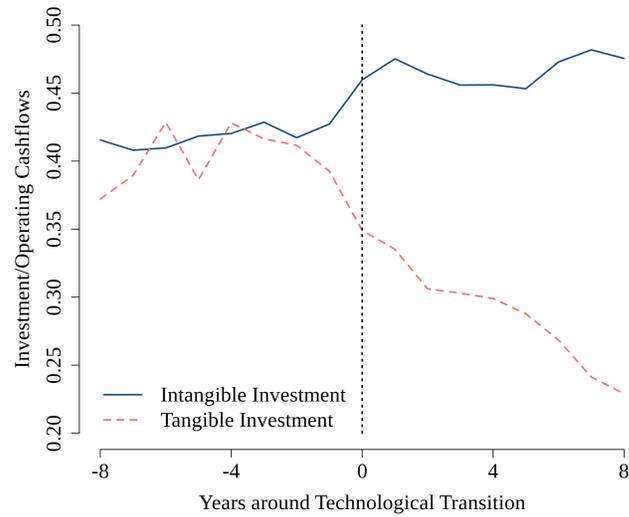
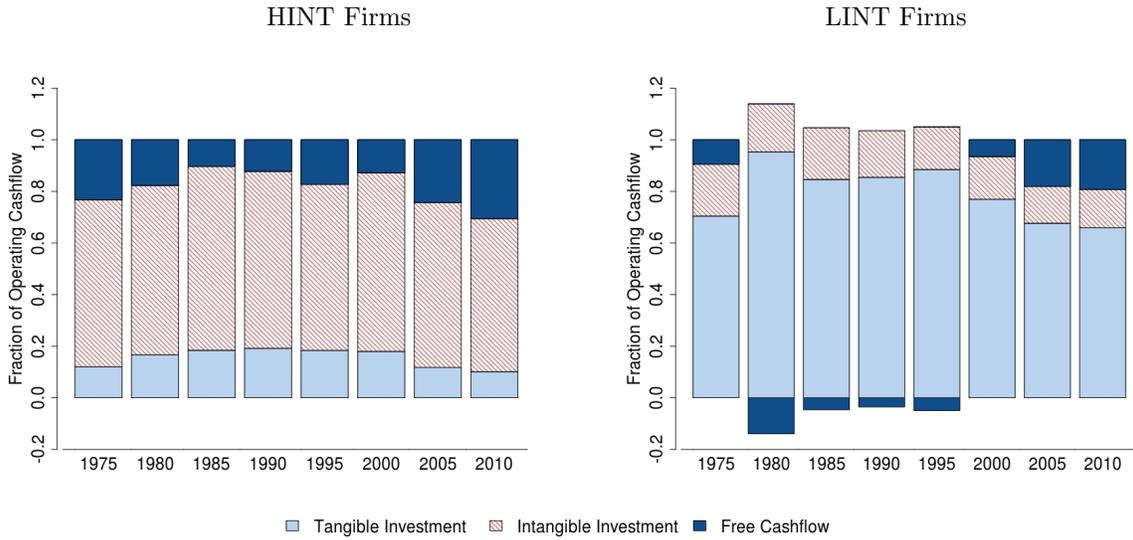


Figure 2.5: Intangibles Usage, Investment Outlays, and Free Cashflows

Panel A shows the fraction of operating cashflows spent on tangible and intangible investment, as well as free cashflows that remain after investment.

Values are plotted for the median HINT and LINT firm. HINT firms have an *Intangibles Ratio* in the highest tercile of the sample distribution, and LINT firms have an *Intangibles Ratio* in the lowest tercile. *Intangibles Ratio* is the firm's stock of intangible assets divided by the sum of intangible assets and net PP&E. In Panel B, we measure technological transitions for each Fama-French 48 industry as a structural break in the time series of *Intangible/Total Investment*, following Andrews (1993).

Panel A. Composition of Outlays



Panel B. Time-Series Evolution of Free Cashflows

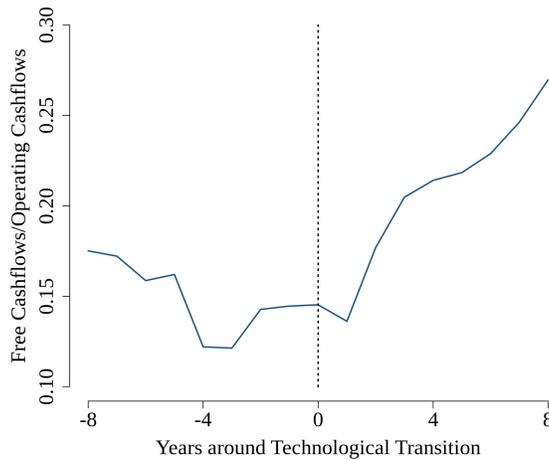
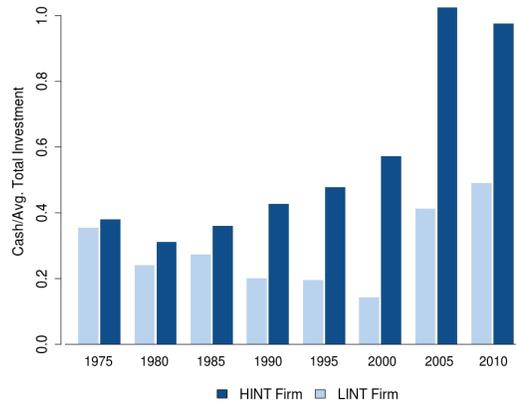


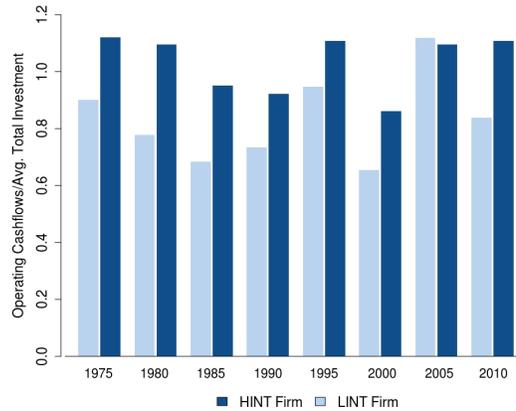
Figure 2.6: Intangibles Usage and Need for Precautionary Savings

Panel A plots the ratio of *Cash Holdings* from the start of the year to *Avg. Total Investment*, the average of annual tangible and intangible investment from the three previous years. Panel B plots the ratio of *Operating Cashflows* from the current year to *Avg. Total Investment*. Both panels show plots for the median HINT and LINT firm. Panel C plots, for all HINT and LINT firms, the fraction of sample years that the sum of *Cash Holdings* and *Operating Cashflows* exceeds *Avg. Total Investment*. Firms that are in the sample for fewer than five years are excluded. HINT firms have an *Intangibles Ratio* in the highest tercile of the sample distribution, and LINT firms have an *Intangibles Ratio* in the lowest tercile. *Intangibles Ratio* is the firm's stock of intangible assets divided by the sum of intangible assets and net PP&E.

Panel A. Coverage from Cash Holdings



Panel B. Coverage from Cashflows



Panel C. Frequency of Sufficient Coverage

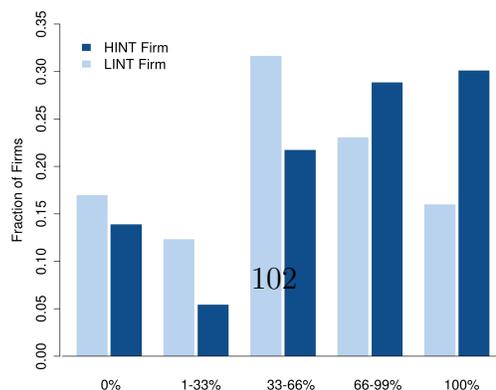


Table 2.1: Growth of Intangibles Usage across Industries

The table presents the median value of *Intangibles Ratio* at the start and end of our sample for a selection of industries. *Intangibles Ratio* is the firm's stock of intangible assets divided by the sum of intangible assets and net PP&E. Industries are based on the Fama-French 48-industry classification.

Industries Experiencing Large Change	<i>Intangibles Ratio</i> in 1970	<i>Intangibles Ratio</i> in 2010	Change from 1970 to 2010
Healthcare	0.097	0.637	0.540
Business Services	0.381	0.882	0.501
Communication	0.112	0.556	0.444
Candy & Soda	0.359	0.731	0.372
Personal Services	0.186	0.539	0.353
Computers	0.545	0.897	0.352
Pharmaceutical Products	0.625	0.962	0.337
Medical Equipment	0.542	0.859	0.317
Apparel	0.492	0.808	0.316
Recreation	0.586	0.886	0.300
Industries Experiencing Small Change	<i>Intangibles Ratio</i> in 1970	<i>Intangibles Ratio</i> in 2010	Change from 1970 to 2010
Steel Works	0.182	0.257	0.076
Shipping Containers	0.214	0.261	0.047
Entertainment	0.200	0.239	0.039
Transportation	0.071	0.087	0.016
Shipbuilding & Railroad Equipment	0.220	0.203	-0.017
Non-Metallic & Industrial Metal Mining	0.095	0.067	-0.029
Petroleum & Natural Gas	0.085	0.045	-0.040
Agriculture	0.320	0.271	-0.050
Coal	0.113	0.035	-0.078
Precious Metals	0.334	0.037	-0.297

Table 2.2: Summary Statistics

Summary statistics are measured across all sample years of 1970 to 2010. HINT firms have an *Intangibles Ratio* in the highest tercile of the sample distribution, and LINT firms have an *Intangibles Ratio* in the lowest tercile. *Intangibles Ratio* is the firm's stock of intangible assets divided by total assets, measured as the sum of intangible assets and net PP&E. *Tangible Investment* is the annual change in PP&E net of depreciation, divided by *Operating Cashflows*. *Intangible Investment* is the sum of R&D spending, $0.2 \times \text{SG\&A}$ expenditures, and acquisition of externally produced intangibles, divided by *Operating Cashflows*.

Intangible/Total Investment is *Intangible Investment* divided by this number and *Tangible Investment*. *Avg. Total Investment* is the average of the sum of *Tangible Investment* and *Intangible Investment* from the three previous years. *Free Cashflows* is *Operating Cashflows* minus the sum of *Tangible Investment* and *Intangible Investment*, all divided by *Operating Cashflows*. *Net Leverage* is total debt minus cash and marketable securities, divided by total assets. *Equity Grants* is the grant-date fair value of annual stock and stock option compensation, divided by market capitalization. It is measured only for ExecuComp firms. *Retained Cash* is *Free Cashflows* minus total payouts, divided by *Free Cashflows*. *Cash Holdings* is the sum of cash and marketable securities, divided by total assets. *Repurchases/Payouts* is stock repurchases divided by the sum of stock repurchases and common dividends. It excludes repurchases in which shares are immediately used to fulfill employee option exercises. *Tobin's Q* is total debt plus the market value of equity minus current assets, all divided by total assets. *Log Total Assets* is the natural logarithm of total assets. *Operating Cashflows* is earnings prior to depreciation and investment minus taxes and interest payments, all divided by total assets. *Cashflow Volatility* is the standard deviation of *Operating Cashflows* over the previous 10 years. *Book Leverage* is total debt divided by total assets. *Stock Volatility* is the standard deviation of the firm's stock returns from the previous 48 months. Standard errors are clustered by firm and year. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

	HINT Firm				LINT Firm				Diff. in Means
	Mean	Median	St. Dev.	No. Obs.	Mean	Median	St. Dev.	No. Obs.	
<i>Intangibles Ratio</i>	0.815	0.814	0.103	54,931	0.131	0.115	0.103	51,679	0.684***
<i>Tangible Investment</i>	0.238	0.151	0.790	41,077	1.249	0.783	1.741	43,727	-1.012***
<i>Intangible Investment</i>	1.04	0.654	1.319	41,086	0.29	0.178	0.638	43,752	0.750***
<i>Intangible/Total Investment</i>	0.801	0.825	0.313	53,500	0.196	0.142	0.309	49,985	0.605***
<i>Avg. Total Investment</i>	1.120	0.834	1.098	29,554	1.417	1.053	1.325	31,735	-0.297***
<i>Free Cashflows</i>	-0.331	0.179	2.134	41,077	-0.606	0.008	2.339	43,727	0.275***
<i>Net Leverage</i>	-0.036	-0.035	0.959	54,717	0.462	0.411	0.815	51,518	-0.498***
<i>Equity Grants</i>	0.029	0.018	0.036	15,272	0.013	0.006	0.024	8,010	0.017***
<i>Retained Cash</i>	-0.446	0.097	2.224	41,026	-0.785	-0.155	2.419	43,623	0.339***
<i>Cash Holdings</i>	0.45	0.211	0.653	54,925	0.234	0.072	0.525	51,660	0.216***
<i>Repurchases/Payouts</i>	0.497	0.487	0.463	19,489	0.245	0.000	0.392	29,173	0.252***
<i>Tobin's Q</i>	2.07	0.842	3.763	48,206	1.791	1.027	2.851	39,567	0.279**
<i>Log Total Assets</i>	3.856	3.651	1.778	51,196	4.670	4.522	2.081	47,725	-0.814***
<i>Operating Cashflows</i>	0.324	0.299	0.394	43,655	0.230	0.194	0.290	42,917	0.094***
<i>Cashflow Volatility</i>	0.244	0.145	0.309	38,216	0.132	0.070	0.230	36,160	0.112***
<i>Book Leverage</i>	0.432	0.174	0.723	51,006	0.677	0.499	0.727	47,583	-0.246***
<i>Stock Volatility</i>	0.172	0.163	0.067	42,614	0.135	0.122	0.055	36,999	0.037***

Table 2.3: Intangibles Usage and Investment Outlays

Columns (1) through (6) report estimates from pooled OLS regressions using our entire sample of U.S. non-financial and utilities firms, from 1970 to 2010. Columns (7) through (10) report estimates from regressions using five-year (two-sided) windows around technological transitions. We measure transitions for each Fama-French 48 industry as a structural break in the time series of *Intangible/Total Investment*, following Andrews (1993). *Tangible Investment* is the annual change in PP&E net of depreciation, divided by *Operating Cashflows*. *Free Cashflows* are *Operating Cashflows* minus tangible and intangible investment, divided by *Operating Cashflows*. *Intangibles Ratio* is the firm's stock of intangible assets divided by total assets, measured as the sum of intangible assets and net PP&E. *Post Transition* is equal to 0 for observations that precede a technological transition, and 1 for observations that follow it. *Tobin's Q* is total debt plus the market value of equity minus current assets, all divided by total assets. *Log Total Assets* is the natural logarithm of total assets. *Operating Cashflows* is operating earnings prior to depreciation and investment minus taxes and interest payments, all divided by total assets. *Cashflow Volatility* is the standard deviation of *Operating Cashflows* over the previous 10 years. *Book Leverage* is total debt divided by total assets. Industry fixed effects are based on Fama-French 48 industries. Computers firms are those in the industries "Computers", "Electronic Equipment", "Measuring and Control Equipment", or "Business Services" (SIC codes 7370-7379 only). In parentheses we report *t*-statistics based on standard errors that are clustered at the firm level. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

