Rising Intangible Capital, Shrinking Debt Capacity and the US Corporate Savings Glut*

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Abstract

This paper explores the hypothesis that the rise in intangible capital is a fundamental driver of the secular trend in US corporate cash holdings over the last decades. Using a new measure, we show that intangible capital is the most important firm-level determinant of corporate cash holdings. Our measure accounts for almost as much of the secular increase in cash since the 1980s as all other determinants together. We then develop a new dynamic dynamic model of corporate cash holdings with two types of productive assets, tangible and intangible capital. Since only tangible capital can be pledged as collateral, a shift toward greater reliance on intangible capital shrinks the debt capacity of firms and leads them to optimally hold more cash in order to preserve financial flexibility. In the model, firms with growth options tend to hold more cash in anticipation of (S,s)-type adjustments in physical capital because they want to avoid raising costly external finance. We show that this mechanism is quantitatively important, as our model generates cash holdings that are up to an order of magnitude higher than the standard benchmark and in line with their empirical averages for the last two decades. Overall, our results suggest that technological change has contributed significantly to recent changes in corporate liquidity management.

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1 Introduction

Public corporations in the US have steadily increased their cash holdings over the last decades. This dramatic trend in corporate liquidity management is an actively debated issue that has attracted wide attention in the popular press, with commentators dubbing it the "corporate saving glut," expressing concerns it might hamper growth of the US economy, and even raising calls to heavily tax corporate savings. Yet, understanding which fundamental economic determinants drive the secular trend in corporate cash holdings and why corporations now hold almost three times as much cash as they used to in the 1970s[1] represents a big outstanding challenge for both empirical and theoretical research in corporate finance.

In particular, on the empirical side, existing evidence on the determinants of the secular trend in corporate cash holdings is at best mixed. Several explanations have been put forth such as, for example, agency conflicts between managers and shareholders, or precautionary motives in the face of uncertainty (Bates, Kahle, and Stulz [2006]). However, these standard cross-sectional determinants of corporate cash holdings have been relatively stable over time and, thus, can offer at best only a partial explanation of why cash holdings have risen so much over time. On the theory side, the cash to asset ratios predicted by standard calibrations of existing models are much smaller than their empirical counterparts (Riddick and Whited [2009]). Thus, the current high levels of cash represent a quantitative puzzle for existing theories.

In this paper, we explore whether firms' growing reliance on intangible capital in their production can help address both the empirical and the theoretical challenges. Intangible capital cannot be easily verified or liquidated and, as such, cannot be pledged as collateral to raise debt financing. Under frictional capital markets where external funds command substantial premiums, we argue that its rising importance as an input of production may have boosted firms' precautionary demand for cash in order to insure that they have sufficient liquidity to weather adverse shocks and to exploit investment opportunities. We document a number of new stylized facts which support this "collateral channel" and suggest a strong empirical link between the rise in intangible capital and the secular trend in corporate cash holdings.

We start by documenting the stylized facts of the link between the rise in intangible capital and the secular trend in corporate cash holdings. To that end, we build on Corrado, Hulten, and Sichel [2009] and Corrado and Hulten [2010] to construct a new comprehensive firm-level measure of intangible capital for all non-financial firms in Compustat between 1970 and 2010.[2] Our measure is defined as the sum of three main components: the stock of information technology (IT) capital; the stock of innovative (R&D) capital; and the stock of human and organizational capital. The stock of innovative capital is constructed by capitalizing R&D expenditures using a standard perpetual inventory method (e.g., Hall [2001]), while the stock of human and organizational capital capitalizes

[1] Survey evidence from CFOs confirms that liquidity management tools such as cash are essential components of a firm's financial policy (Lins, Servaes, and Tufano [2010], Campello, Giambona, Graham, and Harvey [2011]).

[2] Existing attempts at measuring intangible capital have been mostly at the aggregate level. For example, one approach is to construct a proxy using aggregate stock market or accounting data (Hall [2001], McGrattan and Prescott [2007]).

a fraction of SG&A expenditures.[3] IT capital is constructed capitalizing expenditures in computer software from BEA.

Using this firm-level measure, we document several new empirical regularities. There is a strong positive relation between intangible capital and corporate cash both in the cross-section and in the time-series, with intangible capital emerging as the most important firm-level determinant of cash holdings robustly across different specifications and out-of-sample forecasting excercises. Intangible capital does not affect only cash levels, but also the adjustment dynamics of cash and the relation between corporate investment and cash holdings. Finally, the link between cash and intangible capital is especially strong for firms that are financially constrained and those that belong to industries with greater investment inflexibility. Overall, our empirical results suggest that intangible capital has a pervasive impact on corporate cash holding decisions and that the impact is due to both financial and real frictions.

In order to better understand the economic forces that drive the empirical link between intangible capital, cash holdings, and corporate investment, we next develop a new dynamic model of financing, risk management, and capital accumulation. The model is cast in an infinite-horizon, discrete-time stochastic environment, where firms make value maximizing investment decisions in real (tangible and intangible) and financial (cash holdings, debt, and equity) assets. There are two key frictions: first, financial frictions including collateral constraint, imperfect pledgeability of intangible capital and costly equity financing; second, real frictions associated with non-convex adjustment costs and (partial) irreversibility of investment, which make adjustment of capital stock infrequent and lumpy (see Abel and Eberly [1994]).

In this setting, we show that the interplay of the financial and non-convex/irreversible investment frictions generates a quantitatively large precautionary demand for cash hoarding because the combination makes it difficult to generate funds by either divesting real assets or raising external finance.[4] Intangible assets further boost this precautionary demand for cash by shrinking debt capacity through a tightening of the collateral constraint. As a result, firms with growth options tend to hold more cash in anticipation of (S,s)-type adjustments in physical capital to avoid raising costly external finance. Using simulations based on a stadard calibration, we show that a technological transformation that increases firms' reliance on intangible assets to levels that match their empirical counterparts in the US economy for the last decade leads to levels of corporate cash holdings that are roughly in line with U.S. data for the same period.[5]

Our results are complementary to those by Karabarbounis and Neiman [2012] who explore the

[3]Lev and Radhakrishnan [2005] and Eisfeldt and Papanikolaou [2013] use related measures of organizational capital. Bloom and Reenen [2007] show evidence that one type of organizational capital, managerial practices, matters for firm performance.

[4]See Bolton, Chen, and Wang [2009], and Riddick and Whited [2009] for related settings, which abstract from debt and capital heterogeneity; Froot, Scharfstein, and Stein [1993] for a seminal model of liquidity management

[5]This finding is robust across equilibrium setting. Falato, Kadyrzhanova, and Sim [2013] shows the same results, but in a stationary general equilibrium model calibrated to U.S. economy. In addition, Falato, Kadyrzhanova, and Sim [2013] shows that the model endogenously generates a large shift of corporations' and households' balance sheets toward switching their roles as net-savers, which is also in line with the data.

link with the rise in the labor share.[6] There are also recent studies by Bolton, Chen, and Wang [2013], Eisfeldt and Muir [2012] and Warusawitharana and Whited [2012], which focus on the short-run fluctuation of cash hoarding associated with equity market timing. Our contribution is to offer a quantitative explanation of the long-run secular trend in corporate savings, which remains challenging even in a setting with equity market timing. Our study also contributes to the small but growing literature on corporate savings (e.g., Bolton, Chen, and Wang [2009], Riddick and Whited [2009], Gamba and Triantis [2008], Hugonnier, Malamud, and Morellec [2013], and Anderson and Carverhill [2012]) by showing that a richer production-side is key to improve the quantitative performance of this class of models.

2 Intangible Capital, Financial Friction and the Rise of Cash

2.1 Measuring Intangible Capital

The main hurdle with measuring intangible capital is that, since investments in intangible assets are expensed in the year in which they are incurred, the capital that is created by such investments is not reported on firm balance sheets.[7] To overcome this problem, we use annual data to construct a firm-level measure of intangible capital. To that end, we retrieve standard accounting data from Compustat to assemble a large panel of 18,535 US corporations over the 1970 to 2010 period (176,877 firm-year observations).[8]

We define intangible capital as the sum of knowledge capital, organizational capital and informational capital. Knowlege capital is measured by capitalizing R&D spending data. This is consistent with the new approach of BEA. Organizational capital is based on capitalization of SG&A expenditure. These investments enhance the value of brand names and other knowledge embedded in firm-specific human and structural resources and include employee training costs, payments to management and strategy consultants, and distribution systems. Since SG&A expenditures include other expenses unrelated to investments in organizational capabilities, we follow Corrado, Hulten, and Sichel [2009] and only weigh the stock of organizational capital by 0.2.[9] Finally, informational capital is constructed by capitalizing the expenditures on computerized information and software. Since these expenses are not reported at the firm level, we use the annual (2-SIC) industry level BEA Fixed Reproducible Tangible Wealth (FRTW) data. We then construct

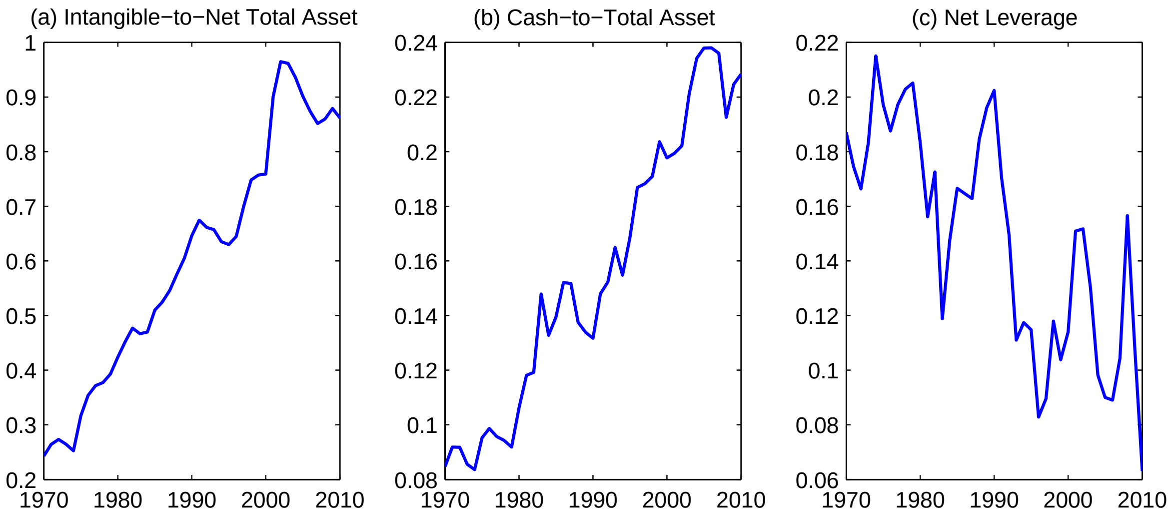
[6]In our model, an increase in capital share also leads to an increase in cash hoarding as in Karabarbounis and Neiman [2012]. However, we did not follow this route since we have found that the the elasticity of profit function with respect to capital of U.S. Compustat firms, which is an increasing function of capital income share, but a decreasing function of market power, has been stable over time since 1970s. This suggests a possibility that there might have been a secular trend in the market share, which offsets the influence of increasing capital income share on the elasticity, leaving the incentive to hold cash through this channel intact on average.