Dependent Variable	Pooled Regressions						Staggered technological transitions			
	<i>Tangible Investment</i>			<i>Free Cashflows</i>			<i>Tangible Investment</i>		<i>Free Cashflows</i>	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
<i>Intangibles Ratio</i>	-1.588*** (-55.85)	-1.443*** (-50.14)	-1.505*** (-46.94)	0.517*** (11.10)	0.338*** (7.59)	0.457*** (9.27)				
<i>Post Transition</i>							-0.205*** (-7.12)	-0.169*** (-6.17)	0.102** (2.47)	0.091** (2.32)
<i>Tobin's Q</i>	0.008*** (3.98)	0.021*** (7.57)	0.022*** (6.28)	0.016*** (4.92)	-0.040*** (-9.05)	-0.039*** (-7.41)	0.011 (1.52)	0.030*** (3.13)	0.020* (1.95)	-0.018 (-1.33)
<i>Log Total Assets</i>	-0.073*** (-23.68)	-0.055*** (-17.46)	-0.060*** (-16.43)	0.135*** (25.87)	0.107*** (22.04)	0.113*** (20.53)	-0.011 (-1.28)	-0.009 (-1.04)	0.086*** (6.73)	0.070*** (5.55)
<i>Operating Cashflows</i>		-0.403*** (-16.95)	-0.443*** (-15.41)		1.471*** (31.44)	1.500*** (27.98)		-0.497*** (-6.32)		1.228*** (10.28)
<i>Cashflow Volatility</i>		0.201*** (7.08)	0.221*** (6.44)		-0.427*** (-8.59)	-0.405*** (-7.13)		0.045 (0.45)		-0.563*** (-3.38)
<i>Book Leverage</i>		-0.009 (-0.76)	0.002 (0.12)		-0.055*** (-3.10)	-0.084*** (-4.37)		0.059** (2.05)		-0.058 (-1.40)
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Computer Firms Omitted	No	No	Yes	No	No	Yes	No	No	No	No
Observations	112,478	89,777	75,075	112,478	89,777	75,075	11,568	9,923	11,568	9,923
Adjusted <i>R</i> ²	0.165	0.161	0.161	0.047	0.070	0.074	0.076	0.078	0.033	0.056

Table 2.4: Intangibles Usage and Corporate Financing

Columns (1) through (6) report estimates from pooled OLS regressions using our entire sample of U.S. non-financial and utilities firms, from 1970 to 2010. Columns (7) through (10) report estimates from regressions using five-year (two-sided) windows around technological transitions. We measure transitions for each Fama-French 48 industry as a structural break in the time series of *Intangible/Total Investment*, following Andrews (1993). *Net Leverage* is total debt minus cash and marketable securities, divided by total assets. *Equity Grants* is the total dollar value of annual stock and option grants to all employees, divided by market capitalization. It is measured only for ExecuComp firms, from 1992 to 2010. *Intangibles Ratio* is the firm's stock of intangible assets divided by total assets, measured as the sum of intangible assets and net PP&E. *Post Transition* is equal to 0 for observations that precede a technological transition, and 1 for observations that follow it. *Tobin's Q* is total debt plus the market value of equity minus current assets, all divided by total assets. *Log Total Assets* is the natural logarithm of total assets. *Operating Cashflows* is operating earnings prior to depreciation and investment minus taxes and interest payments, all divided by total assets. *Cashflow Volatility* is the standard deviation of *Operating Cashflows* over the previous 10 years. *Book Leverage* is total debt divided by total assets. Industry fixed effects are based on Fama-French 48 industries. Computers firms are those in the industries "Computers", "Electronic Equipment", "Measuring and Control Equipment", or "Business Services" (SIC codes 7370-7379 only). In parentheses we report *t*-statistics based on standard errors that are clustered at the firm level. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

Dependent Variable Sample	Pooled Regressions						Staggered technological transitions			
	<i>Net Leverage</i>			<i>Equity Grants</i>			<i>Net Leverage</i>		<i>Equity Grants</i>	
	All Firms			ExecuComp Firms			All Firms		ExecuComp Firms	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
<i>Intangibles Ratio</i>	-0.618*** (-20.13)	-0.547*** (-15.89)	-0.473*** (-12.47)	0.015*** (10.42)	0.013*** (9.97)	0.008*** (6.18)				
<i>Post Transition</i>							-0.030 (-1.57)	-0.046** (-2.34)	0.002** (2.08)	0.002** (2.48)
<i>Tobin's Q</i>	-0.037*** (-13.20)	-0.024*** (-5.14)	-0.015** (-2.47)	-0.001*** (-7.62)	-0.001*** (-7.72)	-0.001*** (-7.50)	-0.026** (-2.32)	0.011 (0.70)	-0.000** (-2.41)	-0.001*** (-4.02)
<i>Log Total Assets</i>	0.022*** (6.02)	0.026*** (6.60)	0.029*** (7.04)	-0.003*** (-17.02)	-0.003*** (-15.00)	-0.003*** (-13.27)	0.036*** (3.43)	0.028** (2.53)	-0.002*** (-3.67)	-0.001* (-1.91)
<i>Operating Cashflows</i>		-0.260*** (-8.87)	-0.242*** (-6.86)		-0.007*** (-6.53)	-0.006*** (-5.25)		-0.363*** (-4.27)		-0.006** (-2.28)
<i>Cashflow Volatility</i>		0.227*** (5.31)	0.250*** (4.91)		0.009*** (6.53)	0.008*** (5.60)		0.082 (0.61)		0.019*** (3.29)
<i>Book Leverage</i>					0.001** (2.18)	0.003*** (5.22)				0.003*** (3.12)
Industry Fixed Effects	Yes	Yes	Yes	Yes						
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Computer Firms Omitted	No	No	Yes	No	No	Yes	No	No	No	No
Observations	132,344	99,987	83,440	22,416	19,033	15,349	12,966	10,794	2,284	2,093
Adjusted R^2	0.153	0.136	0.108	0.171	0.176	0.132	0.053	0.054	0.048	0.092

Table 2.5: Resource Retention and Cash Holdings

Columns (1) through (3) report estimates from pooled OLS regressions using our entire sample of U.S. non-financial and utilities firms, from 1970 to 2010. Columns (4) and (5) report estimates from regressions using five-year (two-sided) windows around technological transitions. We measure transitions for each Fama-French 48 industry as a structural break in the time series of *Intangible/Total Investment*, following Andrews (1993). *Retained Cash* is *Free Cashflows* minus total payouts, divided by *Free Cashflows*. *Intangibles Ratio* is the firm's stock of intangible assets divided by total assets, measured as the sum of intangible assets and net PP&E. *Post Transition* is equal to 0 for observations that precede a technological transition, and 1 for observations that follow it. *Tobin's Q* is total debt plus the market value of equity minus current assets, all divided by total assets. *Log Total Assets* is the natural logarithm of total assets. *Operating Cashflows* is operating earnings prior to depreciation and investment minus taxes and interest payments, all divided by total assets. *Cashflow Volatility* is the standard deviation of *Operating Cashflows* over the previous 10 years. *Book Leverage* is total debt divided by total assets. Industry fixed effects are based on Fama-French 48 industries. Computers firms are those in the industries "Computers", "Electronic Equipment", "Measuring and Control Equipment", or "Business Services" (SIC codes 7370-7379 only). In parentheses we report *t*-statistics based on standard errors that are clustered at the firm level. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

Dependent Variable	Pooled Regressions			Staggered technological transitions	
	<i>Retained Cash</i>			<i>Retained Cash</i>	
	(1)	(2)	(3)	(4)	(5)
<i>Intangibles Ratio</i>	0.282*** (7.49)	0.412*** (9.25)	0.404*** (8.43)		
<i>Post Transition</i>				0.160*** (4.11)	0.174*** (3.95)
<i>Tobin's Q</i>	-0.003 (-1.40)	-0.013*** (-3.55)	-0.019*** (-4.21)	-0.001 (-0.18)	-0.019 (-1.46)
<i>Log Total Assets</i>	-0.115*** (-24.48)	-0.105*** (-19.97)	-0.112*** (-19.68)	-0.119*** (-10.03)	-0.101*** (-7.45)
<i>Operating Cashflows</i>		-0.043 (-1.52)	-0.071** (-2.10)		-0.016 (-0.21)
<i>Cashflow Volatility</i>		0.030 (0.67)	0.009 (0.17)		0.138 (1.41)
<i>Book Leverage</i>		0.278*** (17.22)	0.288*** (16.22)		0.184*** (4.79)
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	No	No
Computer Firms Omitted	No	No	Yes	No	No
Observations	72,183	59,748	49,985	7,709	6,774
Adjusted R^2	0.043	0.050	0.050	0.029	0.032

Table 2.6: Employee Insurance for Cash Holdings

All columns report estimates from pooled OLS regressions using U.S. non-financial and utilities firms in ExecuComp, for which equity grant data is available. *Cash Holdings* is the sum of cash and marketable securities, divided by total assets. *Intangibles Ratio* is the firm's stock of intangible assets divided by total assets, measured as the sum of intangible assets and net PP&E. *High Volatility* equals 1 for firm-fiscal years with above-median *Stock Volatility*, and 0 for firm-years with below-median volatility. *Stock Volatility* is the standard deviation of the firm's stock returns from the 48 months prior to the start of the year. *High Equity Grants* equals 1 for firm-fiscal years with above-median values of *Equity Grants*, and 0 for firm-fiscal years with below-median values. *Equity Grants* is the total dollar value of annual stock and option grants to all employees, divided by market capitalization. It is measured only for ExecuComp firms, from 1992 to 2010. *Tobin's Q* is total debt plus the market value of equity minus current assets, all divided by total assets. *Log Total Assets* is the natural logarithm of total assets. *Operating Cashflows* is operating earnings prior to depreciation and investment minus taxes and interest payments, all divided by total assets. *Cashflow Volatility* is the standard deviation of *Operating Cashflows* over the previous 10 years. *Book Leverage* is total debt divided by total assets. Industry fixed effects are based on Fama-French 48 industries. In parentheses we report *t*-statistics based on standard errors that are clustered at the firm level. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

Dependent Variable Sample	<i>Cash Holdings</i> ExecuComp Firms				
	(1)	(2)	(3)	(4)	(5)
<i>Intangibles Ratio</i>	0.110** (2.08)	0.092* (1.80)	0.064 (1.16)	-0.004 (-0.07)	0.210*** (2.84)
<i>Intangibles Ratio</i> × <i>High Volatility</i>	0.171*** (4.50)		0.152*** (3.71)	0.127*** (2.94)	0.084** (2.40)
<i>Intangibles Ratio</i> × <i>High Equity Grants</i>		0.147*** (4.38)	0.097*** (2.95)	0.084** (2.50)	0.047** (2.04)
<i>High Volatility</i>	-0.030 (-1.33)		-0.024 (-0.97)	-0.025 (-0.91)	-0.028 (-1.49)
<i>High Equity Grants</i>		-0.053*** (-2.68)	-0.042** (-2.11)	-0.038* (-1.94)	-0.035*** (-2.91)
<i>Tobin's Q</i>	0.048*** (16.25)	0.049*** (16.65)	0.049*** (15.55)	0.046*** (12.58)	0.030*** (10.38)
<i>Log Total Assets</i>	-0.056*** (-10.03)	-0.064*** (-11.89)	-0.056*** (-9.26)	-0.047*** (-7.64)	-0.101*** (-8.45)
<i>Operating Cashflows</i>				0.039 (1.52)	
<i>Cashflow Volatility</i>				0.204*** (2.97)	
<i>Book Leverage</i>				-0.058** (-2.55)	
Industry Fixed Effects	Yes	Yes	Yes	Yes	No
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes
Firm Fixed Effects	No	No	No	No	Yes
Observations	23,605	20,687	19,913	17,878	19,913
Adjusted R^2	0.337	0.342	0.337	0.333	0.108

Table 2.7: Intangibles and Cash Holdings: Accounting for Financial Constraints

All columns report estimates from pooled OLS regressions using U.S. non-financial and utilities firms in ExecuComp, for which equity grant data is available. Regressions in Panel A control for various measures of financial constraints, listed above each column. Regressions in Panel B are estimated on a subsample of firms that have a partially or fully undrawn line of credit (column (6)); or that paid out cash to shareholders during the year (column (7)). *Cash Holdings* is the sum of cash and marketable securities, divided by total assets. *Intangibles Ratio* is the firm's stock of intangible assets divided by total assets, measured as the sum of intangible assets and net PP&E. *High Volatility* equals 1 for firm-fiscal years with above-median *Stock Volatility*, and 0 for firm-years with below-median volatility. *Stock Volatility* is the standard deviation of the firm's stock returns from the 48 months prior to the start of the year. *High Equity Grants* equals 1 for firm-years with above-median values of *Equity Grants*, and 0 for firm-years with below-median values. *Equity Grants* is the total dollar value of annual stock and option grants to all employees, divided by market capitalization. It is measured only for ExecuComp firms, from 1992 to 2010. *High Constraints* equals: 1 in columns (1) through (3) for firm-years with Hadlock-Pierce, Whited-Wu, or Kaplan Index values in the top tercile of the sample distribution; 1 in columns (4) and (5) for firm-years without a credit rating or in which no dividends were paid; and 0 in all other firm-years. *Tobin's Q* is total debt plus the market value of equity minus current assets, all divided by total assets. *Log Total Assets* is the natural logarithm of total assets. *Operating Cashflows* is operating earnings prior to depreciation and investment minus taxes and interest payments, all divided by total assets. *Cashflow Volatility* is the standard deviation of *Operating Cashflows* over the previous 10 years. *Book Leverage* is total debt divided by total assets. Industry fixed effects are based on Fama-French 48 industries. In parentheses we report *t*-statistics based on standard errors that are clustered at the firm level. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

Dependent Variable	Panel A. Financial Constraint Controls					Panel B. Subsample Analysis	
	<i>Cash Holdings</i>					<i>Cash Holdings</i>	
Sample	ExecuComp Firms					ExecuComp Firms with: Undrawn Credit Line	Positive Payouts
Measure of Constraints	HP Index	WW Index	KZ Index	Credit Rating	Dividend Payouts		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
<i>Intangibles Ratio</i>	0.057 (0.97)	0.085 (1.50)	-0.043 (-0.74)	0.012 (0.22)	0.065 (1.19)	0.038 (0.92)	0.070 (1.20)
<i>Intangibles Ratio</i> × <i>High Volatility</i>	0.086** (2.06)	0.170*** (4.14)	0.142*** (3.50)	0.124*** (2.88)	0.132*** (2.96)	0.191*** (3.65)	0.158*** (3.01)
<i>Intangibles Ratio</i> × <i>High Equity Grants</i>	0.057* (1.65)	0.088*** (2.63)	0.063* (1.89)	0.064* (1.92)	0.070** (2.16)	0.105** (2.11)	0.119*** (2.99)
<i>Intangibles Ratio</i> × <i>High Constraints</i>	0.250*** (5.24)	-0.293*** (-16.83)	0.093*** (4.55)	0.170*** (4.06)	0.098** (2.27)		
<i>High Volatility</i>	0.031 (1.30)	0.023 (0.96)	0.038 (1.62)	0.027 (1.08)	0.025 (0.99)	-0.028 (-0.93)	-0.025 (-0.81)
<i>High Equity Grants</i>	-0.009 (-0.45)	-0.013 (-0.65)	0.005 (0.26)	-0.013 (-0.65)	-0.016 (-0.89)	-0.053* (-1.92)	-0.053** (-2.42)
<i>High Constraints</i>	-0.040 (-1.41)	0.049*** (4.08)	-0.160*** (-13.04)	-0.003 (-0.12)	-0.015 (-0.64)		
<i>Tobin's Q</i>	0.051*** (16.62)	0.050*** (16.09)	0.049*** (15.56)	0.052*** (17.10)	0.053*** (17.20)	0.042*** (10.97)	0.050*** (10.68)
<i>Log Total Assets</i>						-0.043*** (-6.83)	-0.063*** (-8.13)
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,912	18,414	18,414	19,913	19,913	7,165	13,138
Adjusted <i>R</i> ²	0.324	0.335	0.337	0.323	0.316	0.319	0.345

Table 2.8: Intangibles Usage and Payout Policy

Columns (1) through (3) report estimates from pooled OLS regressions using our entire sample of U.S. non-financial and utilities firms, from 1970 to 2010. Columns (4) and (5) report estimates from regressions using five-year (two-sided) windows around technological transitions. All regressions include only firm-fiscal years with positive payouts. We measure transitions for each Fama-French 48 industry as a structural break in the time series of *Intangible/Total Investment*, following Andrews (1993). *Repurchases/Payouts* is stock repurchases divided by the sum of stock repurchases and common dividends. It excludes repurchases in which shares are immediately used to fulfill employee option exercises. *Intangibles Ratio* is the firm’s stock of intangible assets divided by total assets, measured as the sum of intangible assets and net PP&E. *Post Transition* is equal to 0 for observations that precede a technological transition, and 1 for observations that follow it. *Tobin’s Q* is total debt plus the market value of equity minus current assets, all divided by total assets. *Log Total Assets* is the natural logarithm of total assets. *Operating Cashflows* is operating earnings prior to depreciation and investment minus taxes and interest payments, all divided by total assets. *Cashflow Volatility* is the standard deviation of *Operating Cashflows* over the previous 10 years. *Book Leverage* is total debt divided by total assets. Industry fixed effects are based on Fama-French 48 industries. Computers firms are those in the industries “Computers”, “Electronic Equipment”, “Measuring and Control Equipment”, or “Business Services” (SIC codes 7370-7379 only). In parentheses we report *t*-statistics based on standard errors that are clustered at the firm level. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

Dependent Variable	Pooled Regressions			Staggered	
	<i>Repurchases/Payouts</i>			technological transitions	
	(1)	(2)	(3)	(4)	(5)
<i>Intangibles Ratio</i>	0.238*** (13.02)	0.253*** (12.92)	0.222*** (10.86)		
<i>Post Transition</i>				0.127*** (10.38)	0.114*** (8.66)
<i>Tobin’s Q</i>	-0.004*** (-2.65)	0.001 (0.53)	0.001 (0.33)	-0.008** (-2.41)	-0.008* (-1.81)
<i>Log Total Assets</i>	-0.040*** (-19.39)	-0.035*** (-16.07)	-0.037*** (-16.55)	-0.053*** (-10.62)	-0.045*** (-8.32)
<i>Operating Cashflows</i>		-0.153*** (-11.47)	-0.150*** (-10.09)		-0.128*** (-3.29)
<i>Cashflow Volatility</i>		0.203*** (9.14)	0.185*** (7.72)		0.337*** (5.17)
<i>Book Leverage</i>		0.060*** (7.72)	0.068*** (8.27)		0.039** (2.12)
Industry Fixed Effects	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	No	No
Computer Firms Omitted	No	No	Yes	No	No
Observations	68,134	57,437	50,885	7,258	6,419
Adjusted R^2	0.250	0.255	0.227	0.144	0.158

Chapter 3

Technological Change and the Evolution of Finance

3.1 Introduction

A rising excess of savings over productive investment in advanced economies has defined a phase of “secular stagnation” (Summers, 2014; Eichengreen, 2015). This paper proposes a growth model describing the general equilibrium impact of technological change on long term real and financial trends. It suggests that the transition to a knowledge-based economy and the associated shift from physical to intangible and human capital is a primary cause for excess savings and falling rates. The interpretation is consistent with a growing share of income for innovators, a progressive reallocation of credit from productive to mortgage financing and the rise in household leverage.

Information technology is widely recognized as a main cause for the rising productivity of high-skill workers and the steady rise in wage inequality and skill premia (e.g. see Autor et al., 1998, 2003). On the capital front it has led to an increasing ratio of intangible to tangible investment (Corrado and Hulten, 2010a), as figure 3.1 documents.

We analyse the consequences of this transition on financial markets. Our key step is to recognize that intangible capital is mostly created by the commitment of creative human capital. While firms hire employees, they cannot purchase their human capital (Hart and Moore, 1994), but must reward them over time as output is realized to ensure their motivation and retention. The transition to intangible investment thus requires less initial investment spending.

It has long been established that firms investing more in intangibles have lower or even negative net leverage (Bates et al., 2009; Falato et al., 2013). This is usually explained

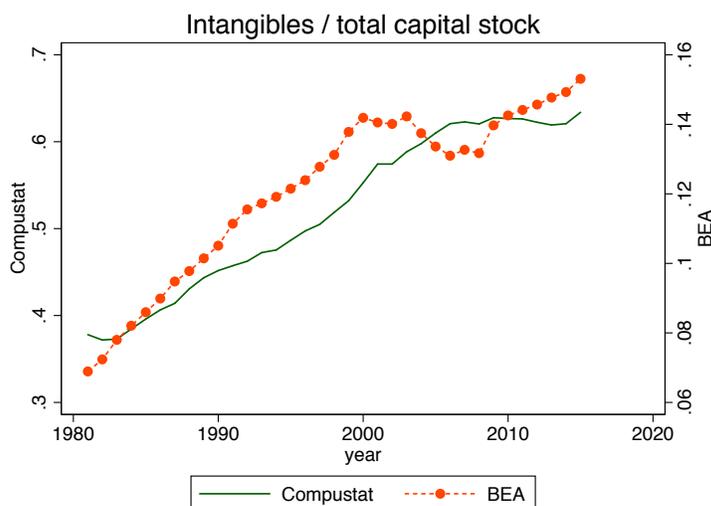


Figure 3.1: Evolution of the intangible capital ratio since 1980.

Ratio of intangible to total capital. The Compustat ratio uses the intangible capital measure by Peters and Taylor (2017), while the BEA data shows the ratio of intellectual property products (IPP) over total fixed assets.

by their poor pledgeability, as intangible assets are deemed hard to verify and extract. Our approach offers a restatement of this intuition in terms of appropriability. Since creative human capital is critical not just to generate but also to operate intangible capital, innovators are able to appropriate a large fraction of its value. Thus even if intangible assets were easily verified, they represent poor collateral for investors because much of their value is already assigned to the creators or under their control.

The distinct implication of this view is that the technological transition does not lead to increasing financial constraints, since human capital is rewarded gradually over time, such that investments in intangibles are essentially "self-funded" inside firms. The overall result is a reduced share of future revenues accruing to investors. In this view, reduced leverage reflects a drop in credit demand by firms even as interest rates fall, rather than rising financial constraints for which there appears to be little evidence.

We study investment and savings behavior in an overlapping generation (OLG) growth model. We adopt a very general production function under constant elasticity of substitution (CES), where physical capital is complementary with manual labor while intangible capital is complementary with high-skill labor. We introduce land (housing) as serving as both durable consumption good and as a store of value for agents' life-cycle savings. As physical capital is fully pledgeable, firms can scale it up till its marginal productivity

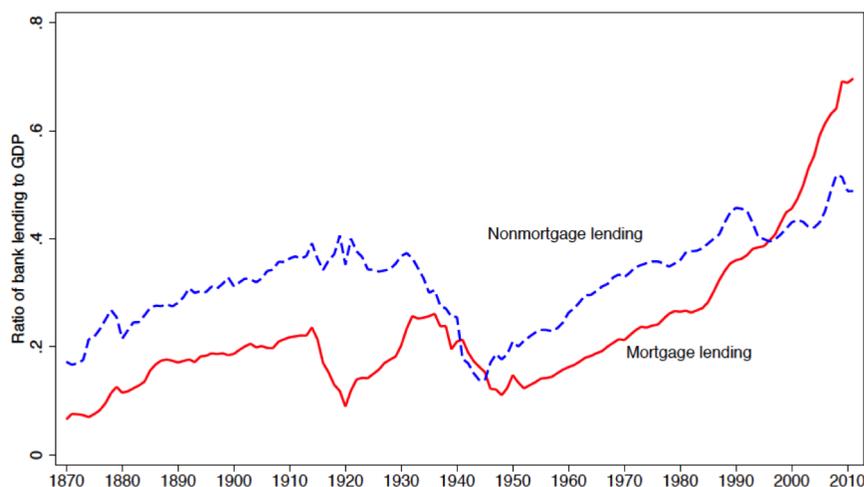


Figure 3.2: Mortgage and commercial credit in OECD countries (Jordà et al., 2016)

equals the cost of borrowing. In contrast, innovative capital cannot be easily scaled up, so intangible capital produces rents that must be shared with innovative employees.

Our benchmark view of technological change is a steady increase in the relative productivity of intangible capital and skilled labor. Over time, the scale of intangible investment rises relative to physical investment. To ensure retention of skilled human capital and avoid the loss of intangible value, firms offer deferred compensation when output is produced (Hart and Moore, 1994; Oyer and Schaefer, 2005b). As a result, firms need less upfront investment funding.

A second effect of the transition is that innovation rents increase over time. While some intangible value is appropriated by existing firms and incorporated in their share prices, a growing capital share needs to be assigned to innovators. As a result, over time the shift reduces the supply of available saving instruments. The general equilibrium consequence is a progressive decline in real interest rates. Critically, a redistributive innovative process can explain the puzzling combination of a steady fall in the cost of credit and rising share prices since 1980 with a falling rate of traditional investment.

In equilibrium the rising excess of savings over corporate credit demand is redirected to fund house purchases. As land is in fixed supply, lower rates also boosts house prices (Knoll et al., 2017).

There is a final effect of the productivity shift on labor income and capital values, leading to rising household leverage as house prices rise relative to unskilled wages. Thus a growing savings supply is matched by a rising demand for mortgage credit. The process explains a declining stock of productive credit relative to mortgage credit across all OECD

countries (Jordà et al., 2016, see figure 3.2).

While it would be challenging to validate empirically this broad interpretation, we offer a clear analytical result. We show that common alternative views of the growth process cannot by themselves explain major financial trends since the 1980s. We evaluate other technological explanations such as a rise in capital productivity, in the rate of innovation, and in the level of education. Among commonly cited non-technological drivers we consider trade, capital flows and demographics. The key insight is that recent growth has taken place in an environment of falling interest rates and declining tangible investment and corporate net borrowing. Lower rates per se imply cheaper funding, and should boost investment. To account for both a drop in the price and quantity of tangible investment does require a structural decline in firm demand, reflecting a major drop in its productivity at the productive frontier (Acemoglu and Autor, 2011).¹

Capital inflows from emerging markets (especially since 1998) and demographic change certainly contributed to a savings glut in many countries. However, neither could be the sole driver, as both are inconsistent with the drop in investment, the evolution in corporate capital structure and relative wages. An increase in education level or in the rate of innovation can contribute to a rise in its scale and productivity, but cannot explain trends such as a falling demand for funding in a period of falling interest rates.

It is extremely challenging to validate empirically such a broad framework, and we do not seek to do so. We do offer a simple quantification of our interpretation of the growth process using US data since 1980. The model's long term framing is not suitable to explain variation around trends, so our limited goal is to match the direction and scale of major economic trends. We calibrate the starting point as an initial steady state in 1980, and derive the implied evolution of individual growth drivers by matching the growth of the intangible-tangible ratio and output. A shift in relative capital productivity appears to offer also a better calibration, matching not just the direction but also the scale of major trends.²

While our formulation for production is quite general, our results do require specific assumptions. Ultimately, any redistributive effect of growth must result from different supply and demand elasticities, an important empirical issue.

Some assumptions appear empirically reasonable. We assume a low elasticity of savings to real interest rates, a well documented result confirmed in recent years. We assume

¹ As we focus on production in OECD countries, this shift may also reflect relocation of some production to lower income countries.

² We report a significant cross-country correlation between adoption of intangibles and the growth of mortgage credit across OECD countries, without suggesting any causal identification.

an inelastic supply of housing. While higher prices may lead to more dense housing, population growth and urban congestion have countervailing effects.

Our simplifying assumption of an exogenous supply of skilled labor is not essential. Endogenizing educational choices would dampen the effect on relative wages, but could not explain the evolution of skill premia and credit allocation.

Our result critically depends on two assumptions. The first is a limited supply elasticity of intangibles, which ensures that innovator rewards rise over time. If all returns to innovation were competed away, there would be no rise in excess savings. While this seems a plausible assumption, the rate of innovation remains an unsolved issue in the debate on long term growth (Gordon, 2012).

The second assumption requires that innovators who stand to gain considerable wealth from their human capital investment cannot borrow against their expected future income and consume when young, reducing the savings surplus. This is a standard assumption in labor economics, reflecting natural moral hazard as well as anti slavery legislation, and relates to the inability to alienate human capital. An additional complicating factor is represented by the extreme uncertainty over the chance of success of innovative ideas, especially in a context of winner-takes-all competition.

The model predicts a steady rise in mortgage leverage for lower income households, so that even a constant house value risk produces a rising mortgage default rate. However, our neoclassical setup offers no direct policy implications. In the absence of externalities or financial constraints the economy is dynamically efficient. Tight loan-to-value (LTV) limits for mortgage loans would reduce house prices, redirecting savings to production by subsidizing physical investment. While resulting in higher labor wages and output, this policy induces large intra- and intergenerational transfers and would not be Pareto-improving. A public intervention is only justified in the presence of a strong externality associated with financial stability. Analysing this issue would require modelling cyclical fluctuations in credit and house prices beyond the scope of our model.

The rest of the paper is organized as follows. Section 3.2 discusses related literature, and section 3.3 describes the model. Section 3.4 discusses the secular trends we seek to explain and lists potential drivers. Section 3.5 derives our main analytical result, namely that among parsimonious drivers, only a strongly redistributive form of technological progress is consistent with all major trends. Section 3.6 offers a limited quantification exercise in line with our results. Section 3.7 introduces mortgage default risk and studies policy responses. Finally, section 3.8 concludes.