[7]Corrado, Hulten, and Sichel (2005) estimate that roughly $1 trillion of intangible investment is excluded from NIPAs annually over the period 2000 to 2003.

[8]As is standard in the literature, we exclude financial firms (SIC codes 6000-6999), regulated utilities (SIC codes 4900-4999), and firms with missing or non-positive book value of assets and sales in a given year.

[9]In robustness analysis we have explored alternative weights in a wide (+/- 50%) range, which leave our results qualitatively unchanged.

Figure 1: Intangible Capital, Cash Hoardings and Leverage



Note: Panel (a), (b) and (c) show intangible capital ratio relative to total (tangible) assets, cash-to-total (tangible) assets and net-debt-to-total (tangible) assets, respectively. The sample includes all Compustat firm-year observations from 1970 to 2010 with positive values for the book value of total assets and sales revenue for firms incorporated in the United States. Financial firms (SIC code 6000-6999) and utilities (SIC codes 4900-4999) are excluded from the sample, yielding a panel of 176,877 observations for 18,535 unique firms. Variable definitions are provided in the Appendix.

a multiple of this stock to tangible capital stock at the industry level and apply the multiple to each firm's tangible capital stock (PPE) to derive a firm-level stock.[10]

To capitalize these expenditures, we use the perpetual inventory method with the depreciation rates of 15% for R&D (Hall, Jaffe, and Trajtenberg [2000]), 20% for SG&A (Lev and Radhakrishnan [2005], Eisfeldt and Papanikolaou [2013]); 31% for information and software following BEA. Our resulting estimate for average intangible to tangible capital over the last decade is close to 1, which is comparable to the estimate in Corrado, Hulten, and Sichel [2009] based on aggregate NIPA accounts.

2.2 Intangible Capital and Corporate Saving: Stylized Facts

We begin our analysis by summarizing the stylized facts of the evolution of corporate cash holdings over time. Figure 1 helps to visualize the main hypothesis of this paper: that the rising share of intangible capital in production is a fundamental driver of the secular downward trend in leverage and upward trend in corporate savings. The figure plots annual averages across firms of the ratio of intangible capital to book value of assets (left panel), of cash holdings to book assets (middle panel), and of net debt to book assets (net leverage ratio, right panel) over the last four decades. The intangible ratio rose tenfold from about 5% of net book assets in 1970 to about 60% in 2010. The share of liquid financial assets in the balance sheets of U.S. corporations has also grown from 8% to 22% over the same period, with cash holdings displaying a pronounced secular upward trend

[10]Our results are little changed if we do not include this stock in our measure of intangible capital.

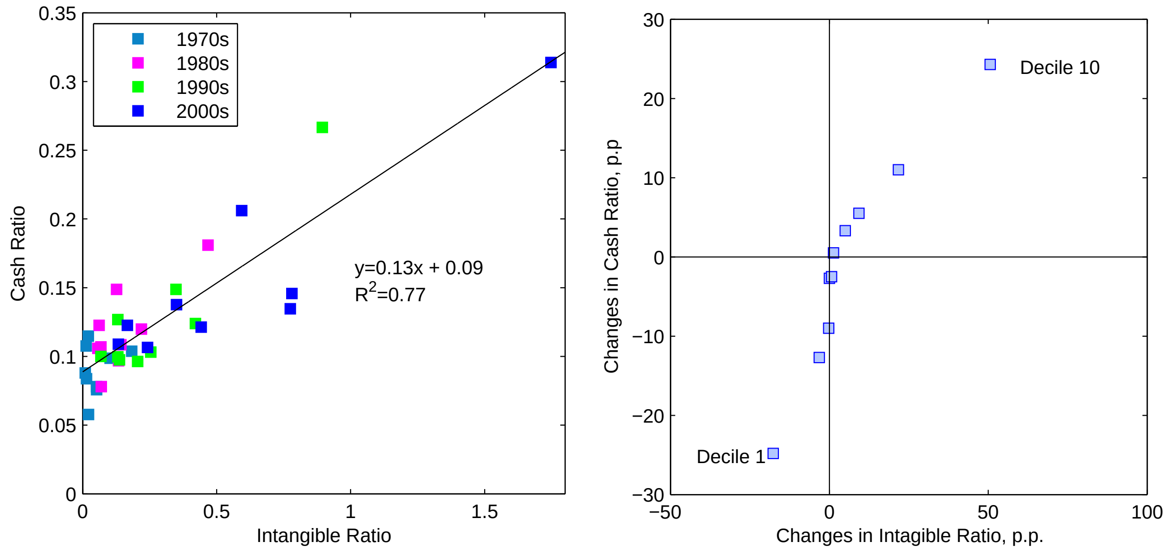
Table 1: Stylized Facts on Intangible Capital, Firm Financing, and Corporate Investment

	Firm Financing				Investment & Firm Dynamics: Difference Between Cash Rich and Cash Strapped Firms			
Panel A: Time-Series Stylized Facts, by Decade								
	Cash		Net Debt		Investment		Sales Growth	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
1970s	0.09	0.05	0.18	0.19	0.04	0.02	0.03	0.02
1980s	0.13	0.06	0.15	0.17	0.07	0.04	0.07	0.06
1990s	0.17	0.07	0.11	0.14	0.08	0.05	0.08	0.08
2000s	0.21	0.11	0.05	0.06	0.06	0.03	0.05	0.05
Panel B: Cross-sectional Stylized Facts, by Quartile of Intangible Capital								
	Cash		Net Debt		Investment		Sales Growth	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Intangible Capital, Q1	0.08	0.04	0.28	0.29	0.04	0.03	0.05	0.05
Intangible Capital, Q2	0.10	0.05	0.20	0.21	0.04	0.03	0.07	0.06
Intangible Capital, Q3	0.13	0.08	0.10	0.11	0.05	0.03	0.09	0.07
Intangible Capital, Q4	0.23	0.12	-0.07	-0.10	0.13	0.06	0.11	0.08
Panel C: Time-Series Stylized Facts for Innovative Firms (R&D>0)								
	Cash		Net Debt		Investment		Sales Growth	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
1970s	0.09	0.05	0.16	0.18	0.04	0.02	0.04	0.03
1980s	0.15	0.07	0.10	0.12	0.08	0.04	0.08	0.07
1990s	0.21	0.11	0.01	0.04	0.09	0.05	0.10	0.09
2000s	0.27	0.19	-0.06	-0.06	0.07	0.03	0.06	0.05
Panel D: Cross-sectional Stylized Facts for Innovative Firms (R&D>0)								
	Cash		Net Debt		Investment		Sales Growth	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Intangible Capital, Q1	0.08	0.04	0.26	0.27	0.03	0.02	0.06	0.06
Intangible Capital, Q2	0.10	0.05	0.18	0.20	0.04	0.02	0.08	0.07
Intangible Capital, Q3	0.14	0.08	0.08	0.10	0.05	0.03	0.10	0.08
Intangible Capital, Q4	0.31	0.23	-0.10	-0.14	0.14	0.06	0.12	0.09

Note: a. The table reports means and medians for various sub-samples of all US nonfinancial firms (excluding Utilities) in Compustat from 1970 to 2010 [176,877 observations for 18,535 unique firms]. b. Firm financing facts refer to cash (ratio of the sum of cash and short-term marketable securities to book assets) and net debt (ratio of total debt net of cash holding to book assets). Investment and firm dynamics facts refer to total investment (the ratio of the sum of capital expenditures and R&D to net book assets) and sales growth (annual change in log sales). The reported figures are mean and median differences between cash rich and cash strapped firms, which are defined as those firms in the top and bottom quartiles of the distribution of year-prior cash holdings, respectively. c. Panels A and C report time-series evidence by decades for the entire sample and the sub-sample of firms that report positive R&D, respectively. Panels B and D report cross-sectional sorts based on intangible capital, which is defined as the sum of stocks of past investments in firms' organizational capabilities, brand equity, and technological knowledge (R&D); it is normalized by net book assets. d. Detailed variable definitions are provided in the Appendix.

which was not concentrated in any particular decade, but rather has been steady; third, despite the cycles over medium-run, the net leverage ratio of U.S. corporations has trended down from 20% to 6% over the same period, and appears to be cointegrated with the cash ratio with a coefficient

Figure 2: Changes in Intangible Capital and Cash: Cross-Industry, Cross-Firm Variations



Note: The sample includes all Compustat firm-year observations from 1970 to 2010 with positive values for the book value of total assets and sales revenue for firms incorporated in the United States. Financial firms (SIC code 6000-6999) and utilities (SIC codes 4900-4999) are excluded from the sample, yielding a panel of 176,877 observations for 18,535 unique firms. Variable definitions are provided in the Appendix.

-1. Panels A and C of Table 1 show averages (and medians) by decades of the cash ratio and net leverage for the entire sample and for the sub-sample of firms that invest in R&D. The increase in cash holdings is even stronger for these firms, suggesting that the secular trend in average cash is not an artifact of these firms becoming more heavily represented. For instance, mean (median) cash holdings ratio for these firms have increased from 9% (5%) to 27 (19%) for the same period, which is 6ppt (8ppt) more than the total sample. Next, we now turn to cross-industry and cross-firm univariate evidence. The left panel of Figure 2 plots the distribution of average industry cash and intangible ratios by decades. Intangible capital ratios have steadily risen in all broad industry categories (12-Fama and French) over the last four decades, consistent with an economy-wide shift in firms' mode of production that affected firms well beyond just high-tech sectors.[11] While the increase has been more dramatic in some industries (e.g., by a factor of almost 40, from 0.13 to 5.07, in Healthcare), the intangible ratio went up by a factor of 10 (from 0.01 to 0.13) even in traditional industries such as retail (Shops). There is a strong correlation between intangible capital and cash ratios over time by industry, with a regression coefficient of about 0.13 and an R^2 of more than 75%.