3.2 Related literature

The paper offers a technological explanation for a rising income share of innovators (Smith et al., 2017; Koh et al., 2016). It is consistent with a rising profit share (Barkai, 2016) and an increasing role of real estate in total wealth (Rognlie, 2015), though its neoclassical setup may not be appropriate to fully describe historical changes in wealth distribution (Piketty, 2014).

The key insight is that a growing productivity of intangible capital is also a key driver for a rising savings surplus. Since human capital cannot be purchased nor pledged (Hart and Moore, 1994), it needs to be rewarded over time, and future income pledged to innovators clearly cannot be shared with investors. Complex, innovative tasks cannot be rewarded by short term contracts (Manso, 2011), so skilled human capital receives direct and indirect claims on future profits via gradual vesting of share grants and career advancement (Pendergast, 1999).

While firms partially co-invest in intangible assets, most R&D and organizational capital expenditures reflect skilled labor compensation (Corrado and Hulten, 2010a). Even corporate brand equity critically depend on key employees (Rajan and Zingales, 2001).

The rise of intangible capital has also been related to the falling net leverage and increasing cash hoardings (Chapter 2 of this thesis, and Falato et al., 2013). Firms with significant intangibles maintain more internal resources to avoid becoming constrained, in the process contributing to the savings glut (Bates et al., 2009).

Suggestive evidence for a falling corporate demand for external finance comes from aggregate data on positive net lending by the non-financial corporate sector in most developed countries (Gruber, 2015). This has been interpreted in terms of tighter financial constraints in Falato et al. (2013), Giglio and Severo (2012) and Caggese and Perez-Orive (2017). Yet recent evidence on firms with more intangible capital suggest they do not appear constrained. Thanks to their lower total investment spending, these firms have higher free cash flow, and do not pay out less to their shareholders (see Chapter 2). They also have more share grants, consistent with a significant human capital co-investment by skilled employees. Gutiérrez and Philippon (2016) find no support for rising financial frictions, and offer evidence of industry effects associated with globalization, competition and short termism. Alexander and Eberly (2016) and Döttling et al. (2017) also find that both in the US and Europe weak investment is associated with the growing role of intangible capital. On aggregate, US listed firms have rising net equity outflows (Lazonick, 2015; Gruber, 2015). Thus overall the rise of intangible investment appears associated with lower funding needs (a lower credit demand) rather than more binding financial constraints (a

tighter credit supply), a result consistent with record low borrowing rates.

A rising productivity of innovative human capital leads to an increasing income share for innovators, either as start up entrepreneurs or top employees with significant outside options (Oyer and Schaefer, 2005b; Eisfeldt and Papanikolaou, 2014). As intangible value accrues directly to its creators, it does not need to be funded by intermediaries or capital markets. The net effect is a reduction in the supply of investables, and savings in excess of investment that investors can appropriate.

Recent evidence suggests the allocation of intangible value between firms and innovators has a significant impact on share prices (Eisfeldt and Papanikolaou, 2013) and across firms and investors (Garlenau and Panageas, 2017). Eisfeldt and Papanikolaou (2013) show how technological shocks alter the outside option of key employees, enabling some to appropriate a large fraction of intangible value. Garlenau and Panageas (2017) study how disruptive entry of innovative firms create unhedgeable risk, boosting demand for safe assets and depressing interest rates while explaining a rising wealth share for innovators. Smith et al. (2017) show how private business income accounts for most of the rise of top incomes since 2000, especially active owner-managers of mid-market firms.

A related literature studies the effect of information technology on the relative productivity of skilled labor, and explains rising wage inequality since 1980 (e.g. see Katz and Murphy, 1992; Autor et al., 1998, 2003). The increasing gap is in part due to a reduction in absolute real wages for unskilled workers in developed economies. Such a trend cannot be explained by a simple rise in the absolute productivity of intangibles and skilled human capital.

Acemoglu and Autor (2011) and other authors interpret it as the outcome of automation of physical tasks. We show similarly that only strongly redistributive form of technological progress can replicate all observed trends, in particular falling quantity of price of corporate borrowing. Another likely cause is a spreading of technology to emerging countries, leading to relocation of physical production.

In his assessment of secular stagnation, Eichengreen (2015) finds a fall in the relative price of investment goods a more explanation than a drop in physical investment opportunities (see also Karabarbounis and Neiman, 2013; Sajedi and Thwaites, 2016). Our setup can accommodate this interpretation, as redistributive progress leads to a fall in the productivity-adjusted cost of physical equipment.³ Our empirical validation has focused on showing how a redistributive technological shift represents the best parsimonious

³ This implies less demand for and a lower cost of physical equipment, so that the total productivity-adjusted cost of each unit of capital falls.

explanation for the combination of observed economic trends. The model thus offers a technological explanation for the rise in house prices, mortgage credit and default rates, reflecting falling interest rates and household leverage as the general equilibrium effect of capital and labor market trends.⁴ The rise in mortgage lending, household debt and default in the US has been interpreted by country-specific factors, such as populist pressure (Rajan, 2010) or large capital inflows. Yet the share of mortgage to total credit has risen rapidly in all OECD countries Jordà et al. (2016). A simple cross countries analysis presented in the empirical section shows how its rise is correlated with the national rate of adoption of intangible investment. Related evidence is offered by Dell’Ariccia et al. (2017), who show that as firms increase their intangible investment, their creditor banks shifts to more real estate funding.

3.3 Model Setup

This section describes the baseline model environment, solves the individual agents optimization problems, and describes the equilibrium.

Time Overlapping generations live for two periods. Time starts at $t = 0$ and goes on to infinity. There is an initial generation $t = -1$.

Goods There are two consumption goods, corn and land.⁵ There is a fixed amount of land \bar{L} , infinitely durable as it does not depreciate. We denote by p_t the relative price of land in terms of corn.

Households Each generation consists of a unit mass of households. Households have a quasi-linear utility function $U(c_{t+1}, L_t) = c_{t+1} + v(L_t)$, where c_{t+1} denotes consumption of corn and L_t are land holdings at the end of period t .⁶ The function $v(L)$ with $v'(L) > 0$, $v''(L) < 0$ captures the utility households achieve from living in their house. A fraction ϕ of households ($i = h$) is born with high human capital and offers \tilde{h} units of high-skill labor, while the rest ($i = l$) provides \tilde{l} units of manual labor. Both types of labor endowments

⁴ As asset bubbles may well occur in equilibrium in an overlapping generation framework, our model is consistent with speculative fluctuations around a long term trend.

⁵ We do not distinguish between houses and land, and will use the terms interchangeably.

⁶ This formulation of household preferences ensures that long-term interest rates are not pinned down by the household’s discount factor (via an Euler equation), but instead by the relative supply of savings vehicles versus household savings.

are supplied inelastically. We assume that high-skill labor is relatively scarce, ensuring that high-skill workers have a higher income than low-skill workers.

Assumption 2.

$$\frac{\phi}{(1-\phi)} < \frac{\eta}{1-\eta}$$

The initial old generation is endowed with all the land \bar{L} .

Representative Firm There is an infinitely lived representative firm in a competitive market, set up in the initial period with a mandate for value maximization. It has access to a nested CES production technology that uses as inputs physical capital K_t , highly complementary with manual labor l_t , as well as intangible capital H_t , complementary with high-skill labor h_t . Aggregate output $F(K_t, H_t, l_t, h_t)$ thus equals

$$A [\eta(H_t^\alpha h_t^{1-\alpha})^\rho + (1-\eta)(K_t^\alpha l_t^{1-\alpha})^\rho]^{\frac{1}{\rho}}. \quad (3.1)$$

where A reflects a common productivity factor, η measures the relative productivity of intangible capital and high-skill labor versus physical inputs, α capital productivity and ρ is related to the elasticity of substitution between physical and intangible factors.

The evolution of production over time may be due to different growth drivers. The main technological factors are A , η and α . Demographic and trade factors may also change labor or savings supply. Intangible supply depends also on innovative effort, as described below.

The firm can invest $I_{K,t}$ units of corn at t to install $K_{t+1} = I_{K,t}$ units of physical capital, to be used in production at $t+1$. In contrast, intangible capital is created by innovative skilled workers. Both types of capital fully depreciate after production, and the firm starts with an initial stock (K_0, H_0) .

Intangible Capital In general, the creation of intangible capital requires co-investment by the firm and its creative employees. Here we assume that all intangible value is generated by a subset of skilled human capital at no monetary cost.⁷ A fraction ε of high-skill households have innovative talent. They can exert effort at a quadratic cost $C(I_{H,t}) = \frac{\beta}{2} I_{H,t}^2$ when young to create intangible capital next period. Here β reflects the

⁷ One could easily introduce that firms need to contribute a fraction of intangible investment value. Since intangibles are not pledgeable, firms would need to accumulate internal resources to fund these investments, hence not growing the amount of investable claims in the economy. See Chapter 2 of this thesis, for a model in which workers and firms co-invest.

ease of innovating, and as it evolves over time it may be a major growth driver. Note that the assumption implies a lower supply elasticity of innovation, while physical capital is easily scalable. As a result, new intangible capital may earn some rents.

A second critical feature of intangibles concerns their financing. The general view is that they are hard to fund externally, as their value cannot be easily pledged. Our insight is that intangibles do not require much external financing even when their future value is both observable and verifiable. As the commitment of human capital cannot be contracted ex ante because of the inalienability of human capital (Hart and Moore, 1994), most intangibles cannot be purchased by firms. We assume innovators can leave at the end of the period with a fraction ω of intangible assets, and sell them next period to other firms for its full value. This credible threat makes it impossible for investors to capture the value of intangibles unless innovators are retained inside the firm.

In order to ensure retention, the firm must offer innovators deferred compensation that vests once production is realized at $t + 1$. This has two effects. First, innovators capture a significant fraction of intangible value, with firms receiving a share $(1 - \omega)$. Second, firms do not become constrained even though some assets cannot be pledged, as they can self finance the cost of human capital by delayed compensation.

Financial Contracts As in the basic setup there is no risk, equity and debt are equivalent. For illustration we refer to external financing as borrowing when backed by land or by physical capital. We refer to external equity as claims backed by the fraction $1 - \omega$ of intangible capital that firms can appropriate, and so in principle may be assigned to investors. Households can thus invest in 1 unit of shares, which pays all profits as dividends. In equilibrium, net profits equal the appropriable revenues from intangible capital creation. Our results do not depend on this interpretation of the firm's capital structure. While consistent with the corporate finance literature, it is not a direct outcome of the model. It may arise endogenously in a model with a tax advantage for debt, in which firm income from intangible capital is a poor source of debt collateral.

3.3.1 Households

Households supply their labor endowment inelastically to the representative firm, receiving income when young. Labor income is $y_t^i \in \{w_t \tilde{l}, q_t \tilde{h}\}$ where w_t denote wages for manual workers and q_t are wages of high-skill workers. Households can buy a house L_t for own use, and sell it to the next generation when they are old, earning some utility plus a possible price appreciation. As they only consume at $t + 1$, they save all other income

for retirement. Next to housing, households can buy shares S_t , which pay a dividend and can be sold to subsequent generations. They also invest a net amount of D_t in capital markets, which is either directed at corporate or mortgage debt. We refer to households with $D_t \geq 0$ as lenders, and $D_t < 0$ as borrowers. While most households have no income when old ($y_{t+1}^i = 0$), innovators receive capital income from the intangible capital they created, $y_{t+1}^i > 0$.

The maximization problem of a household is:

$$\begin{aligned}
& \max_{c_{t+1}, L_t, S_t, D_t} U(c_{t+1}, L_t) = c_{t+1} + v(L_t) \\
s.t. \quad & p_t L_t + f_t S_t + D_t \leq y_t^i \\
& c_{t+1} \leq y_{t+1}^i + p_{t+1} L_t + (f_{t+1} + d_{t+1}) S_t + (1 + r_{t+1}) D_t \\
& c_{t+1}, L_t \geq 0
\end{aligned} \tag{3.2}$$

The first two constraints are budget conditions for young and old respectively, while the third rules out negative consumption. As the budget constraints are binding, households choose their housing demand by the first order condition w.r.t. L_t ,

$$p_t = \frac{p_{t+1} + v'(L_t^i)}{1 + r_{t+1}}.$$

The price of housing reflects the discounted potential house price appreciation plus its utility value. The relevant discount rate is either the mortgage interest (for a borrower) or the opportunity cost of investing (for a lender), which in a competitive equilibrium is equal to r_{t+1} .

Note that housing demand is independent of income, as mortgages enable all households to consume the same amount of housing.⁸ So the role of mortgage credit is to allocate land efficiently, equalizing the marginal utility of housing across agents with heterogeneous income.

The first order condition w.r.t. S_t yields a pricing equation for shares:

$$f_t = \frac{f_{t+1} + d_t}{1 + r_{t+1}}. \tag{3.3}$$

Investments in debt instruments follow as a residual $D_t^i = y_t^i - f_t S_t - p_t L_t$. Households with $y_t^i \geq p_t L_t + f_t S_t$ have an income high enough to buy their house and invest the

⁸ We consider borrowing constraints in the extension on mortgage default.

remainder in shares and corporate debt. In contrast, those with $y_t^i < p_t L_t + f_t S_t$ need to borrow.

We focus on equilibria in which all households can afford to buy shares out of their income and only borrow against their house, implying $y_t^i > f_t S_t$. In this setup households with $D_t^i < 0$ take out a mortgage loan provided by surplus households. In the absence of risk, the intermediation process is not explicitly modelled.

3.3.2 Physical Capital and Labor

Firms employ labor l_t and h_t , and accumulate physical capital K_t , so as to maximize the infinite stream of dividends d_t :

$$\max_{K_t, l_t, h_t} \sum_{t=0}^{\infty} d_t \quad (3.4)$$

As investment in physical capital is financed by debt, credit demand is always equal to K_t . Firm equity will also have positive value, since dividends can be written as

$$d_t = F(K_t, H_t, l_t, h_t) - w_t l_t - q_t h_t - (1 + r_t) K_t - \omega R_t H_t.$$

Here $\omega R_t H_t$ denotes the return to intangible capital appropriated by innovators, where R_t is determined below. Under perfect competition, workers and suppliers of funding for physical capital are compensated according to their marginal productivity, $w_t = F_{l,t}$ and $q_t = F_{h,t}$. Since physical capital is fully eligible as collateral, firms are financially unconstrained and can always scale up tangible investment until:

$$1 + r_t = F_{K,t}. \quad (3.5)$$

3.3.3 Creation of Intangibles

A fraction of high-skill employees can exert effort to produce intangible capital for the next period. Competitive firms are willing to pay $R_t = F_{H,t}$ per unit of intangible capital, reflecting its productive value. Since the productive use of intangible capital requires the commitment of creative human capital, innovators have a credible threat that enables them to capture some value created.⁹ Firms need to match this outside option by adequate deferred compensation equal to $\omega R_t H_t$. That is, innovators capture a fraction ω of the return to the intangibles they created.

⁹ In an alternative formulation, innovators create start up firms and sell intangible capital to other firms.

Exerting effort innovators incur the cost $C(I_{H,t}) = \frac{\beta}{2}I_{H,t}^2$. They will scale up investment in intangibles until

$$\omega R_t = \beta I_{H,t-1}. \quad (3.6)$$

As a result of a sharply increasing cost of innovation, new intangible capital earns positive rents, unlike physical capital. Firms appropriate a fraction $1 - \omega$ of intangible value, which (conditional on successful retention) are verifiable and can be promised to investors. Since production function has constant returns to scale, dividends are given by

$$d_t = (1 - \omega)R_t H_t.$$

Note that the firm is never financially constrained over intangible investment, since it can self-finance its formation by deferred equity to innovators that vest once intangible capital produce output.

3.3.4 Equilibrium

Market clearing in the land market requires that $\int_0^1 L_t^i di = \bar{L}$. Since mortgages allow for an efficient homogenous allocation of land, $L_t^i = \bar{L}$ for both high-skill and manual workers.

Total net savings by households equal labor income earned by the young generation minus their house purchases $w_t \tilde{l} + q_t \tilde{h} - p_t \bar{L}$. Net savings are invested in corporate debt $D_t = K_{t+1}$ and equities f_t . Using that $w_t \tilde{l} + q_t \tilde{h} = (1 - \alpha)Y_t$, financial market clearing can thus be written as

$$(1 - \alpha)Y_t = p_t \bar{L} + f_t + D_t, \quad (3.7)$$

where the LHS is the savings supply (labor income saved for retirement) while the RHS are all assets that can carry savings over time, namely housing, corporate debt backed by physical capital investment, and equity backed by the return on intangibles captured by firms.

3.3.5 The allocation of savings in steady state

To understand how technology impacts financial trends in the model, it is useful to understand its impact on the steady state allocation of savings.

The financial market clearing condition (3.7) indicates that households save a fraction $(1 - \alpha)$ of their income. How are savings allocated? A share is invested in corporate debt backed by tangible investment. There are two other savings vehicles, corporate shares and

houses. In steady state their value can be written as

$$f = \frac{(1 - \omega)RH}{r}, \quad (3.8)$$

$$p = \frac{v'(\bar{L})}{r}. \quad (3.9)$$

As the relative role of intangible capital in the economy grows, firms demand relatively less external finance to fund physical investment. Some savings are absorbed by share prices, which rise in value as the return on intangibles increases. However, as firms only appropriate a fraction $(1 - \omega)$ of the return to intangibles, innovators receive a rising share of total income. As this increasing share of the capital stock is not investable, excess savings push down interest rates, and all long-term assets increase in value. Thus the evolution of intangible value is an indirect driver of share and house prices, even though its direct effect is to subtract a rising share of income from investment assets.

3.4 Secular trends

This section analyzes alternative formulations of the growth process to assess what factors can best explain the evolution of economic trends since 1980. After describing the main trends we examine analytically how well they may be explained by individual growth factors. We complement these analytical results with a suggestive quantitative exercise to study the combined impact of different drivers. Technological progress is the natural driver of long term growth, but we also consider social trends such as demographics and rising education levels as well as global capital and trade flows.

Most factors can account for some subset of trends. Our main result is that only a strongly redistributive form of technological progress can by itself drive the observed combination of growth, falling investment and interest rates. We show analytically that this core set in turn produces all other major trends.

3.4.1 Major secular trends

This section lists major economic trends over the past 35 years that a broadly specified growth model should be able to account for.

Falling real interest rates Real rates have gradually fallen across advanced economies since the early 1980s (King and Low, 2014). For the U.S. we compute the real interest

rate as the 10 year treasury yield minus inflation.¹⁰ From a peak above 8% in the early 1980s, US real rates have steadily been declining, to a level around 0% in recent years.

Rising intangible relative to tangible investment Corporate investment in intangible assets has risen even as total investment has declined (Corrado and Hulten, 2010b).¹¹

We compute the ratio of intangible to total capital for the US economy aggregating firm-level data from Compustat, combined with the measure of intangible capital of Peters and Taylor (2017).¹² We also compute the intangibles ratio from national accounts using data from the BEA's NIPA tables.

Figure 3.1 in the introduction plots the estimated intangible ratio from these two sources. The Compustat intangibles ratio is higher, since Peters and Taylor (2017) capitalizes more spending flows than the BEA estimates.¹³ Whatever the better definition, there is a clear and steady upward trend in both series. In the language of the model, this trend is represented by a growing value of H relative to K .

Decreasing corporate net borrowing US corporations have been reducing their net borrowing, while repurchasing more shares than they issued. The left panel of figure 3.3 replicates the drop in corporate net leverage of Compustat firms in Bates et al. (2009), next to own calculations showing how the decrease is concentrated among firms with the most intangible assets.¹⁴ Among others, Lazonick (2015) shows how U.S. firms experienced net equity outflows since 1980, even after the recent crisis.

This overall decrease in external financing by firms is further confirmed by data on net borrowing of US non-financial businesses from the Flow of Funds, scaled by nominal GDP.¹⁵ This series in the right panel of figure 3.3 displays an even sharper downward trend. This is puzzling as a fall in real rates reduces the marginal cost of tangible investment and

¹⁰Both series are downloaded from FRED.

¹¹Intangible capital is here defined as the capitalization of expert human capital invested in corporate knowledge, organizational capability, computerized information and internal software.

¹²This approach capitalizes R&D and some SG&A expenses, as they represent investments in knowledge capital, organizational structure, and brand equity. We then define the aggregate intangible ratio as the ratio of aggregate intangible capital relative to aggregate total (physical plus intangible) capital. Physical capital is defined as property plant and equipment (PPENT). Computing this metric, we restrict the sample to firms with non-missing and at least \$1m in total assets. We also exclude financial firms (SIC codes 6000 - 6999) and utilities (SIC codes 4900 - 4999).

¹³For example, the BEA measure does not capitalize any SG&A spending that contributes to a firm's organizational capital.

¹⁴The figure plots average total debt (DLTT + DLC) net of cash holdings (CHE) scaled by assets (AT) for Compustat firms. HINT firms are in the highest tercile of the intangibles ratio distribution in a given year, while LINT are in the lowest tercile.

¹⁵This series is defined as total liabilities minus total financial assets.

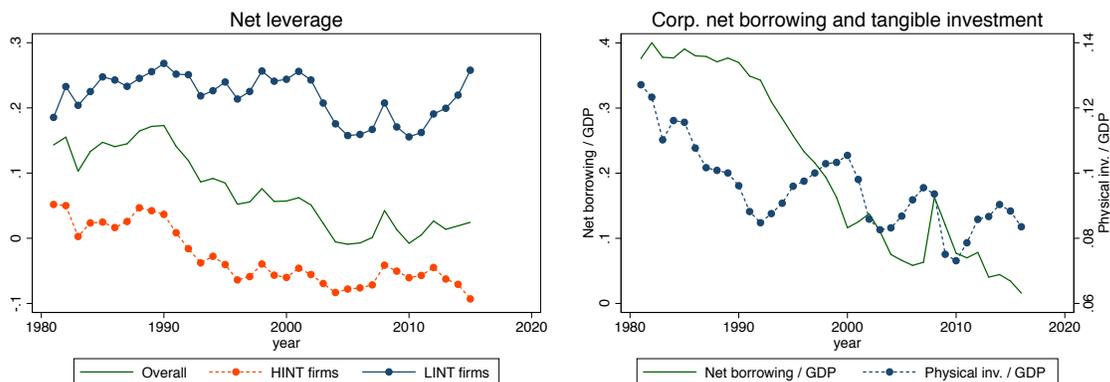


Figure 3.3: Net leverage and borrowing by non-financial corporations

borrowing.

Note that we interpret external financing for tangible investment K as debt. For comparison, the right panel of figure 3.3 also plots BEA data on non-residential, non-IPP investment relative to GDP, which can also represent K/Y in our model. Both series exhibit an overall downward trend. Therefore, the key growth factor should be able to account for a falling $\frac{K}{Y}$ in our model.

Mortgage credit growth In contrast to falling corporate credit, mortgage credit has shown a steady rise relative to GDP, as figure 3.4 shows using data from the Flow of Funds.¹⁶ While the real estate credit bubble of the 2000s played a role, the figure shows a clear secular growth since 1980.

While several authors have highlighted specific US factors for the recent real estate credit boom, Jordà et al. (2016) show how all advanced economies experienced strong mortgage credit growth relative to corporate credit. This shift appears correlated to the rise of intangible capital (Dell’Ariccia et al., 2017). Such a global trend suggests a generalized reallocation of credit correlated with a common long term growth factor. In our model this trends is represented by growth of $\frac{m}{Y}$.

Rise of land values Knoll et al. (2017) show that real house prices across advanced economies were largely stable from 1870 until the mid 20th century. Since 1980 they have

¹⁶The left panel plots aggregate home mortgage credit by households. This series is derived from the Flow of Funds and defined as the total amount of home mortgage debt outstanding by households and nonprofit organizations, divided by nominal GDP. The right panel plots land values computed by (Davis and Heathcote, 2007), divided by nominal GDP. The red dashed line plots the trend components with an HP filter with smoothing parameter 1600.

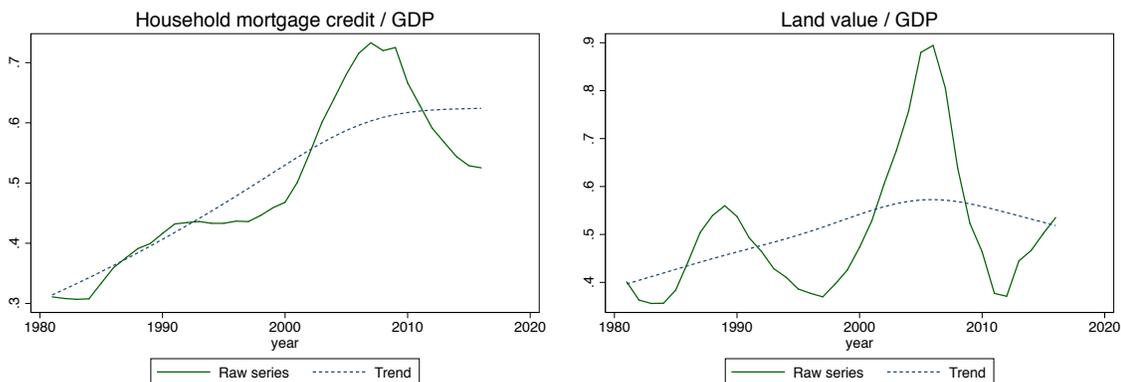


Figure 3.4: Mortgage credit and land values to GDP

started rising strongly in real terms. This growth appears largely driven by rising demand, since land is largely in fixed supply and urban density is constrained by regulation.

The right panel of figure 3.4 shows the aggregate value of US land scaled by GDP, estimated by subtracting from house prices the cost of structures (Davis and Heathcote, 2007). While the bubble in the 2000s is even more visible here, there is an overall upward trend. The value of scarce land in desirable locations has probably risen much more than average. This trend is represented by growth of $\frac{p}{Y}$ in our model.

Stock market capitalization World Bank data shows US stock market capitalization over GDP rising from 50% in 1980 to levels between 100% and 150% since the 2000s. Give the scale of net equity outflows, this value reflects a significant revaluation effect driven by lower rates and rising profits. In the model this value is measured by $\frac{f}{Y}$, the value of outstanding shares relative to income.

Rising wage inequality Survey data from the US Bureau of Labor Statistics show a sharp increase in relative earnings of workers with at least a Bachelor degree since 1980. This skill premium trend has been interpreted as the result of skill-biased technological change complementary with high cognitive skills that replaces low skill functions (Acemoglu and Autor, 2011). It is represented by an increase in $\frac{q}{w}$ in the context of our model.

This list defines a set of trends that we seek to explain in the context of our model, $\mathcal{T} = \{r \downarrow, \frac{H}{H+K} \uparrow, \frac{K}{Y} \downarrow, \frac{m}{Y} \uparrow, \frac{p}{Y} \uparrow, \frac{f}{Y} \uparrow, \frac{q}{w} \downarrow\}$.

3.4.2 Key growth drivers

What parsimonious description of the growth progress can at best reproduce these secular trends? Our general production function suggests some technological explanations. A uniform growth effect driven by a rising common productivity factor A as in the classic Solow model would benefit all factors of production equally. Such a growth driver is inconsistent with the growing role of intangible capital and rising skill premium in wages. Hence, we focus on intangible-biased growth drivers.

- An improvement in the rate of innovation, such as an IT-induced reduction in the cost of producing intangible capital (a fall in β) is a natural growth driver. It boosts the supply of intangible capital, and leads to higher rewards for complementary factors such as skilled labor. A higher intangible capital creation also implies more total income accruing to innovators. This form of progress is weakly redistributive, as physical factors also benefit indirectly through their complementarity.
- A more redistributive shift would interpret technological progress as a strong rise in the productivity of intangible capital and skilled labor relative to physical capital and labor at the technological frontier (a rise in η). Such progress leads to aggregate income growth provided there is sufficient skilled labor supply. In this formulation, the absolute productivity of some factors in the optimal productive combination (3.1) may actually fall over time, consistent with the notion that new technologies replace physical labor at the technological frontier (Acemoglu and Autor, 2011).¹⁷

Given the evidence on a growing role of intangible capital, it is natural to focus on technological growth drivers. However, general economic trends certainly reflect multiple causes, so we evaluate other relevant factors. We list here the drivers that we can directly study in our model:

- The share of university educated workers has risen steadily in recent decades. More skilled labor may explain a growing supply of intangible capital. This process is described by an exogenous increase of ϕ , the fraction of skilled labor.
- Piketty (2014) highlights a historical fall in the labor share since the 1970s. This is a redistributive factor that may explain some observed changes in the income distribution. In our model it can be the results of a rising technological importance of capital α in our model.

¹⁷As we discuss later, this effect is reinforced by globalization of production as the result of knowledge spillovers.

- A rising ω would reflect an increased bargaining power for innovators over corporations. This factor may boost intangible capital and reduce the investment opportunities available to the public.
- A savings glut with significant capital inflows from abroad may have contributed to the rise of housing prices and mortgage credit in the US. To study capital inflows in our model, suppose foreigners invest a fraction x_t of GDP in domestic financial claims. As they live abroad, foreigners do not gain utility from housing, so holding land directly yields only the price appreciation. Thus, foreigners only invest in financial assets. Given capital inflows x_t the market clearing condition becomes

$$(1 - \alpha + x_t)Y_t = p_t\bar{L} + K_{t+1} + f_t. \quad (3.10)$$

This list defines a set of growth drivers that have a direct representation in our model, $\mathcal{G} = \{\eta, \beta, \phi, \alpha, \omega, x\}$, that may potentially explain the secular trends \mathcal{T} .

Other drivers that have been highlighted in the literature can also be interpreted in the context of our model. Demographic changes such as aging may have a direct effect on savings supply. In a model with a richer live-cycle structure, a gradual increase in longevity would lead to a rise in savings. In a reduced form, we can capture this effect as an exogenous increase in savings x , in a similar way as foreign capital inflows.