Moving on to cross-firm variation, we compute for each firm the change in average intangible capital ratio before and after 1990 and divide the sample into deciles according to these firm-level

[11]In additional graphical analysis, we have divided the sample into terciles each year by size and age, high-tech and other sectors, and incumbent and entrant firms. This analysis shows that the secular trend in cash has not been confined to any particular subset of firms and, thus, has been an economy-wide development.

changes in intangible capital. The right panel of Figure 2 plots the corresponding average change in cash ratios before and after 1990 for each decile of the distribution of firm-level changes in intangible capital. Firms in the lower deciles have declines in intangible capital, while firms in the top deciles correspond to the largest increases. Changes in cash line up quite well along the diagonal, with firms that experienced a decline in intangible capital also seeing their cash ratios decline, while firms for which intangible capital rose the most also experiencing the greatest increases in cash.

Panels B and D of Table 1 show additional univariate evidence on cross-firm variation by stratifying the sample into four subsamples, based on quartiles of the empirical distribution of intangible capital and showing the average (and median) cash and net leverage ratios for each of these quartiles for the entire sample and for the sub-sample of firms that invest in R&D, respectively. Mean (median) cash ratios strongly and monotonically increase from about 8% (4%) in the bottom quartile of intangible capital to about 23% (12%) in the top quartile. The univariate relation between cash and intangible capital is even stronger when we restrict the sample to exclude firms that do not report R&D, with mean (median) cash ratios now going up to about 31% (23%) in the top quartile. Finally, the columns to the right show that firms in the top quartile of intangible capital are also those for which cash matters the most to finance growth opportunities, as especially in this top quartile cash rich firms have on average been investing relatively more and growing faster.

To formalize the graphical evidences documented above, we regress cash holdings and net leverage ratios on our measure of intangible capital, while controlling for a set of standard determinants of cash holdings (e.g., Opler, Pinkowitz, Stulz, and Williamson [1999] and Bates, Kahle, and Stulz [2006]). In particular, we consider two specifications, OLS and fixed effects[12], with firm-level controls such as industry cash flow volatility, market-to-book ratio, firm size, cash flow, capital expenditures, (cash) acquisitions expenditures, and a dummy for whether the firm pays dividend in any given year, as well as year effects to control aggregate factors.[13] We evaluate statistical significance using robust clustered standard errors adjusted for non-independence of observations within firms.

The resulting estimates are reported in Panel A of Table 2 for the overall sample (Columns (1)-(4)) and for the subset of firms that report positive R&D (Columns (5)-(8)), to address the concern that the overall sample may reflect spurious differences in average cash holdings between non-innovative vs. innovative firms.[14] The coefficient on intangible capital is robustly positive and statistically significant across the two samples and both specifications.[15]

[12]Although the time dimension of our sample is long (40 years), the panel is unbalanced. In order to reduce the "within groups bias" on explanatory variables, we exclude firms with less than five years of data. For the fixed-effects specification we report the within-group R^2.

[13]See Appendix C for detailed variable definitions.

[14]The results are robust to median regressions that address the concern that outliers firm-year observations with very high levels of cash may be driving the OLS estimates, as well as OLS estimates for a specification in changes, rather then levels. Detailed coefficient estimates for the control variables are reported in Appendix D.

[15]Signs and statistical significance of coefficients on control variables are also unchanged across specifications and are in line with the findings of the previous literature, with large firms and firms that pay dividends holding less cash, and firms with higher cash flow volatility and market-to-book holding more. The coefficients on capital expenditures and acquisitions are negative and significant, consistent with firms using their cash holdings to pursue investment opportunities. See Appendix D for a complete summary of estimation results.

Table 2: Panel Evidence on Intangible Capital and Firm Financing

	Whole Sample				R&D>0 Firms			
Panel A: Intangible Capital, Cash, and Net Indebtness								
	Cash		Net Debt		Cash		Net Debt	
	OLS	FE	OLS	FE	OLS	FE	OLS	FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intangible	0.086***	0.061***	-0.111***	-0.047***	0.104***	0.067***	-0.125***	-0.067***
Capital_{t-1}	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
% Pred rise	42.5%				43.4%			
Pred rise	0.069				0.075			
Year effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.299	0.665	0.235	0.602	0.340	0.689	0.240	0.601
Panel B: Cash Dynamics By Quartiles of Intangible Capital								
		OLS	FE	GMM		OLS	FE	GMM
		(1)	(2)	(3)		(4)	(5)	(6)
Q1, SOA		0.463***	0.721***	0.557***		0.527***	0.748***	0.729***
Half-life		[1.1]	[0.5]	[0.9]		[0.9]	[0.5]	[0.5]
Q2, SOA		0.350***	0.631***	0.512***		0.381***	0.643***	0.550***
Half-life		[1.6]	[0.7]	[1.0]		[1.4]	[0.7]	[0.9]
Q3, SOA		0.266***	0.526***	0.348***		0.300***	0.537***	0.331***
Half-life		[2.2]	[0.9]	[1.6]		[1.9]	[0.9]	[1.7]
Q4, SOA		0.210***	0.424***	0.294***		0.225***	0.431***	0.319***
Half-life		[2.9]	[1.3]	[2.0]		[2.7]	[1.2]	[1.8]

Note: a. The sample consists of all US nonfinancial firms in Compustat from 1970 to 2010. b. Panel A reports estimates from panel regressions of cash holdings to book assets and net debt to book assets on intangible capital for OLS and firm fixed effects specifications. Reported coefficients are the change in the dependent variable associated with a one-standard deviation change in intangible capital. Columns (1)-(4) and (5)-(8) are for the entire sample and for the subsample of firms with positive R&D, respectively. c. Panel B reports estimates of the speed of adjustment (SOA) of cash for different sub-samples based on quartiles of the distribution of intangible capital. This specification adds a lagged dependent variable (first lag of cash) to the same set of explanatory variables as in Panel A: $Cash_{it}$ = a0+ (1-a)$Cash_{it-1}$ +βX_{it-1} + e_{it}. We report etimates of OLS regressions analogous to Fama and French (2002) (Columns (1) and (4)), OLS regressions with firm fixed effects analogous to Flannery and Rangan (2006) (Columns (2) and (5)), GMM estimates based on Blundell and Bond (1998) (Columns (3) and (6)). Speed of adjustment is a. Cash half-life is the time (in years) that it takes a firm to adjust back to the target cash after a one-unit shock to e, ln(0.5)/ln(1 - a). d. Year dummies as well as firm-level controls for standard determinants of financial policies are included in all regressions. p-values are in parentheses and are clustered at the firm level. e. Predicted change in cash due to change in a determinant is obtained by taking the point estimates from the OLS regression estimated over the 1970-1989 period and multiplying them by the difference in average value of each determinant between the estimation (1970-1989) and the post-estimation 2000-2010 period. f. Detailed variable definitions are in the Appendix.

Intangible capital is also economically significant. For example, for the baseline OLS specification in Column (1), one standard deviation increase in intangible capital is associated with about 8.5% increase in the cash ratio, which is equal to about half the sample mean value of the cash ratio of 15%. In the specification with firm fixed effects (Column (2)), the estimates decline by only about 2.5%, suggesting that intangible capital is also an economically significant determinant of the within-firm time-series evolution of cash holdings. Estimates for firms with R&D are even larger than those for the entire sample, suggesting that the OLS result is not spurious and that intangible capital is an even more important determinant of cash holdings for innovative firms.

When we replicate our tests for net leverage, which is the ratio of total debt net of cash to book assets, the coefficient on intangible capital is robustly negative and statistically significant across both samples and specifications. It is also economically significant. For example, for the baseline OLS specification in Column (3), one standard deviation increase in intangible capital is associated with about 11 % decrease in net leverage ratio, which is almost as large as the sample mean value of net leverage of 14%. These results suggest that intangible capital is not only an important determinant of firms' cash holdings decisions, but also of their capital structure.[16]

2.3 The Role of Financial and Real Frictions

To better understand why intangible capital is an economically important determinant of corporate cash holdings, we use sample-split analysis. In particular, we examine both financial and real investment frictions, which are the key ingredients of our model. If firms with more intangible capital hold more cash because of financing frictions, we would expect that the relation between intangible and cash should be stronger among firms for which financing frictions are more severe. As for investment frictions, the basic insight of the vast literature on real options (e.g., Abel and Eberly [1994], Bertola and Caballero [1994]) is that fixed adjustment costs lead firms to make large, lumpy investments. Thus, if intangible capital makes it more difficult to raise external finance, these real frictions may lead firms with more intangible capital to accumulate even more cash to finance their large investments.

Panel A of Table 3 shows evidence supporting the role of financial frictions. We follow the standard approach in the literature (e.g., Hennessy and Whited [2007]) and in every year over the sample period we rank firms based on five ex-ante indicators of their financial constraint status, which include firm size, dividend payer status, the WW-Index by Whited and Wu [2006], a measure of asset liquidity by Berger, Ofek, and Swary [1996], and an index of industry asset redeployability by Balasubramanian and Sivadasan [2009]. We assign to the financially constrained (unconstrained) groups those firms in the bottom (top) quartile of the annual distribution of each of these measures in turn, except for the financial constraints index, for which the ordering is reversed. Consistently across specifications and irrespective of which indicator of ex-ante financing status is chosen, we find that the economic significance of the coefficient on intangible capital is much stronger in the sub-samples of firms that are more likely to face financial frictions. For example, the coefficient in Column (1) more than triples when we go from the top to the bottom quartile of the size distribution (Rows [1] and [2]).

[16] In additional checks, we have verified that these results are robust to controlling for R&D expenditures (flow), to using different definitions of cash ratios (cash as a ratio to market value of assets or net book assets), and to excluding entrants (i.e., firms that are not present in every year of the sample period) and firms in high technology sectors.