Globalization is most certainly a first order factor in recent economic evolution. Its redistributive effect represents, next to technological change, a second cause for a shift of factor productivity at the technological frontier in developed countries. Relocation of tangible investment contributes an additional channel for a fall in real labor wages next to automation of manual tasks. Ideally, one would want to study this driver in an explicit multi-country setup. In the reduced form of the model, a combination of technology progress in advanced economies and knowledge spillovers to emerging countries is consistent with a progressive rise in η in the efficient production frontier of advanced economies.

Similarly, a falling price of (productivity-adjusted) capital goods can reflect a growing productivity of software and skilled labor employed along physical equipment, while reflecting the lower cost of the physical input.

Lastly, our model cannot easily accommodate changes in the level of competition, so it does not incorporate the effect of rising concentration since the 2000s. This is an important driver of economic evolution (Gutiérrez and Philippon, 2016) and is consistent with a rising profit share and equity valuations, though its effect on interest rates, tangible

investment and skilled wages is not obvious.

3.5 Analytical comparison of growth drivers

This section assesses analytically how the growth drivers \mathcal{G} listed above predict the evolution of secular trends \mathcal{T} in the context of our model. Our approach is to study the effect of individual drivers on the economy's long-run allocation. This comparative static exercise assumes an initial steady state around 1980, and a final steady state around 2015. Section 3.6 complements this approach by calibrating the model and calculating the combined effect of different factors across steady states.

3.5.1 Analytical results

For our analytical results we restrict attention to the Cobb-Douglas case (the limiting case once $\rho \rightarrow 0$, see appendix 3.9.1 for the general CES case). We start with a simple observation:

Observation. *To individually explain all secular trends \mathcal{T} simultaneously, any growth driver must be able to explain falling corporate borrowing and physical investment $\frac{D}{Y} = \frac{K}{Y}$, along with falling interest rates r .*

This observation conveys a simple intuition. Physical capital can always be scaled up to the point where its marginal productivity equals the cost of external finance. Any driver behind the observed trends must explain a simultaneous drop in the quantity and price of external finance. A combination of falling quantity and cost of physical capital at the technological frontier suggests a structural decline in its demand.

Falling corporate net borrowing and interest rates are directly manifested in the data. Moreover, in the model the financial market clearing condition (3.7) shows clearly that a rising $\frac{K}{Y}$ requires either $\frac{p}{Y}$ or $\frac{f}{Y}$ to be decreasing, directly contradicting their observed trend.

$$(1 - \alpha) = \frac{p}{Y} \bar{L} + \frac{f}{Y} + \frac{K}{Y}.$$

This observation mirrors the insight in the labor literature that rising wage inequality coupled with an increase in high-skill employment must be the result of growing demand for skilled workers (e.g. Autor et al., 1998).

After this useful insight we can state our main result:

Theorem. *Among all growth drivers in the set \mathcal{G} , only a strongly redistributive form of technological progress (defined as an increase of η) can simultaneously produce all observed trends in the set \mathcal{T} .*

To see this result, consider the steady-state value of the real interest rate:

$$1 + r = \alpha(1 - \eta)\frac{Y}{K}, \quad (3.11)$$

As observed above, both $\frac{K}{Y}$ and r need to drop to explain all secular trends. In (3.11) the interest rate is equal to the marginal product of physical capital. The key insight of the theorem is that by (3.11), falling interest rates can only be the result of a rising ratio $\frac{K}{Y}$ - unless η rises, or α falls. A falling income share going to capital α is not supported by the data, which rather suggest it has increased (e.g. Dorn et al., 2017). Hence, rising η survives as the only candidate that may individually drive all secular trends.

All other growth drivers in the model can be consistent with falling $\frac{K}{Y}$ only if interest rates increase. Moreover, with falling $\frac{p}{Y}$, also mortgage credit to GDP rises unless η falls. To see this, restate the steady state value of $\frac{m}{Y}$ in the case of positive mortgage credit demand as

$$\frac{m}{Y} = (1 - \phi)\frac{p}{Y}\bar{L} - (1 - \alpha)(1 - \eta). \quad (3.12)$$

Clearly, with falling $\frac{p}{Y}$, a rising share of mortgage credit requires a rising η and/or a rising α , but the second case is not consistent with falling interest rates.

In conclusion, our analytical results show that η is the only growth driver consistent with all long term trends. Of course, the world is complex and not one single driver explains all trends. But this result suggests that a strongly redistributive shift is among the key drivers explaining the weak demand for credit by corporations in an environment of falling interest rates. In section 3.6 we examine the joint effect of different growth drivers.

3.5.2 Strongly redistributive technological progress

Under what conditions can a rising η indeed generate all observed trends? While it is not possible to pin down precise conditions in terms of parameters, we show in the appendix that rising η generates all secular trends if parameters are chosen such that

- (i) changes in η result in positive, but not too strong output growth, and
- (ii) ω is sufficiently large.

While a rising η implies directly a decreasing relative productivity of K , by general complementarity all factors benefit from overall output growth. Provided the effect of η on growth is not too strong the direct effect dominates, resulting in a falling equilibrium ratio of $\frac{K}{Y}$.

When rising η results in falling $\frac{K}{Y}$, firms demand less external financing. As long as ω is significant, a large fraction of the return to innovation is captured by human capital, and hence does not constitute a savings vehicle for the general public. As a result, the growth in stock prices is limited and land values rise to absorb some of the slack savings.

To summarize, strongly redistributive technological progress shifts firm investment to intangible capital, inducing a fall in their external financing needs. As long as overall growth is not too strong, firms decrease their leverage despite falling interest rates. It also results in increasing house and share prices, a rising ratio of mortgage to productive credit and more wage inequality.

3.6 Calibration and Empirical Validation

Our analytical results allow us to study the impact of individual drivers. We now calibrate our model and use a numerical solution to (i) understand in more detail why other drivers fail, and (ii) assess the combined impact of multiple drivers. To that end, we calibrate our economy to 1980 and change individual drivers to match the evolution of the intangible-tangible ratio over time. We then compare the evolution of unmatched endogenous variables to the data, to see how well individual drivers explain those trends.

While our model is not suited for a full-blown quantitative assessment of different drivers, the results indicate that capital inflows and rising education levels help explaining the magnitude of trends. Still, a shift towards intangibles still emerges as a necessary driver to explain why corporations borrow less in the light of low interest rates.

3.6.1 Calibration to 1980

Throughout we use the functional form $v(L) = \ln(L)$, and need to calibrate parameters $\alpha, \bar{L}, A, \phi, \rho, \eta, \beta, \tilde{h}$ and \tilde{l} . Some parameters can be directly drawn from actual data. For ϕ we use the percent of the population with a Bachelor degree or higher in 1980, reported to be 17% in the census data. We set $\alpha = 0.33$, a standard value in the literature in line with the share of income going to capital. To calibrate ρ we use the elasticity of substitution between high-skill and low-skill workers. In the SBTC literature this elasticity is measured to be between 1.4 and 2 (Acemoglu and Autor, 2011), so we set ρ to get an elasticity at the

center of this range at 1.7. In line with the discussion in section 3.5.2, we set ω to a high value such that human capital appropriates most of the returns to intangibles, $\omega = 0.95$. We normalize $\bar{L} = 1$ and set $A = 1$.

This leaves us with the free parameters η , β , \tilde{h} and \tilde{l} .¹⁸ We set these parameters to match data moments around 1980. All of these parameters impact the relative usage of physical vs intangible capital, as well as mortgage credit and house prices. Accordingly, we jointly set these parameters to target the aggregate intangibles ratio from Compustat (shown in figure 3.1), represented by $\frac{H}{H+K} = 0.38$ in the model. We also target mortgage credit over GDP, $\frac{m}{Y} = 0.28$, and land values over GDP to $\frac{p}{Y} = 0.43$.¹⁹

3.6.2 Individual Drivers and Why They Fail

Given the calibration to 1980, our approach is to gradually change individual growth drivers over time, and see whether they can replicate the observed trends. In a first experiment, we adopt the parsimonious approach from our analytical results and change each technological growth driver individually. The goal is to match the evolution of the intangibles ratio over time. Other trends are not targeted, and we simply compare how well the model-implied trends match those observed in the data.

The results of this exercise are reported in table 3.1. The top panel reports the relative change of the different moments of interest between 1980 and 2015. The lower panel compares the trends in the data to those implied by the model, under different individual drivers.

The first row confirms that strongly redistributive growth η generates the right sign for all trends (red numbers indicate that the model-implied change differs from that observed in the data). A falling cost of producing intangibles β also results in a growing intangibles ratio and falling interest rates (second row). However, by general complementarity physical factors benefit too, such that the drop in interest rates is accompanied by an increase in K/Y . As $\frac{K}{Y}$ grows and more funding flows to businesses, both mortgage credit and land values drop relative to GDP, contradicting the trends observed in the data.

¹⁸Note that only the ratio $\beta = \tilde{\beta}/\varepsilon$ is identified, not the individual parameters.

¹⁹The resulting parameter values are $\eta = 0.845$ and $\beta = 3.105$. The values for labor are $\tilde{l} = 19.211$, corresponding to an aggregate number of $l = 15.945$, and $\tilde{h} = 143.75$, implying $h = 24.438$. The model succeeds in matching the intangible ratio quite precisely (0.377 vs 0.376 in the data), and delivers a realistic level of land values over GDP (0.399 vs 0.432) and mortgage credit over GDP (0.311 vs 0.280). Under this calibration, the level of $\frac{K}{Y}$ is equal to 0.173, which lies between the mean net leverage of Compustat firms (0.193), and the level of nonresidential investment excl. IPP over GDP from the BEA (0.121). Other non-matched endogenous variables such as the level of interest rates and stock market capitalization are not as close to their actual levels. Our focus is to evaluate how well the model predicts their relative change in observed trends.

Data						
	Intangible Ratio	Real rate	Net borrowing / GDP	Mortgages / GDP	Land price / GDP	Stock market cap / GDP
Δ 1980-2015	65.82%	-72.27%	-86.20%	86.23%	37.12%	201.11%
Model						
	H/(H+K)	r	K/Y	m/Y	p/Y	f/Y
$\eta \uparrow$	65.21%	-17.84%	-61.67%	51.98%	19.71%	36.30%
$\beta \downarrow$	65.24%	-31.11%	29.05%	-18.38%	-16.43%	47.98%
$\alpha \uparrow$	65.13%	113.52%	-39.88%	-8.31%	-14.42%	-30.73%
$\omega \downarrow$	24.23%	92.22%	-50.20%	-49.52%	-37.40%	515.80%
$x \uparrow$	-28.82%	-34.59%	61.96%	64.22%	48.61%	51.29%
$\phi \uparrow$	-20.07%	-25.00%	16.41%	-28.61%	-10.29%	36.29%

Table 3.1: Relative changes across steady states implied by individual growth drivers.

A rising income share of capital α can also replicate the observed increase in intangibles (third column). However, it is the result of falling savings supply from young workers. Accordingly, an increase in α results in higher interest rates, contradicting the data.

Adjusting the income share going to innovators ω we are unable to match the observed increase in the intangibles ratio. In fact, intangibles only rise if we *decrease* ω , and even then we manage to generate a growth of at most 24% (by letting ω drop to 0.41). This may seem a bit unintuitive, since innovators should exert more effort as they capture a larger fraction of the returns going to intangibles. The reason that falling ω generates an increase in the intangibles ratio is that it boosts share prices, absorbing savings that would otherwise fund physical investment.

Our remaining drivers are capital inflows from abroad x and rising education levels ϕ . Since we can directly observe how these two evolve in the data, we follow a slightly different approach. Rather than trying to adjust them so as to fit the rise in intangibles, we change these two drivers according to their directly observed evolution in the data.

From 1980 to the mid-1990s the US current account was relatively balanced, while large foreign inflows start in the end of the 1990s. In line with the data, we let x grow from 0 to 0.35 in the final steady state. While a savings glut pushes down interest rates, by itself it cannot explain why foreign funding did not flow to corporations to fund physical investment.

Finally, we adjust the fraction of high-skill households from $\phi = 0.17$ in 1980, to $\phi = 0.3$ in 2015, in line with the evolution of the fraction of the U.S. population with a Bachelor degree or higher. Higher incomes increase the savings supply, which pushes down interest rates but also flows to firms and investment in physical capital.

	Data						
	Intangible Ratio	Real GDP	Real rate	Net borrowing / GDP	Mortgages / GDP	Land price / GDP	Market cap / GDP
$\Delta 1980$ $\Delta 2015$	65.82%	140.82%	-72.27%	-86.20%	86.23%	37.12%	201.11%
	Model						
	H/(H+K)	Y	r	K/Y	m/Y	p/Y	f/Y
$\eta + A, \phi, x$	64.98%	140.78%	-75.04%	-74.52%	89.38%	66.42%	366.30%
$\beta + A, \phi, x$	65.14%	140.88%	-64.14%	107.33%	6.17%	15.78%	47.98%
$\alpha + A, \phi, x$	63.61%	-48.84%	31.28%	-14.55%	49.48%	48.90%	14.82%
$\omega + A, \phi, x$	51.90%	-40.12%	43.81%	-46.99%	5.87%	16.12%	727.73%

Table 3.2: Relative changes across steady states implied by combination of growth drivers.

3.6.3 The Joint Effect of Multiple Drivers

While a redistributive technological shift η emerges as the primary growth driver able to explain lower credit demand along with falling interest rates, economic trends reflect multiple causes. We now calibrate the effect of drivers that seem to be able to generate an increase in the intangibles ratio (η, β, α and ω), incorporating information on capital inflows and education levels. In other words, when assessing each individual driver we also adjust capital inflows x and education ϕ as observed in the data. Moreover, we implicitly adjust A so as to match the actual growth of output from 1980 to 2015.

Table 3.2 reports the results of this exercise. Strongly redistributive growth η and a falling cost of intangibles β do well at matching the observed growth in the intangible ratio and output. Adjusting ω and α cannot even generate an increase in output in a context of rising intangibles.

Combining falling β with additional trends helps get the correct sign for more trends. However, K/Y still falls in the light of lower interest rates, as physical factors benefit by general complementarity. Hence, growing η still emerges as the technological driver best suited to generate observed trends.

Comparing table 3.1 to table 3.2 shows that allowing for capital inflows and rising education levels bring the magnitude of the trends generated by rising η closer to their actual evolution in the data. As capital inflows push up house prices, they help in particular to produce higher land values and mortgage borrowing.

This is further illustrated in figure 3.5, which compares the model-generated trends to the data, by plotting the simulated perfect-foresight path between the 1980 and 2015 steady states.²⁰ The dashed line plots the endogenous evolution of the respective variables

²⁰ When indicated, data series are normalized by their mean level across the years 1978-1983, and model series by their initial steady state.