Table 3: Why does Intangible Capital Matter? Panel Evidence on Financial andReal Frictions

		Panel A: Financial Frictions						*Panel B: Real Frictions*			
		Whole Sample		R&D>0 Firms				Whole Sample		R&D>0 Firms	
		OLS	FE	OLS	FE			OLS	FE	OLS	FE
		(1)	(2)	(3)	(4)			(5)	(6)	(7)	(8)
By Firm Size						By Industry Frequency of Investment Inaction					
[1]	Q1	0.102	0.112	0.120	0.120	[1]	Q1	0.024	0.031	0.030	0.036
		(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)
[2]	Q4	0.030	0.028	0.037	0.039	[2]	Q4	0.137	0.112	0.162	0.133
		(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)
By Dividend Payer Status						By Investment Spikes in the Industry					
[3]	No	0.100	0.075	0.124	0.090	[3]	No	0.049	0.048	0.061	0.049
		(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)
[4]	Yes	0.028	0.034	0.033	0.035	[4]	Yes	0.095	0.079	0.120	0.081
		(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)
By WW-Index						By Time-Series Skewness of Industry Investment					
[5]	Q4	0.104	0.090	0.126	0.107	[5]	Q1	0.044	0.043	0.060	0.047
		(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)
[6]	Q1	0.055	0.050	0.065	0.058	[6]	Q4	0.100	0.079	0.145	0.104
		(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)
By Asset Liquidation Value						By Time-Series Kurtosis of Industry Investment					
[7]	Q1	0.145	0.109	0.152	0.115	[7]	Q1	0.048	0.046	0.065	0.051
		(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)
[8]	Q4	0.051	0.049	0.059	0.054	[8]	Q4	0.092	0.078	0.133	0.093
		(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)
By Degree of Asset Redeployability						By Time-Series Variability of Operating Costs					
[9]	Q1	0.199	0.126	0.207	0.132	[9]	Q4	0.038	0.040	0.054	0.050
		(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)
[10]	Q4	0.062	0.048	0.084	0.059	[10]	Q1	0.102	0.080	0.133	0.096
		(0.000)	(0.000)	(0.000)	(0.000)			(0.000)	(0.000)	(0.000)	(0.000)

Note: a. The sample consists of all US nonfinancial firms in Compustat from 1970 to 2010. The table reports parameter estimates from panel regressions of cash holdings to book assets on intangible capital for several subsample splits based on ex-ante proxies for the severity of financial (Panel A) and investment (Panel B) frictions faced by firms. b. Reported coefficients are the change in the dependent variable associated with a one-standard deviation change in intangible capital, which is defined as the sum of stocks of past investments in firms' organizational capabilities, brand equity, and technological knowledge (R&D) normalized by net book assets. c. Columns (1)-(2) and (5)-(6) report results for the whole sample, while Columns (3)-(4) and (7)-(8) are for the subsample of firms that report positive R&D. For each of the two samples, we report estimates of OLS regressions and regresssions with firm fixed effects. Controls are as in Table 2. d. In Panel A, the sample is split between bottom and top quartiles of (year-prior) values of: firm size (Rows [1] to [2]), Whited and Wu (2006) WW-Index (Rows [5] to [6]), Berger et al. (1996) asset liquidation value (Rows [7] to [8]), and Balasubramanian and Sivadasan (2009) index of industry asset redeployability (Rows [9] to [10]), and by dividend payer status (Rows [3] to [4]). p-values clustered at the firm level are in parentheses. e. In Panel B, the sample is split between bottom and top quartiles of: (4-SIC) industry frequency of investment inaction - $|\text{Capex/book assets}| < 01$ (Rows [1] to [2]), and whether in the industry there are investment spikes - $|\text{Capex/book assets}| > 2$ (Rows [3] to [4]), all based on Cooper and Haltiwanger (2006); time-series skewness (Rows [5] to [6]) and kurtosis (Rows [7] to [8]) of annual aggregate industry investment (Capex/book assets), based on Caballero (1999); and the time-series standard deviation of aggregate industry operating costs (Rows [9] to [10]). f. Variable definitions are in the Appendix.

Panel B splits the sample between bottom and top quartiles of the following five (time-invariant) proxies of investment frictions: (4-SIC) industry frequency of investment inaction and an indicator for whether there are investment spikes in the industry, which are both defined following Cooper and Haltiwanger [2006]; the skewness and kurtosis of annual aggregate industry investment, both based on Caballero [1999]; and the standard deviation of aggregate industry operating costs. The intuition underling these proxies is that, due to technological differences, the extent to which firms face fixed costs varies across industries. Thus, industries where fixed cost are higher are those where firms are more likely to adjust investment infrequently, and, conditional on adjusting, by a proportionally larger amount. In addition, in these industries fixed costs lead to a time-series distribution of aggregate investment that is sharply right-skewed and fat-tailed. Thus, we assign to the high (low) investment friction groups those firms in the top (bottom) quartile of the distribution of each of these measures in turn, except for the variability of operating costs, for which the ordering is reversed. Consistently across specifications and irrespective of the indicator chosen, the economic significance of the coefficient on intangible capital is much stronger in the sub-samples of firms that are more likely to face investment frictions. For example, the OLS coefficient in Column (1) about doubles for firms that are in industries with investment spikes compared to those without such spikes (Rows [3] and [4]).

3 A Structural Model of Corporate Cash Management

This section develops a dynamic model of corporate risk management in which illiquidity of productive assets and financial market frictions interact with each other to determine firms' optimal liquidity management policy.

3.1 Technology

We assume that a firm combine two types of capital to produce output, tangible (K_T) and intangible (K_N). In particular, the the profit function of the firm is given by

$$\Pi(Z, \boldsymbol{K}) = Z^{1-\gamma} \Phi(\boldsymbol{K})^{\gamma} \tag{1}$$

where $\boldsymbol{K} \equiv [K_T \ K_N]'$, the vector of capital inputs, Z is a technology shock, following a Markov process, γ is the curvature of the profit function, which reflects either the degree of decreasing returns to scale (DRS) or the market power of the firm, and $\Phi(\boldsymbol{K})$ is a capital aggregator that combines the capital services of the two types of capital. In particular, we assume a constant elasticity of substitution (CES),

$$\Phi(\boldsymbol{K}) = \left[\theta\left(\frac{K_T}{\theta}\right)^{-\rho} + (1-\theta)\left(\frac{K_N}{1-\theta}\right)^{-\rho}\right]^{-1/\rho}. \tag{2}$$

The elasticity of substitution is given by $1/(1+\rho)$. In the special case of $\rho = \infty$, the CES aggregator is equivalent to a Leontief function, $\min\{K_T/\theta, K_N/(1-\theta)\}$. In this special case, $K_T/\theta = K_N/(1-$

$\theta) \equiv K$, and hence the profit function is simply given by $\Pi(Z, K) = Z^{1-\gamma} K^{\gamma}$.

To motivate firms' cash holdings, it is necessary, although not sufficient, to introduce the illiquidity of capital assets. For this reason, we assume that all capital expenditures are only partially reversible (Abel and Eberly [1994]). We denote initial purchase prices and liquidation values by p_i^+ and p_i^- for $i = T, N$. The partial irreversibility can be formally expressed as $0 \le p_i^- \le p_i^+$. In addition, we also assume that adjustment of capital is costly in either direction because it involves fixed costs of adjustment (interchangeably, non-convex adjustment costs), F_i^K for $i = T, N$. Combining the assumptions about capital illiquidity, we can express the adjustment cost as

$$G(\boldsymbol{K'}, \boldsymbol{K}) = \sum_{i=T,N} G_i(K_i', K_i) \tag{3}$$

where the type specific adjustment cost function is given by

$$G_i(K_i', K_i) = P_i(K_i', K_i)[K_i' - (1-\delta_i)K_i] + F_i^K K_i \tag{4}$$

and the price of capital function $P_i(K_i', K_i)$ is defined as

$$P_i(K_i', K_i) \equiv \begin{cases} p_i^+ & \text{if} \quad K_i' - (1-\delta_i)K_i \ge 0 \\ p_i^- & \text{if} \quad K_i' - (1-\delta_i)K_i < 0 \end{cases} \tag{5}$$

where δ_i is the type specific depreciation rate of capital. As indicated by (4), we assume that the fixed costs of adjustment are proportional to the size of the capital stock in place. Note that the definition of adjustment cost includes the fixed cost of adjustment always. However this does not imply that the firm has to pay the fixed cost regardless of its action/inaction status since the adjustment cost, as will be the case below, enters the definition of dividend multiplied by a decision variable $\nu_i^K \in \{0, 1\}$. This convention follows Abel and Eberly [1994].

3.2 Financing Frictions

Firms have three financing options: (i) internal funds, including operating income and cash holdings; (ii) debt financing; and (iii) equity issuance. We consider capital market frictions that make the capital structure of the firm deviate from the Modigliani-Miller theorem.

3.2.1 Debt Market Friction

It is well-established in the literature that capital assets of more tangible quality support more debt (see Shleifer and Vishny [1992], Hart and Moore [1994] and Rampini and Viswanathan [2010] for theoretical arguments, and Sibilkov [2009] for empirical evidence). This is because intangible capital, by its very own nature, is difficult to verify in quality or quantity. In fact, it often embodies the human capital of developers, which cannot be easily transferred to a third entity in its entirety. As a consequence, intangible capital is rarely pledged as collateral in debt contracts. To capture this feature, we assume that the firm cannot commit to transfer the technology embodied in the intangible capital stock to creditors upon default. Since embodied human capital cannot be transferred, intangible capital cannot be liquidated for a positive value by a third party.[17]

Furthermore, in the spirit of Hart and Moore [1994], we assume that the firm's output is observable, but not verifiable by a court. Hence, no debt contract can be written on the outcome of the firm's output. Under this circumstance, as shown by Kiyotaki and Moore [1997], the only possible form of debt contract is a risk-free debt contract collateralized by capital assets. We differ from Kiyotaki and Moore [1997] however in that we introduce intangible capital in production and assume that only tangible capital assets constitute eligible collateral.[18] The resulting risk-free debt contract is subject to the following borrowing constraint:

$$B' \leq \bar{B}(K_T'; p_T^-) \equiv p_T^- \frac{(1-\delta_T)K_T'}{1+r(1-\tau_I)} \tag{6}$$

where r is a risk free interest rate and τ_I is the tax rate on interest income. The assumption that intangible assets cannot be used as collateral is also broadly factual. Using a large sample of syndicated loans to US corporations for which a detailed breakdown of type of collateral used is available, we have verified that contractual loan terms state that only assets that can be easily valued represent eligible collateral.[19] Consistent with the legal definition of eligible collateral, only an extremely small minority of secured syndicated loans (about 3% of total loan value) have patents or brands used as collateral.[20]

For later reference, we define the financial slack of the firm as $\bar{B}(K_T'; p_T^-) - B'$. A natural interpretation of $\bar{B}(K_T'; p_T^-)$ is *collateralized line of credit* arrangement. Note that the constraint is an occasionally binding one. Financial slack can be decomposed into two parts as follows:

$$\bar{B}(K_T'; p_T^-) - B' \;=\; \underbrace{\bar{B}(K_T'; p_T^-) \;-\; \underbrace{\max\{0, B'\}}_{\text{Debt}}}_{\text{Unused line of credit}} \;+\; \underbrace{[-\min\{0, B'\}]}_{\text{Cash}}. \tag{7}$$

[17]However, we allow the firm to have downsizing option, i.e., the firm can partially liquidate intangible capital stock by incurring the liquidation cost $1 - p_N^-$. An implicit assumption is that the firm, as long as it operates as a going concern, can commit itself to deliver the human capital to the entity that is obtaining the liquidated part of intangible capital.

[18]Rampini and Viswanathan [2013] recently developed a model of investment, capital structure and risk management in a similar setting in which only tangible capital works as collateral asset. However, we differ from Rampini and Viswanathan [2013] in that they consider a state contingent contract based on the realized cash flow. In our setting, we assume that the debt contract cannot be contingent upon the realized cash flow for both realism and greater precautionary savings.

[19]Using an additional data source, Capital IQ, which covers a smaller cross-section of firms (about 1,000 per year) and a shorter time-series (2002-2010) but has detailed information on firm debt structure, we have verified that the median ratio of secured to total debt value is about 80%. We also find a similar pattern in the loan information from a 2011 extract of Loan Pricing Corporation's (LPC) Dealscan database, which consists of dollar-denominated private loans made by bank (e.g., commercial and investment) and nonbank (e.g., insurance companies and pension funds) lenders to U.S. corporations during the period 1981 to 2010, which includes about 90,000 loans. Most of the loans in this dataset are senior secured claims, features common to commercial loans. However, a detailed brakedown of collateral types is available for only 20,000 loans.

[20]Our measure of intangible capital does not include patents or brands for this reason. We consider them as a part of tangible capital stock.

The second term on the right-hand side can be interpreted as debt while the last term as cash. The difference between the first and the second term is equivalent to the unused line of credit.

In our stylized setting, the same firm never holds debt and cash at the same time. In the case when a firm finds it optimal to have strictly positive cash balances, the firm's financial (liquidity) facility is composed of two terms: option to borrow up to the debt capacity given by $\bar{B}(K'_T; p_T^-)$ and the cash holdings given by $-\min\{0, B'\}$. When the firm finds it optimal to carry debt, the firm's remaining liquidity facility is given by $\bar{B}(K'_T; p_T^-) - \max\{0, B'\}$, the unused line of credit.

3.2.2 Equity Market Friction

If there were no equity market frictions, the debt market friction would play no role since the firm could undo it at no cost by issuing new equity. Thus, to create scope for active risk management policies, we assume that equity finance is costly in that raising outside equity reduces the value of existing shareholders more than the notional amount of equity issuance (See Myers and Majluf [1984] and Cooley and Quadrini [2001]). We capture the loss to existing shareholders using a "dilution" function, $\varphi(E)$:

$$\varphi(E) \equiv \varphi_0 \sum_{i=T,K} p_i^+ K_i + \varphi_1 \cdot \max\{0, E\}. \tag{8}$$

In words, the firm incurs fixed costs (φ_0) when issuing new equity, which are proportional to its size measured by the book value of capital assets.[21] In addition, the firm also incurs linear costs (φ_1) that are proportional to the amount issued. This specification is standard in the literature and facilitates comparison with the results of Bolton, Chen, and Wang [2009], who show that fixed costs of equity issuance significantly strengthen firms' precautionary demand for cash.

3.3 Value Maximization Problem

To define the value maximization problem of the firm, we introduce a notation, $\boldsymbol{\nu} \equiv (\nu_T^K, \nu_N^K, \nu^E) \in \{0,1\}^3$, a Cartesian product. ν_T^K, ν_N^K, and ν^E indicate the action/inaction status of the firm regarding the adjustment of tangible and intangible capital and equity issuance. For instance $\boldsymbol{\nu} = (1,1,1)$ implies that the firm's gross investments of tangible and intangible capital are nonzero and the firm finances its expenditure at least partially by issuing new shares. For later use, we also define $\boldsymbol{\nu}^K \equiv (\nu_T^K, \nu_N^K) \in \{0,1\}^2$. The flow of funds constraint facing the firm can be expressed as

$$D = (1-\tau_C)\left[\Pi(Z, \boldsymbol{K}) - ZF^O\right] - \sum_{i=T,N} \left[\nu_i^K G_i(K'_i, K_i) - \tau_C \delta_i K_i\right] - [1 + r(B)]B + B' + E \tag{9}$$

[21]Here again, we let the fixed component be included in the dilution cost regardless of the firm's financial action/inaction status in terms of equity issuance. This is not only innocuous because the dilution cost enters the flow of funds constraint of the firm with a decision variable $\nu^E \in \{0,1\}$, but also convenient for later discussion.

where D denotes the dividends payout under the finance/investment regime $\boldsymbol{\nu}$, τ_C is a flat rate of corporate income tax.[22] We allow B' to be negative, in which case B' is interpreted as investment in liquid assets (cash accumulation). We assume that the interest income tax rate, τ_I is lower than the corporate income tax rate, τ_C, which creates scope for the firm to accumulate debt. We also assume that when the firm invest in liquid assets – i.e., when it accumulates cash, it earns a return that is strictly less than risk-free after-tax return, $r(1-\tau_I)-\kappa$. We interpret κ as agency cost of cash holdings.[23] Hence, after-tax interest rate can be expressed as

$$r(B) = \begin{cases} r(1-\tau_C) & \text{if } B \geq 0 \\ r(1-\tau_I)-\kappa & \text{if } B < 0 \end{cases} \tag{10}$$

Despite the tax advantage of debt, the firm may optimally choose to hold cash. In order to preserve tractability, we do not introduce frictions, such as transaction costs, that make frequent refinancing of debt costly. These frictions may lead the firm to *simultaneously* hold debt and liquid assets, an issue that is not central to the task of explaining the low frequency movement of cash.[24]

The firm problem can then be defined recursively as the maximization of the value of equity,

$$W(\boldsymbol{K}, B, Z) = \max_{\boldsymbol{\nu}\in\{0,1\}^3} \{W(\boldsymbol{K}, B, Z|\boldsymbol{\nu})\} \tag{11}$$

where the conditional value function $W(\boldsymbol{K}, B, Z|\boldsymbol{\nu})$ is defined as

$$\begin{aligned} W(\boldsymbol{K}, B, Z|\boldsymbol{\nu}) \;=\; & \min_{\lambda,\psi} \max_{E,\boldsymbol{K}',B'} \Bigg\{ D(\boldsymbol{\nu}^K) + \frac{1}{1+r(1-\tau_I)} \int W(\boldsymbol{K}', B', Z') Q(Z, dZ') \\ & - [E + \nu^E \varphi(E)] + \lambda D(\boldsymbol{\nu}^K) + \mu \left[\frac{p_T^-(1-\delta_T)}{1+r(1-\tau_C)} K_T' - B' \right] \Bigg\} \\ & \text{s.t. (3), (8), (9) and (10),} \end{aligned} \tag{12}$$

$Q(Z, dZ')$ is the transitional function of the Markov process Z, and λ and μ are the Lagrangian multipliers associated with the nonnegativity constraint for dividends and the collateralized borrowing constraint, respectively. In particular, the former can be interpreted as the shadow value of internal funds. Regarding the shock process, we assume that Z follows a geometric random walk,

$$\log Z' = \log Z + \eta, \quad \eta \sim N(0.5\sigma^2, \sigma^2). \tag{13}$$

We denote the cumulative distribution function of η by $H(\eta)$ below.

[22] For simplicity, we assume no dividend taxation.

[23] The same assumption is made by Bolton, Chen, and Wang [2009].

[24] Technically, to consider this case we would need to introduce an additional state variable. As pointed out in the earlier section, cash and net leverage are cointegrated with a coefficient close to -1 despite short run deviation from each other.

3.3.1 Homogeneity

It can be easily shown that the objective function and the constraint correspondents of problem (12) are jointly homogenous of degree 1 in (K_T, K_N, B, K_T, K_N, B, K'_T, K'_N, B', Z).[25] The homogeneity then implies that $W(\boldsymbol{K}, B, Z)/Z = W(\boldsymbol{K}/Z, B/Z, 1) \equiv w(\boldsymbol{k}, b)$ where $\boldsymbol{k} \equiv [k_T \; k_N]' = [K_T/Z \; K_N/Z]'$ and $b \equiv B/Z$. We define a series of normalized variables: $e \equiv E/Z$, $\tilde{b}' \equiv B'/Z$, $\tilde{k}'_i \equiv K'_i/Z$. It is then straightforward to show that the problems (12) and (11) are equivalent to

$$w(\boldsymbol{k}, b) = \max_{\boldsymbol{\nu} \in \{0,1\}^3} \{w(\boldsymbol{k}, b|\boldsymbol{\nu})\} \tag{14}$$

where

$$\begin{aligned} w(\boldsymbol{k}, b|\boldsymbol{\nu}) \;\; &= \;\; \min_{\lambda,\mu} \max_{e,\tilde{\boldsymbol{k}}',\tilde{b}'} \left\{ d(\boldsymbol{\nu}^K) + \frac{1}{1 + r(1-\tau_I)} \int \eta' w(\tilde{\boldsymbol{k}}'/\eta', \tilde{b}'/\eta') dH(\eta') \right. \\ &\left. - [e + \nu^E \varphi(e)] + \lambda d(\boldsymbol{\nu}^K) + \mu \left[\frac{p_T^-(1-\delta_T)}{1 + r(1-\tau_C)} \tilde{k}'_T - \tilde{b}' \right] \right\}, \end{aligned} \tag{15}$$

$$d(\boldsymbol{\nu}^K) = (1-\tau_C)\left[\Phi(\boldsymbol{k})^\gamma - F^O\right] - \sum_{i=T,N} [\nu_i^K g_i(\tilde{k}'_i, k_i) - \tau_C \delta_i k_i] - [1 + r(b)]b + \tilde{b}' + e, \tag{16}$$

and

$$g_i(\tilde{k}'_i, k_i) \equiv P_i(\tilde{k}'_i, k_i)[\tilde{k}'_i - (1-\delta_i)k_i] + F_i^K \quad \text{for} \quad i = T, N. \tag{17}$$

3.3.2 Efficiency Conditions

Payout and Equity Issuance If $\nu^E = 1$, i.e., $w(\boldsymbol{k}, b|\nu^E = 1) - w(\boldsymbol{k}, b|\nu^E = 0) \geq 0$, the first order condition for equity issuance is given by

$$1 + \lambda = 1 + \varphi'(e) = 1 + \varphi_1 > 1. \tag{18}$$

This condition states that the firm issues new shares to finance its expenditure *only if* its value of internal funds exceeds 1. It also implies that the firm's shadow value of internal funds is bounded above by $1 + \varphi_1$ as it faces unlimited supply of external funds at the marginal price φ_1. However, the converse of this proposition is not true: the efficiency condition (18) does not establish the optimality of $\nu^E = 1$. In other words, even when the firm finds its shadow value of internal funds exceeding 1, it may be still optimal to delay the issuance. This is a direct consequence of the fixed cost of equity finance. It is not enough that the marginal value of $w(\boldsymbol{k}, b|\nu^E = 1)$ is improved with the issuance. The value $w(\boldsymbol{k}, b|\nu^E = 1)$ must be improved sufficiently to compensate for the foregone fixed cost of issuance such that $w(\boldsymbol{k}, b|\nu^E = 1) - w(\boldsymbol{k}, b|\nu^E = 0) \geq 0$.