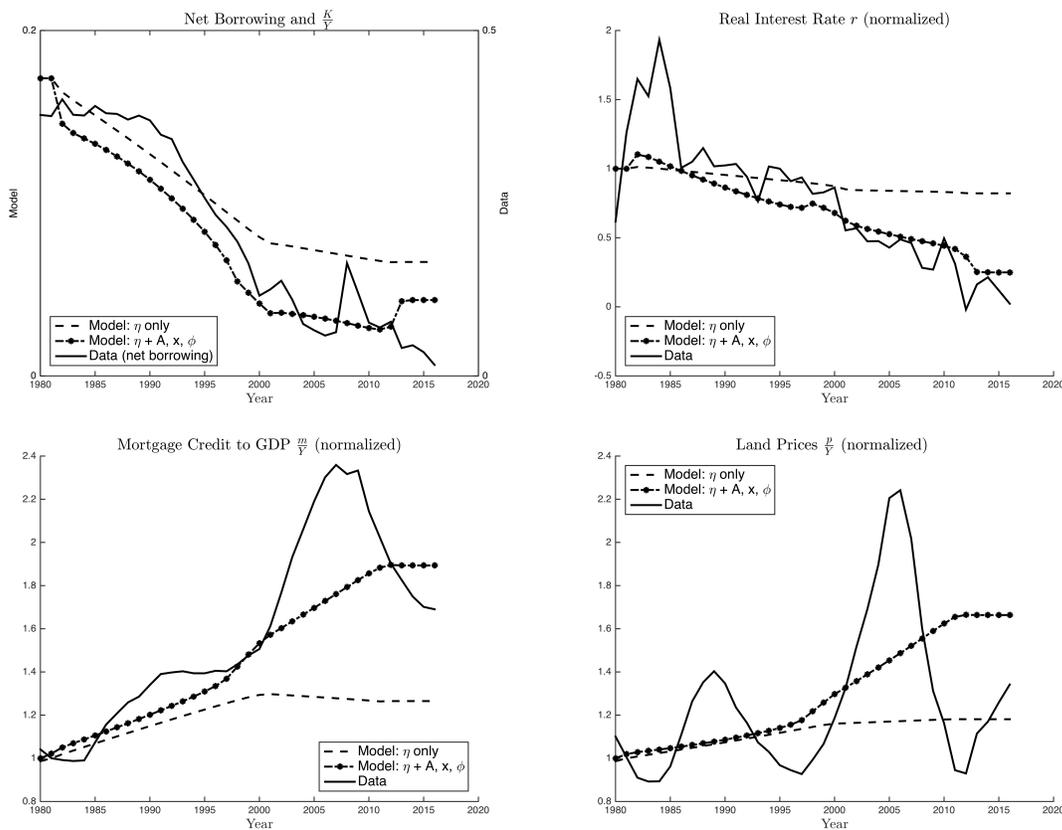


Figure 3.5: Simulated perfect-foresight time path compared to actual series.

when we only change η over time, and match the evolution of the intangibles ratio.²¹ The dashed-dotted line plots the time path when η is adjusted in combination with A , x and ϕ , and output growth is targeted.

Comparing the model-implied timepath to the data, a clear picture emerges. Rising η accounts well for the overall trend in the series, in particular when matching actual output growth and accounting for capital inflows and education. While the growth of intangible capital flattens in the late 1990s, foreign inflows help especially to boost the magnitude of the growth in mortgage credit and house prices since this period. Still, technological change is a necessary driver in the background, explaining why the foreign capital did not flow to corporations.

Actual economic series are naturally much more volatile, and our long term approach cannot match oscillations around trends. This is particularly visible in the land price and mortgage credit series during the real estate bubble in the 2000s. Overall, as our simple long term model is only calibrated to match the intangibles ratio and output growth, the

²¹Note that η grows faster until 2000, then the growth of intangibles flattens somewhat (see figure 3.1).

Table 3.3: Cross country evidence on mortgage credit and intangible investment

Mortgage Ratio is the ratio of mortgage to total credit. *Intangibles Ratio* is the ratio of intangibles to total assets. Reported *t*-statistics based on errors clustered at the firm level. ***, **, * indicate significance at 1%, 5%, and 10% level. All independent variables are lagged one year.

	(1)	(2)	(3)	(4)
	Mortgage Ratio	Mortgage Ratio	Mortgage Ratio	Mortgage Ratio
Intangibles Ratio (INTAN-Invest)	0.777*** (5.00)	0.706*** (4.05)		
Intangibles Ratio (Compustat)			0.299*** (3.29)	0.432*** (3.34)
Log GDP per capita		0.00360 (0.04)		-0.870 (-1.70)
Current Account		0.00175 (0.40)		0.00928 (1.37)
Year Fixed Effects	No	Yes	No	Yes
Observations	263	263	264	264
Adjusted R^2	0.402	0.392	0.152	0.270

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

model-generated series seem relatively close to the underlying trend in the data.

3.6.4 Cross-country evidence

According to the model, excess savings driven by intangible use by firms boost mortgage credit over GDP. We further examine this empirical relationship in a panel of OECD countries, seeking to account for the evolving national share of mortgage credit to total credit calculated by Jordà et al. (2016) in terms of the national rate of adoption of new technology.

We use the intangible capital measures based on National Accounts, available through the INTAN-Invest project (see Corrado et al., 2012). As an alternative measure we use Compustat Global firm data, estimating intangibles by capitalizing R&D and SG&A expenditures as in Chapter 2 of this thesis, and Peters and Taylor (2016).²²

Table 3.3 presents the results of fixed effect and pooled OLS regressions using the two intangible ratio measures, GDP per capita as a general control and capital inflows to include net external savings. Including time fixed effects maintains the significance of the

²²For details see Chapter 2. Compustat Global data coverage is from 1989 to 2015, the INTAN-Invest series from 1995 to 2010. These measures are strongly correlated, with an average of 0.82.

results.

In all specifications, a higher intangibles ratio is significantly associated with more mortgage credit. Its impact is economically significant, as each percentage point increase in the intangibles ratio increases the ratio of mortgage to total credit by between 0.3 and 0.78 percentage points.

Overall, cross-country correlations are consistent with our conjecture that a rising usage of intangibles results in reduced corporate demand for credit and a re-allocation of funding to existing assets such as real estate. The results mirror the US evidence in Dell’Ariccia et al. (2017), that higher usage of intangible capital by firms induces banks to shift away from productive, towards mortgage lending.

3.7 Rising default rates and policy issues

A growing scale of mortgage credit may have consequences for financial stability (Jordà et al., 2015), as it increases the chance that the high debt burden will be unsustainable. As a consequence, policy debate has centered on how to control mortgage credit risk. To assess this issue we introduce some time-invariant uncertainty in house prices.

Our key result is that in a redistributive growth process, low-skill households need to increase their loan to income ratio to acquire housing. Over time, this endogenous rise in household leverage produces more frequent mortgage defaults, even with a constant risk factor.

Suppose that after yielding utility to their owner, but before it is sold to the next generation, agent i ’s house value receives a temporary shock ξ_t^i with zero mean that alters its value. In appendix 3.9.3 we solve the modified model, presenting a ”weather shock” that may damage houses. In this interpretation houses hit by a negative shock require repairs and therefore trade at a discount, $p_t^i = p_t(1 - \xi_t^i)$, defining a threshold

$$\hat{\xi}_t^i = 1 - \frac{p_{t-1}}{p_t} LTV_{t-1}^i$$

such that for realizations of $\xi_t^i > \hat{\xi}_t^i$ household i defaults on her mortgage. Here $LTV_{t-1}^i \equiv \frac{(1+r_t)(-D_{t-1}^i)}{p_{t-1}L_{t-1}^i}$ is defined as the loan-to-value (LTV) ratio of a home buyer.

As shown in the appendix, a stationary shock leaves the equilibrium allocation unchanged. As a result we immediately have the following corollary:

Corollary 1. *Define $\chi_t \equiv 1 - G(\hat{\xi}_t^l)$ as the aggregate default of low-skill workers. Technological progress that results in rising mortgage credit relative to GDP also produces*

increasing steady-state default among low-skill workers ($\frac{dx}{d\eta} \geq 0$)

As technological progress increases income inequality and house prices, low-skill workers end up with higher LTV-ratios, lowering the threshold $\hat{\xi}^l$. Thus even for a given distribution of shocks, default occurs more frequently.

While rising mortgage default rates were a main cause for the 2008 financial crisis, in our current formulation any default is just an ex-post transfer with no aggregate welfare loss. As lenders are compensated by a higher interest rate, there is no inefficiency that needs to be addressed by a Pareto-improving policy intervention, since the economy is dynamically efficient. If however mortgage defaults caused a financial externality, e.g. through fire sales (Lorenzoni, 2008) or aggregate demand externalities (Korinek and Simsek, 2016), stronger policy intervention over time may be warranted, for example through tightening loan-to-value ratios.

Such a policy has interesting side effects for the long run allocation in our model. Restraining the borrowing of young home buyers restricts their ability to bid up the price of land, reducing house prices while pushing interest rates even lower. As the released savings are redirected towards physical investment, in general equilibrium both output and wages grow via the indirect subsidy to production. The trade off is that the old generation suffers a capital loss, and the stock of housing is allocated less efficiently. Interestingly, the policy benefits most those for whom the borrowing constraint becomes binding. Young low-skill workers gain through smaller transfers to older generations and a higher capital stock - a consequence of lower equilibrium land prices.²³

This result mirrors Deaton and Laroque (2001), who show that introducing land in a baseline OLG growth model eliminates the "Golden Rule" steady state that maximizes long-run consumption. As land absorbs savings, there is generally an under-accumulation of productive capital. Our model highlights that this effect may be stronger in a knowledge economy where capital is becoming more intangible-intensive over time.

3.8 Conclusion

We offer a neoclassical growth view that may account for the growing excess of savings over productive investment dubbed "secular stagnation". Our broad framework allows to shed light on what type of technological change may have driven these secular trends. While information technology has clearly favored some factors, our analysis and evidence suggests that growth in the last decades cannot be simply explained by a rise in the absolute

²³We derive these results formally and they are available upon request.

productivity of intangibles. Only a highly redistributive reallocation of productivity can account for the observed trends, in particular with the combination of a steady fall in physical investment, falling interest rates and labor wages in a context of aggregate growth.

While skill-biased technological progress is acknowledged as a key cause of the evolution of relative wages (Acemoglu and Autor, 2011), our framework extends its effect to concomitant trends in credit allocation and asset prices. A boost to the productivity of intangible investment increases the value captured by innovators who invest their own human capital, resulting in a fall in corporate demand for finance. The savings glut progressively lowers interest rates, leading to repricing of long term assets and increasing household leverage. The model endogenizes popular explanations for a persistent period of low investment, such as a drop in investment opportunities and a fall in the relative price of investment goods.

Critically, excess savings arise because savers cannot fully co-invest in the development of intangible capital, whose value largely accrues to innovators (Hart and Moore, 1994). Innovative startups nowadays need only modest upfront investment, relying on co-investment by skilled human capital funded by deferred compensation. Anecdotal evidence suggests that a large fraction of value created by innovative firms accrues to founders and employees. Even once listed, innovative firms remain largely self financed, and maintain a high share dilution rate to fund grants to employees.

Our result on the implied evolution of relative factor productivity in developed economies is certainly reinforced by their growing specialization in high intangible industries, while some physical production is relocated to emerging markets. Next to the direct impact of IT on production and the composition of demand, a shift in comparative advantage probably explains the absolute fall in the productivity of physical inputs.

Overall, more insight is needed on the evolution of capital in a knowledge economy. We have here highlighted the consequences of the special nature of intangible capital, where a large share of its return must be assigned to innovative human capital that creates it. On the other hand, while innovators may be richly rewarded, the knowledge they create is non excludable. As it becomes available to others it contributes to the spread of knowledge, with additional redistributive effects in a global economy.

3.9 Paper Appendix

3.9.1 General case

In the more general CES case (not restricted to Cobb-Douglas), the steady-state interest rate (3.11) can be expressed as

$$r = A^\rho \alpha (1 - \eta) \frac{Y^{1-\rho}}{K^{1-\alpha\rho}} l^{(1-\alpha)\rho} \quad (3.9.1)$$

$$\frac{q}{w} = \frac{\eta}{1 - \eta} \left(\frac{H}{K} \right)^{\alpha\rho} \left(\frac{\tilde{l}}{\tilde{h}} \right)^{1-(1-\alpha)\rho} \quad (3.9.2)$$

Other conditions such as market clearing (3.7), and steady state mortgage credit to GDP (3.12) remain the same.

Relative to the Cobb-Douglas case, the interest rate still depends on $\frac{K}{Y}$, though not linearly. The new parameters that show up are ρ , A and l . A decrease in A or l could also explain simultaneously falling $\frac{K}{Y}$ and r . However, this would also lower output, while on average US real GDP has grown by more than 2% a year since the 1980s. The effect of ρ on the secular trends is ambiguous, but changing complementarity between intangible and tangible capital seems an implausible driver behind the relevant secular trends.

Note that in the CES case income inequality depends on the ratio $\frac{H}{K}$. The growth of intangibles may therefore give an additional boost to inequality. Consequently, modeling technological change other than growth in η may also produce rising income inequality.

3.9.2 Strongly redistributive growth

This appendix elicits that when a rise in η results in positive but not too extreme growth $\frac{1}{1-\eta} \geq \frac{dY}{d\eta} \geq 0$. As a first step we collect the relevant equations and evaluate them in steady state. The model's core is defined by (3.1), (3.5), (3.6), (3.3), (3.3.1) and (3.7).

The steady-state equilibrium for the variables r, R, K, H, f, p and Y is defined by the

following equations, together with the production function (3.1):

$$r = \alpha(1 - \eta)\frac{Y}{K} \quad (3.9.3)$$

$$R = \alpha\eta\frac{Y}{H} \quad (3.9.4)$$

$$H = \frac{\omega}{\beta}R \quad (3.9.5)$$

$$f = \frac{(1 - \omega)RH}{r} \quad (3.9.6)$$

$$p = \frac{v'(\bar{L})}{r} \quad (3.9.7)$$

$$(1 - \alpha)Y = p\bar{L} + f + K \quad (3.9.8)$$

We start by showing that an increase in η results in falling $\frac{K}{Y}$ if growth is not too strong, i.e. if $\frac{dY/d\eta}{Y} \leq \frac{1}{1-\eta}$

Using (3.9.3) and (3.9.4) in (3.9.8), and solving for $\frac{K}{Y}$ yields the following expression:

$$\frac{K}{Y} = \frac{1 - \alpha}{1 + (1 - \omega)\eta(1 + \eta) + (1 + \eta)\frac{v'(\bar{L})\bar{L}}{\alpha Y}}$$

Taking a derivative w.r.t. η and evaluating when $d\left(\frac{K}{Y}\right)/d\eta \leq 0$ yields the following condition:

$$\frac{dY/d\eta}{Y} \leq \frac{1}{1 + \eta} \left[1 + \frac{(1 - \omega)(1 + 2\eta)\alpha Y}{v'(\bar{L})\bar{L}} \right]$$

Since $\omega \leq 1$ this condition is always satisfied if $\frac{dY/d\eta}{Y} \leq \frac{1}{1-\eta}$, showing that it is a necessary condition for $d\left(\frac{K}{Y}\right)/d\eta \leq 0$.