[25]More specifically, the profit function (1), the capital aggregator (2), the adjustment costs of capital (3), the collateralized debt constraint (6) and finally, the equity dilution cost function (8) satisfy this property.

Debt and Cash Accumulation The efficiency condition regarding $\tilde{b}'$ is given by

$$1 + \lambda - \mu = q^F(\tilde{\boldsymbol{k}}', \tilde{b}') \tag{19}$$

where

$$q^F(\tilde{\boldsymbol{k}}', \tilde{b}') \equiv -\frac{1}{1 + r(1 - \tau_I)} \int w_b(\tilde{\boldsymbol{k}}'/\eta', \tilde{b}'/\eta') dH(\eta'). \tag{20}$$

$q^F(\tilde{\boldsymbol{k}}', \tilde{b}')$ measures the marginal value of saving through either decreasing the firm's stock of debt or accumulating liquid assets. When the firm does not issue debt and hold a strictly positive amount of cash, this is essentially equivalent to what Bolton, Chen, and Wang [2009] called marginal value of cash. However, since we allow debt issuance subject to the occasionally binding collateral constraint (6), $q^F(\tilde{\boldsymbol{k}}', \tilde{b}')$ deviates from the marginal value of cash. This is one reason why cash may not be equivalent to negative debt.

The Benveniste-Scheinkman's formula implies $w_b(\boldsymbol{k}, b|\boldsymbol{\nu}) = -(1 + \lambda)[1 + r(b)]$ regardless of $\boldsymbol{\nu}$. Hence, $w_b(\boldsymbol{k}, b) = -(1 + \lambda)[1 + r(b)]$. We can then express the first order condition as

$$1 + \lambda - \mu = \frac{1 + r(1 - \tau_C)}{1 + r(1 - \tau_I)} \int (1 + \lambda') dH(\eta') \quad \text{if } \tilde{b}' \geq 0 \tag{21}$$

and

$$1 + \lambda = \frac{1 + r(1 - \tau_I) - \kappa}{1 + r(1 - \tau_I)} \int (1 + \lambda') dH(\eta') \quad \text{if } \tilde{b}' < 0 \tag{22}$$

where we use the fact that the collateral constraint is a slack, i.e., $\mu = 0$ when $\tilde{b}' < 0$.

Consider (21) first. Suppose that the firm issues new shares today. In this case $1 + \lambda = 1 + \varphi_1$. Since $1 + \lambda' \leq 1 + \varphi_1$, $1 + \lambda > \int (1 + \lambda') dH(\eta')$. Furthermore, $[1 + r(1 - \tau_C)]/[1 + r(1 - \tau_I)] < 1$. Hence, it must be the case that the collateral constraint binds, $\mu > 0$. This means that the firm never issues shares before it uses up its borrowing capacity.[26]

Now consider (22). Again suppose that the firm issues new shares today. Since $1 + \lambda > \int (1 + \lambda') dH(\eta')$ and $[1 + r(1 - \tau_I) - \kappa]/[1 + r(1 - \tau_I)] < 1$, the condition (22) cannot be satisfied. This means that the firm never simultaneously issue shares and accumulate liquid assets. This holds even when the cost of holding liquidity is zero as long as there is a strictly positive probability of $1 + \lambda' = 1$.

Now suppose that the firm does not issue new shares. With the presence of the fixed cost of issuance, this assumption does not necessarily imply that $\lambda = 0$ as mentioned earlier. However, for the sake of argument, suppose that the firm's liquidity condition is indeed good enough such that $\lambda = 0$ today and the left hand side of (22) is equal to 1. This means that the firm pays out a strictly positive amount of dividends to shareholders. Since $\int (1 + \lambda') dH(\eta') \geq 1$, the condition (22) cannot be met without $\kappa > 0$. If $\kappa = 0$ in this situation, the marginal benefit of holding liquid asset, the right hand side of (22), is too large relative to the marginal cost, the left hand side, and the firm may want to hold indefinite amount liquid assets on its balance sheet.

[26] This argument does not depend on the differential tax treatment debt.

Tangible and Intangible Investments To derive the efficiency conditions for tangible and intangible capital, we closely follow Abel and Eberly [1994]'s approach. However, we show how the financial friction in the model interacts with the real friction (see Gilchrist, Sim, and Zakrajsek [2014] for a similar approach, but in the context of unsecured debt contract rather than secured debt contract as in the current context). We first derive the efficiency condition for tangible investment and then applies the steps used for tangible investment to intangible investment. As in Abel and Eberly [1994], we proceed as if $\nu_T^K = 1$ were optimal, and derive the efficiency condition that would be optimal under this assumption. To that end, we define the marginal value of tangible capital[27]:

$$q_T^K(\tilde{\boldsymbol{k}}', \tilde{b}') \equiv \frac{1}{1 + r(1 - \tau_I)} \int w_{k_T}(\tilde{\boldsymbol{k}}'/\eta', \tilde{b}'/\eta') dH(\eta') \tag{23}$$

If there were no non-convex/irreversible investment frictions, one could derive the efficiency conditions as

$$(1 + \lambda) g_{T,1}(\tilde{k}_T', k_T) - \mu \frac{p_T^-(1 - \delta_T)}{1 + r(1 - \tau_C)} = q_T^K(\tilde{\boldsymbol{k}}', \tilde{b}')$$

where $g_{T,1}(\tilde{k}_T', k_T)$ is the derivative of $g_T(\cdot, \cdot)$ with respect to the first argument.

In practice, however, the above condition may not lead to optimal investments because the firm may find it optimal to delay (dis)investment due to the non-convex adjustment costs and the partial irreversibility. To take into account this possibility, we define the left- and right-hand side derivatives of $q_T^K(\tilde{\boldsymbol{k}}', \tilde{b}')$ evaluated at $\tilde{k}_T' = (1 - \delta)k_T$:

$$q_T^{K-} = \lim_{\tilde{k}_T' \uparrow (1-\delta)k_T} \left[(1 + \lambda) g_{T,1}(\tilde{k}_T', k_T) - \mu \frac{p_T^-(1 - \delta_T)}{1 + r(1 - \tau_C)} \right] \tag{24}$$

and

$$q_T^{K+} = \lim_{\tilde{k}_T' \downarrow (1-\delta)k_T} \left[(1 + \lambda) g_{T,1}(\tilde{k}_T', k_T) - \mu \frac{p_T^-(1 - \delta_T)}{1 + r(1 - \tau_C)} \right] \tag{25}$$

We can then state the optimality condition for tangible investment in the following way. The optimal choice for $\tilde{k}_T'$ satisfies

$$g_{T,1}(\tilde{k}_T', k_T) = \frac{1}{1 + \lambda} \left[\mu \frac{p_T^-(1 - \delta_T)}{1 + r(1 - \tau_C)} + q_T^K(\tilde{\boldsymbol{k}}', \tilde{b}') \right] \tag{26}$$

if $q_T^K((1 - \delta_T)k_T, \tilde{k}_N', \tilde{b}') \notin [q_T^{K-}, q_T^{K+}]$. Otherwise, $\tilde{k}_T' = (1 - \delta_T)k_T$ is optimal.

To get intuition behind (26), consider the case without financial friction. In this case, $\lambda = \mu = 0$. Also note that in contrast to Abel and Eberly [1994], we assume that $g_T(\tilde{k}_T', k_T)$ do not include a convex adjustment cost, which, under the assumption of frictionless financial market, implies that

[27] While $w_{k_T}(\tilde{\boldsymbol{k}}'/\eta', \tilde{b}'/\eta')$is discontinuous due to the non-convex adjustment costs, $q_T^K(\tilde{\boldsymbol{k}}', \tilde{b}')$ is well defined nontheless since the discontinuity occurs finite times.

$q_T^{K-} = p_T^-$ and $q_T^{K+} = p_T^+$. In this environment, the condition (26) is equivalent to

$$\begin{aligned} p_T^+ &= q_T^K(\tilde{\boldsymbol{k}}', \tilde{b}') && \text{if } q_T^K((1-\delta_T)k_T, \tilde{k}'_N, \tilde{b}') > p_T^+ \\ p_T^- &= q_T^K(\tilde{\boldsymbol{k}}', \tilde{b}') && \text{if } q_T^K((1-\delta_T)k_T, \tilde{k}'_N, \tilde{b}') < p_T^- \\ \tilde{k}'_T &= (1-\delta_T)k_T && \text{if } p_T^- \le q_T^K((1-\delta_T)k_T, \tilde{k}'_N, \tilde{b}') \le p_T^+ \end{aligned} \tag{27}$$

The (27) implies the followings: if the marginal value of tangible capital evaluated at $(1-\delta_T)k_T$ is strictly greater than the purchase price of capital, the firm should increase its investment until the marginal value of tangible capital falls to the level of its purchase price; if the marginal value of tangible capital evaluated at $(1-\delta_T)k_T$ is strictly less than the liquidation value, the firm should liquidate the capital until the marginal value of tangible capital rises to the level of its liquidation value; if none of these conditions are met, the firm should do nothing. If there were no non-convex adjustment costs, this would be a necessary and sufficient condition of optimality. However, with the presence of the non-convex adjustment costs, (27) is only a necessary condition. The optimality also requires $w(\boldsymbol{k}, b|\nu_T^K = 1) - w(\boldsymbol{k}, b|\nu_T^K = 0) \ge 0$. This last condition expands the inaction region in q_T^K space, $[q_T^{K-}, q_T^{K+}]$ since the condition requires a large enough gain from (dis)investment to warrant an action.

Comparing (26) and (27) show how the financial market friction modifies the optimality condition characterizing the neoclassical problem. The left-hand side of (26) measures the marginal cost of investment and the right-hand side measures the marginal benefit of investment. First, and most importantly, (26) modifies the neoclassical efficiency condition by discounting the marginal benefit of investment more by the current liquidity condition, $1+\lambda$. It is in this sense that today's liquidity problem raises the required return on equity, and thus providing an explanation as to "why the stock market value falls more than in proportion to corporate profit during recessions" (see Hall [2014]). Second, under the occasionally binding collateral constraint, investing in tangible capital benefits the firm not only by increasing future profits, but also by expanding its debt capacity, the benefit of which is measured by the shadow value μ. This second aspect is irrelevant for intangible capital, which has an important implication for the accumulation of intangible capital.[28]

In a symmetric manner, we define the marginal value of intangible capital as

$$q_N^K(\tilde{\boldsymbol{k}}', \tilde{b}') \equiv \frac{1}{1+r(1-\tau_I)} \int w_{k_N}(\tilde{\boldsymbol{k}}'/\eta', \tilde{b}'/\eta') dH(\eta') \tag{28}$$

Following the same steps, one can derive the efficiency condition for intangible capital as

$$g_{N,1}(\tilde{k}'_N, k_N) = \frac{1}{1+\lambda} q_N^K(\tilde{\boldsymbol{k}}', \tilde{b}') \tag{29}$$

[28] Another way of looking at how the financial friction in the model affects the (S,s)-type adjustment is to consider the effects on the action/inaction boundaries in Tobin's marginal q space, (24) and (25). It can be seen that the liqudity problem as measured by λ increase both investment and disinvestment boundaries in q space. This, if $q_T^K(\tilde{\boldsymbol{k}}', \tilde{b}')$ can be shown to be non-increasing in $\tilde{k}'_T$, implies underaccumulation of capital with the financial friction. It can also be seen that the shadow value of collateral constraint decreases the action/inaction boundaries in q space, and implying overaccumulation of capital through this channel.

if $q_N^K(\tilde{k}'_T, (1-\delta_N)k_N, \tilde{b}') \notin [q_N^{K-}, q_N^{K+}]$ where

$$q_N^{K-} = \lim_{\tilde{k}'_N \uparrow (1-\delta)k_N} (1+\lambda) g_{N,1}(\tilde{k}'_N, k_N) \tag{30}$$

and

$$q_N^{K+} = \lim_{\tilde{k}'_N \downarrow (1-\delta)k_N} (1+\lambda) g_{N,1}(\tilde{k}'_N, k_N). \tag{31}$$

Otherwise, $\tilde{k}'_N = (1-\delta_N)k_N$ is optimal. Again, the optimality requires $w(\boldsymbol{k}, b|\nu_N^K = 1) - w(\boldsymbol{k}, b|\nu_N^K = 0) \geq 0$.

An important difference between (26) and (29) is the lack of the benefit of exapanding debt-capacity in the case of intangible capital. This means that other things being equal, the firm finds an optimal tangible-to-intangible capital ratio above the technological efficiency level $\theta/(1-\theta)$ implied by (2) as the firm strikes a balance between the loss of technologial efficiency due to overinvesting in tangible assets and the gains from the financial flexibility provided by the pledgeability of tangible assets. However, our simulation results indicate that this effect is small, and θ in fact determines the central tendency of tangible capital ration in the long-run. Technological changes that lower θ induces the firm to rebalance its real investment strategy toward a greater share of intangible assets. In contrast to tangible capital, which creates a greater scope for debt financing, intangible capital can be expanded only through cash accumulation. It also exposes the firm to a greater liqudity risk since neither can it be liquidated nor be pledged for external financing. The current paper is an attempt to quantify the effect of the technological change over the last 40 years on the firms' liquidity management.

3.4 A Special Case: Leontief

Before we move on to the simulation results, it is useful to consider a polar case of $\rho = \infty$. This case is useful as it provides us with the maximum intuition. In this limiting case, (2) becomes a Leontief function:

$$\Phi(\boldsymbol{k}) = \min\left\{\frac{k_T}{\theta}, \frac{k_N}{1-\theta}\right\}. \tag{32}$$

In this case, the firm always use the two types of capital in a fixed proportion: $k_T/\theta = k_N/(1-\theta) \equiv k$. A natural interpretation of k is the *total* capital stock of the firm.[29] The profit function is simplified into $\Pi(\boldsymbol{k}) = k^\gamma$. If we further assume that the two types of capital have the same depreciation rate, we can reduce the number of state variables from three to two. (18) and (19) continue to serve as the efficiency conditions for financial policies. Only (26) and (29) need to be merged into a single efficiency condition:

$$g_1(\tilde{k}', k) = \frac{1}{1+\lambda}\left[\mu \frac{p_T^- \theta(1-\delta)}{1+r(1-\tau_C)} + q^K(\tilde{k}', \tilde{b}')\right] \tag{33}$$

[29] Indeed, if we assume $p_T^+ = p_N^+ = p^+$, p^+k measures the book value of total capital stock. Also in this case, $g(\tilde{k}', k) = \{p^+\mathbf{1}(\tilde{k}' \geq (1-\delta)k) + [\theta p_T^- + (1-\theta)p_N^-]\mathbf{1}(\tilde{k}' \leq (1-\delta)k)\}[\tilde{k}' - (1-\delta)k)] + F^K$

with q^{K+}, q^{K-} and $q^{K}(\tilde{k}', \tilde{b}')$ defined similarly as in (24)∼(23) (or in (28)∼(31)). On the right-hand side of (33), note the presence of θ, which should now be interpreted as 'tangible share' of total capital. Only a fraction θ of total capital works as a collateral. In this case, the technological change that lowers θ has a direct consequence on the debt capacity and liquidity demand.

Figure 3 illustrates the properties of optimal liquidity holding strategy, production capacity choice, and equity issuance policy in the case of Leontief. Owing to the low dimensionality of this case, it provides us with maximum intuition. Using simulations, however, we show later that main predictions of the theory continue to hold even in the case of general CES technology. In the figure, we assume $\theta = 0.3$. Since $\tilde{k}'_T = \theta \tilde{k}'$ in this special case, (6) implies that only 30 percent of undepreciated capital stock is colletralizable at a liquidation value p^{-}, which is sitrictly less than the initial purchase price p^{+}.

To show the role of financial market friction, we consider two cases in the figure, one under the frictionless capital market (left panels) and the other under the firctional capital market (right panels). To create an environment without the financial friction, we only need to set the cost of equity finance equal to zero in the left panels: while we still impose the collateralized borrowing constraint, this, as will be shown, is neutral to the determination of the first best choice of production capacity.[30] In contrast, the right panels show the case with both equity and debt markets subject to the frictions described above.

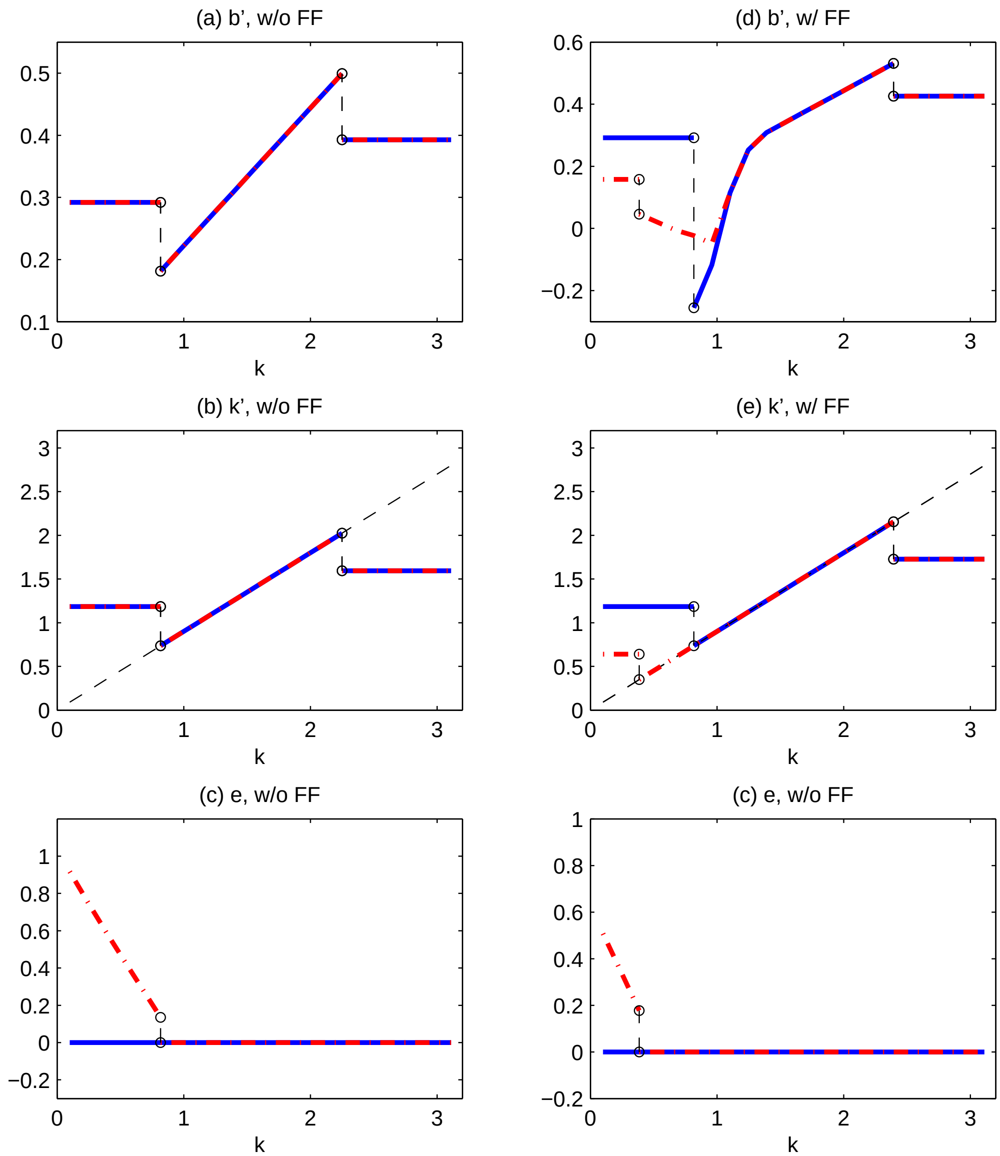
The optimal policies can be expressed as functions of current financial condition (b) and current production capacity (k), both normalized by the current technology level, i.e., $\tilde{b}' = \tilde{b}'(b, k)$, $\tilde{k}' = \tilde{k}'(b, k)$, and $e = e(b, k)$. The figure shows relationships between the current production capacity k and the optimal policies under two different financial conditions b: $b_1 = -1.0 \cdot \mathbb{E}[k]$ (blue, solid lines) and $b_2 = 0.13 \cdot \mathbb{E}[k]$ (red, dash-dotted lines), where $\mathbb{E}[k]$ denotes the mean level of total capital stock in our stochastic simulation. The first can be thought of as the case of so called *cash cow* firms whose current net leverage ratio is negative (i.e., a net creditor) and the magnitue of liquid assets on their balance sheets is as large as the book value of the mean level of capital in the model.[31] The second case is considered to match the average net leverage ratio of Compustat firms in 2014:Q1.