We next show that when $\omega \rightarrow 1$, and $\frac{dY/d\eta}{Y} \leq \frac{1}{1-\eta}$ holds, an increase in η can generate all observed trends, here again summarized for convenience: (i) $\frac{dr}{d\eta} \geq 0$, (ii) $\frac{d\frac{q}{w}}{d\eta} \geq 0$, (iii) $\frac{d\frac{H}{K}}{d\eta} \geq 0$, (iv) $\frac{d\frac{K}{Y}}{d\eta} \leq 0$, (v) $\frac{d\frac{f}{Y}}{d\eta} \geq 0$, (vi) $\frac{d\frac{m}{Y}}{d\eta} \geq 0$, (vii) $\frac{d\frac{p}{Y}}{d\eta} \geq 0$

Rising $\frac{H}{K}$ (iii) directly follows from rising η , as an increase in η directly boosts the productivity of H relative to K . Consequently, it must be that innovators want to create more H relative to the usage of K by firms. By (3.9.2) it must then be that $\frac{q}{w}$ always increases in η , showing trend (ii).

We already showed above that when $\frac{dY/d\eta}{Y} \leq \frac{1}{1-\eta}$, $\frac{K}{Y}$ falls, as required for trend (iv). We now proceed showing that from falling $\frac{K}{Y}$ all other trends follow.

By (3.9.6), when $\omega \rightarrow 1$, $f \rightarrow 0$. Using this, the market clearing condition (3.9.8) can

be written as

$$(1 - \alpha) = \frac{p}{Y} \bar{L} + \frac{K}{Y}.$$

Since the left hand side is a constant and the right hand side is both increasing in $\frac{p}{Y}$ and $\frac{K}{Y}$, it must be that when $\frac{K}{Y}$ falls, $\frac{p}{Y}$ increases, in line with trend (vi).

Observe that by (3.9.7), rising $\frac{p}{Y}$ must mean that rY falls. But since technological progress results in output growth ($\frac{dY}{d\eta} \geq 0$), this can only be if interest rates fall, as in trend (i).

Furthermore, with $\frac{p}{Y}$ and η rising, by (3.12) it must also be that mortgage credit $\frac{m}{Y}$ is rising, consistent with trend (vii).

Finally, too see that share valuations rise, write them as

$$\frac{f}{Y} = (1 - \omega) \frac{\alpha \eta}{r}. \quad (3.9.9)$$

Clearly, with falling rates, an increase in η must result in rising share values. This completes the proof for all trends (i) - (vii).

3.9.3 The model with default

We now introduce some idiosyncratic risk to allow for the possibility of default. Suppose that after yielding utility to their owner, but before it is sold to the next generation, agent i 's house receives a temporary "bad weather shock" ξ_t^i , with a CDF $G(\xi)$ with support $[-1, 1]$ and zero mean.

The weather shock is drawn every period, and its effects are thus temporary. Realizations of $\xi_t < 0$ mean the house stands in a neighborhood that temporarily experiences particularly good weather, yielding their owner some additional utility $-p_t \xi_t$ per unit of land. In contrast, realizations of $\xi_t > 0$ are bad weather shocks that damage the house. A damaged house will not yield any utility to the next owner unless it is repaired at cost $p_t \xi_t$ per unit of land. As the cost has to be ultimately borne by the seller, a damaged house trades at a discount such that $p_t^i = p_t(1 - \xi_t^i)$.

As a result of the shocks, households with very larger shocks default. In particular, default occurs if $-(1 + r_{t+1})s_t^i \geq p_{t+1}^i L_t^i$, defining a threshold

$$\begin{aligned} \hat{\xi}_t^i &= 1 - \frac{(1 + r_t)(-s_{t-1}^i)}{p_t L_{t-1}^i} \\ &= 1 - \frac{p_{t-1}}{p_t} LTV_{t-1}^i \end{aligned}$$

such that for realizations of $\xi_t^i > \hat{\xi}_t^i$ a household defaults on her mortgage, and where $LTV_{t-1}^i \equiv \frac{(1+r_t)(-s_{t-1}^i)}{p_{t-1}L_{t-1}^i}$ is defined as the loan-to-value ratio of a home buyer. Note that default can only occur if $\hat{\xi}_t^i < 1$, i.e. if $\hat{\xi}_t^i$ is within the support of ξ_t^i . As a result, whenever i is a borrower ($s_{t-1}^i \leq 0$), she may default.

To compensate lenders for the possibility of default, borrowers pay a higher rate. We assume that savers pool their mortgage lending through an intermediary that just breaks even and pays lenders the riskless rate r_t . The household maximization is analogous to (3.2). In particular, denoting the risky rate by rr_t^i the maximization problem of household i in the model with default becomes

$$\begin{aligned} \max_{c_{t+1}^i, L_t^i, s_t^i} \quad & \mathbb{E}_t U(c_{t+1}^i, L_t^i) = \mathbb{E}_t c_{t+1}^i + v(L_t^i) \\ \text{s.t.} \quad & s_t^i \leq y_t^i - p_t L_t^i \\ & c_{t+1}^i \leq \max \{ y_{t+1}^i + p_{t+1}(1 + \xi_{t+1}^i L_t^i + (1 + rr_{t+1}^i) s_t^i), 0 \} \\ & c_{t+1}^i, L_t^i \geq 0 \end{aligned}$$

where the max-function in the $t+1$ budget constraint reflects that households are protected by limited liability. The probability of default is $[1 - G(\hat{\xi}_t^i)]$, so that expected consumption at $t + 1$ can be written as

$$\mathbb{E}_t c_{t+1} = G(\hat{\xi}_{t+1}^i) \left\{ p_{t+1}(1 + \mathbb{E}_t[\xi_{t+1}^i | \xi_{t+1}^i \leq \hat{\xi}_{t+1}^i]) L_t^i + (1 + rr_{t+1}^i) s_t^i \right\}$$

Now, the break even condition for the intermediary on borrower i is

$$-(1 + r_{t+1}) s_t^i = -G(\hat{\xi}_{t+1}^i)(1 + rr_t^i) s_t^i + (1 - G(\hat{\xi}_t^i)) p_{t+1}(1 + \mathbb{E}_t[\xi_{t+1}^i | \xi_{t+1}^i > \hat{\xi}_{t+1}^i]) L_t^i.$$

Plugging this condition into $\mathbb{E}_t c_{t+1}$ the objective function can be written as follows

$$\mathbb{E}_t U(c_{t+1}^i, L_t^i) = y_{t+1}^i + p_{t+1} L_t^i + (1 + r_{t+1})(y_t^i - p_t L_t^i) + v(L_t^i)$$

The household problem boils down to choosing L_t^i to maximize $\mathbb{E}_t U(c_{t+1}^i, L_t^i)$. Differentiating w.r.t L_t^i results in the first order condition and thus demand for land (??). It follows that the allocation in the model with default is equivalent to the model without default. However, now households with $\xi_t^i > \hat{\xi}_t^i$ default.

Summary

The three essays in this thesis cover topics at the intersection between Financial- and Macroeconomics.

The first chapter develops a dynamic macro-banking model, to analyze how the zero lower bound (ZLB) on deposit rates affects (optimal) banking regulation and risk taking incentives. The paper builds on micro-founded banking theory and takes this to a dynamic macro setting, in which stochastic variation in household discount factors generate exogenous variation in interest rates over time. Three core results emerge. First, the ZLB can induce banks to “search for yield” and increase risk taking incentives, due to its adverse effect on interest margins and profitability. Second, exactly during times when risk taking incentives are heightened, the ZLB can make capital requirements less effective in curbing those incentives. The reason is that tight capital requirements disproportionately undermine bank franchise values when the ZLB hinders banks from passing on the cost of capital to depositors. Third, these two effects have implications for optimal capital requirements, which optimally vary with the level of interest rates. The model thus delivers a novel rationale for adjusting capital requirements over the cycle, and highlights a novel interaction between monetary- and prudential policies.

The second and third chapters center around the question how recent technological advances affect firm financial policies and the wider macro-economy as a whole. Advances in ICT technology since the 1980s have had a major effect on the kind of products firms produce, and the inputs they use. In the past, production largely required tangible inputs such as factories and machinery, whereas digital technologies, R&D, organizational structure, high-skill human capital and other intangible assets dominate the production process of modern firms.

The second chapter shows how this technological revolution affects corporate financing, payout and employee compensation. While it has long been recognized that intangibles do not serve as collateral, the new insight is that human capital co-invests in intangible assets and becomes part of the firm’s capital structure. Intangible-intensive firms may

thus have lower investment outlays, while needing to promise more future cashflows to high-skill employees. As human capital is risk-averse, this provides a rationale to insure employees by implementing a conservative financial policy, even for firms that are not at the risk of becoming financially constrained. Intangible-intensive firms may also favor repurchases over dividends as a form of payout. All these patterns hold in a large sample of U.S. public companies in the Compustat database, controlling for observable differences between those firms. Intangible-intensive firms have lower leverage and hold more cash, even for the subset of firms that do not appear financially constrained. These firms also issue more deferred equity to employees, repurchase more shares and pay less dividends.

The third chapter builds a long-run overlapping generations growth model to analyze the aggregate implications of the rise of intangibles. As intangibles grow in importance over time, high-skill, innovative employees become major claimants on future cash flows, and firms raise less financing for investment overall. As a result, the aggregate supply of investable assets falls as intangibles grow in importance of time. The general equilibrium effect is a gradual fall in interest rates and while savings are redirected to other fixed asset such as real estate and stocks, pushing up their valuation. The concomitant rise in house prices and wage inequality leads to higher mortgage demand by households , pushing up leverage and mortgage default risk over time. A key result from the model is that these trends can only be the result of a strongly redistributive productivity shift from tangible and low-skill labor towards intangibles and high-skill labor. Intuitively, only a drop in demand can explain both a drop in the quantity and price (the interest rate) of physical investment and external financing raised by firms. Thus, physical capital must have become less productive over time at the technological frontier.

Samenvatting

De drie essays in dit proefschrift behandelen onderwerpen op het kruispunt van financiële economie en macroeconomie.

Het eerste hoofdstuk ontwikkelt een dynamisch macro-bancair model, en analyseert hoe de zero lower bound (ZLB) van depositorente invloed heeft op (optimale) bankregulering en stimulansen voor het nemen van risico's. Het artikel bouwt voort op microgefundeerde bancaire theorieën en past dit toe op een dynamische macro-omgeving, waarin stochastische variaties in gezinskortingsfactoren exogene variatie in rentepercentages in de loop van de tijd genereren. Er zijn drie kernresultaten. Ten eerste kan de ZLB banken ertoe aanzetten om "te zoeken naar rendement" en de risicobereidheid vergroten, vanwege het negatieve effect op de rentemarges en de winstgevendheid. Ten tweede kan de ZLB, juist in tijden waarin de risicobereidheid wordt verhoogd, kapitaalvereisten minder effectief maken om die prikkels te beteugelen. Dit komt door dat strenge kapitaalvereisten onevenredig de bankfranchise ondermijnen wanneer de ZLB banken belemmert om de kapitaalkosten door te storten naar rekeninghouders. Ten derde hebben deze twee effecten implicaties voor optimale kapitaalvereisten, die optimaal variëren met het niveau van de rentetarieven. Het model levert dus een nieuwe beweegreden voor het aanpassen van kapitaalvereisten gedurende de cyclus, en benadrukt een nieuwe interactie tussen monetair en bedrijfseconomisch beleid.

Het tweede en derde hoofdstuk concentreren zich op de vraag hoe recente technologische ontwikkelingen van invloed zijn op het financiële beleid van bedrijven en de bredere macro-economie als geheel. Vooruitgang in ICT-technologie sinds de jaren tachtig heeft een groot effect gehad op het soort producten dat bedrijven produceren en op de inputs die zij gebruiken. In het verleden vereiste de productie grotendeels materiële inputs zoals fabrieken en machines, terwijl digitale technologieën, R&D, organisatiestructuur, hoog gekwalificeerd menselijk kapitaal en andere immateriële activa het productieproces van moderne bedrijven domineren.

Het tweede hoofdstuk laat zien hoe deze technologische revolutie de bedrijfsfinancier-

ing, uitbetaling en werknemerscompensatie beïnvloedt. Hoewel er al lang wordt erkend dat immateriële activa niet als onderpand dienen, is het nieuwe inzicht dat het menselijk kapitaal mede-investeert in immateriële activa en onderdeel wordt van de kapitaalstructuur van de onderneming. Immaterieel-intensieve bedrijven kunnen dus lagere investeringsuitgaven hebben, terwijl ze meer toekomstige cashflows aan hooggekwalificeerde werknemers moeten beloven. Omdat menselijk kapitaal risicomijdend is, biedt dit een reden om werknemers te verzekeren door een conservatief financieel beleid te voeren, zelfs voor bedrijven die niet het risico lopen om financieel begrensd te worden. Immaterieel-intensieve bedrijven kunnen ook de voorkeur geven aan terugkoop over het uitgeven van dividend om te voorkomen dat niet-gedekte claims worden verwaterd. Deze patronen bevatten een groot panel van Amerikaanse openbare bedrijven in de Compustat-database, wanneer er aangepast wordt op waarneembare kenmerken. Immaterieel-intensieve bedrijven hebben een lagere leverage en houden meer contanten aan, zelfs voor het gedeelte van bedrijven die niet financieel beperkt lijken te zijn. Deze bedrijven geven ook meer uitgesteld vermogen uit aan werknemers, kopen meer aandelen in en betalen minder dividenden.

Het derde hoofdstuk bouwt een langetermijn-groei-model op basis van overlappende generaties om de geaggregeerde implicaties van de opkomst van immateriële activa te bestuderen. Omdat immateriële activa in de loop van de tijd steeds belangrijker worden, worden hooggekwalificeerde, innovatieve werknemers belangrijke claimgerechtigden op toekomstige kasstromen en trekken bedrijven minder financiering aan voor investeringen in het algemeen. Als gevolg hiervan daalt het totale aanbod van publieke belegbare activa. Het algemene evenwichtseffect is een geleidelijke daling van de rentetarieven, terwijl de besparingen worden doorgestuurd om de waardering van andere vaste activa op te drijven, zoals onroerend goed en aandelen. Wat betreft arbeid komt technologische vooruitgang ten goede aan hooggeschoolde werknemers en gaat ten koste van laaggeschoolde arbeid. De daarmee gepaard gaande stijging van de huizenprijzen en loonongelijkheid leidt tot een hogere hypotheekvraag van huishoudens, waardoor leverage en het hypothecaire debiteurenrisico in de loop van de tijd omhoog gaat. Een belangrijk resultaat van het model is dat deze trends alleen het resultaat kunnen zijn van een sterk herverdelende productiviteitsverschuiving van tastbare en laaggeschoolde arbeid naar immateriële en hooggeschoolde arbeid. Intuïtief kan alleen de dalende vraag zowel een daling in de hoeveelheid en prijs (de rentevoet) van fysieke investeringen en externe financiering aangetrokken door bedrijven verklaren. Het fysieke kapitaal moet dus in de loop van de tijd aan de technologische grens minder productief zijn geworden.

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