Comparing the top and middle left panels reveals that absent financial friction, the current financial condition measured by the net leverage ratio has no prediction at all either on financial policy or on investment policy. The two cases exactly coincide with each other, perhaps not surprisingly. The contour of the net leverage policy $\tilde{b}' = \tilde{b}'(b, k)$ closely resembles that of investment policy $\tilde{k}' = \tilde{k}'(b, k)$. This is due to the fact that absent financial friction, the firm's net leverage policy is simply to maximize the tax benefit of debt, and to use up all borrowing capacity, which is shaped by $\tilde{k}'$. If doing so results in unwanted cash inflow, the firm simply pays out the proceeds as dividends. When needed, the firm issues more debt or raises funds by issuing new equities as shown by the bottom left panel. Owing to the tax benefit, however, issuance of debt is always preferable to equity finance. When binding, the constraint (6) implies that the net debt moves in lockstep

[30] However, the colleteralized borrowing constraint still affects the value of the firm through the tax benefits.

[31] We compute this using a simulation with the size of $T = 1,000$ and $N = 10,000$. See the next section for the calibration strategy.

Figure 3: Financial Friction, Liquidity Management and Optimal Capacity



Note: Left panels are the cases without financial friction. Right panels are the cases with financial friction. Blue, solid line is the case of a firm with a large cash holding and red, dash-dotted line is the case of a firm with its net leverage set equal to that in the data.

with production capacity, and the leverage ratio never changes as long as the institutional features of the lending market remains the same.

Without the capital market friction, investment policy follows a standard (S, s) policy owing to the non-convex adjustment cost and the partial irreversibility. In the middle left panel, the black, dashed line from the origin displays the path of capital stock when the firm is in inaction mode, i.e., $\tilde{k}' = (1 - \delta)k$. There exists two distinct target capital stocks, one for expansion and the other for contraction, both of which exhibit discontinuity from the inaction line. One can imagine a situation of the firm located in the middle of the inaction line initially. Since the fundamental of the firm neither is good nor bad enough, the firm floats along the line of inaction until the capacity-technology ratio ($k = K/Z$) reaches the lower or upper threshold, at which point, (dis)investment bursts.

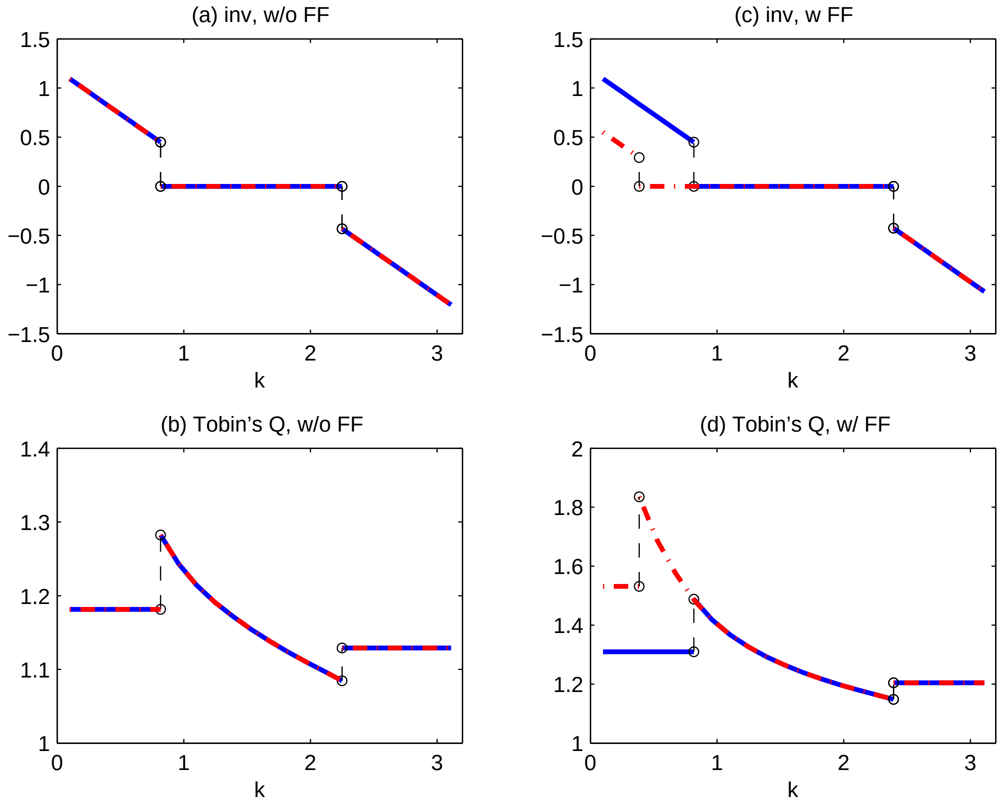
The middle right panel shows how the financial market friction modifies the properties of optimal capacity choice. In contrast to the frictionless case, the expansion targets (located in the southwest corner of the panel) crucially depend on the financial condition. When the firm has ample liquidity on its balance sheet (shown by the blue, solid line), its investment policy closely follows the frictionless case. However, when the firm's financial condition is calibrated to match the average net leverage ratio in the data, the firm delays its investment action until its capacity-technology ratio deteriorates substantially more, and chooses a much lower level of capacity as shown by the red, dash-dotted line in the middle right panel.

Accordingly, the firm's liquidity policy is importantly influenced by the current real and financial conditions. As shown by the blue, solid line in the top right panel, how the firm manages the current excess liquidity crucially depends on its anticipation of investment opportunity. When the growth opportunity is considered remote either due to excess capacity (large K) or due to low current technology, the firm's liquidity policy closely mimics that of a firm under the frictionless capital market: it disburses all excess liquidity to shareholders as dividends, and borrows up to the capacity to maximize the tax benefit. However, as the capacity depreciates or technological condition improves, with both leading to a decline in k on the horizontal axis and moving the firm closer to the expansion target, the firm starts reducing debt more than required to hold the collateral constraint binding as the production capacity (to technology ratio) shrinks. In other words, the firm starts making the borrowing constraint a slack and accumulating unused line of credit, and eventually starts saving a substantial portion of the current excess liquidity as can be in the fact that $\tilde{b}'$ becomes negative. Once the firm reaches the expansion trigger, the firm eliminates all liquid assets to invest in production capacity. In addition, it uses up the borrowing capacity to maximize the tax benefit. As can be seen in the behavior of blue, solid line of the bottom right panel, the firm in this case manages to avoid costly equity financing.

Such liquidity policy, however, cannot be followed always. Without the current excess liquidity (the case of $b = b_2$), as shown by the red, dash-dotted line of the top right panel, it can be too costly to accumulate a substantial amount of cash holdings for tomorrow ($\tilde{b}' < 0$) even when the firm anticipates the arrival of investment opportunities. In this case, the firm's liquidity policy involves stopping dividend payouts, paying down debt to keep the unused line of credit available as much as possible, and accumulating retained earnings if possible until the firm's capacity approaches the expansion trigger, at which point, the firm uses up all debt capacity and raises equity capital to finance investment expenditure provided that the marginal efficiency of investment warrants such a costly funding method, as shown by the red, dashed-dotted line of the bottom right panel. In our environment however, the firm never issues new shares to accumulate cash on the balance sheet as mentioned before.[32] Note that not only investment policy but also equity issuance policy exhibit

[32]If the cost of issuing new equities is stochastic and the firm views today's realization of the cost as particularly low,

Figure 4: Financial Friction, Nonconvex Investment and Tobin's Q



Note: Left panels are the cases without financial friction. Right panels are the cases with financial friction. Blue, solid line is the case of a firm with a large cash holding and red, dash-dotted line is the case of a firm with its net leverage set equal to that in the data.

discontinuous jump due to the non-convex cost of equity issuance. Also note that the amount of equity issuance for a given level of capacity-technology ratio is much smaller for the case with the financial friction. This is because the equity capital is much more expensive to raise by assumption, but also because such friction endogenously reduces the funding gap by reducing the target level of capital stock.

Figure 4 displays how the financial friction affects the relationship between firm's investment policy and a popular measure of firm's investment opportunity, Tobin's average Q:

$$Q(k,b) \equiv \frac{1}{1+r(1-\tau_I)} \int \frac{w(\tilde{k}'/\eta', \tilde{b}'/\eta') + [1+r(\tilde{b}'/\eta')]\tilde{b}'/\eta'}{\tilde{k}'/\eta'} dH(\eta') \tag{34}$$

where $w(k,b) + [1+r(b)]b$ is defined as the total value of the firm.[33] As in figure 3, we display the

it may issue equities and keep the proceeds on balance sheet especially when the firm considers high the probability of large expenditure on production capacity and partial reliance on new equities in near future. Such a market timing behavior does not occur in our environment since we assume a constant dilution cost. See Warusawitharana and Whited [2012] and Eisfeldt and Muir [2012] for the market timing.

[33] Note that when the firm's net leverage is negative, the total value of the firm is less than the value of equity as the firm is a creditor.

case without the financial friction on the left panels and the case with the financial friction on the right. The financial conditions on the left and right panels follow those of figure 3.

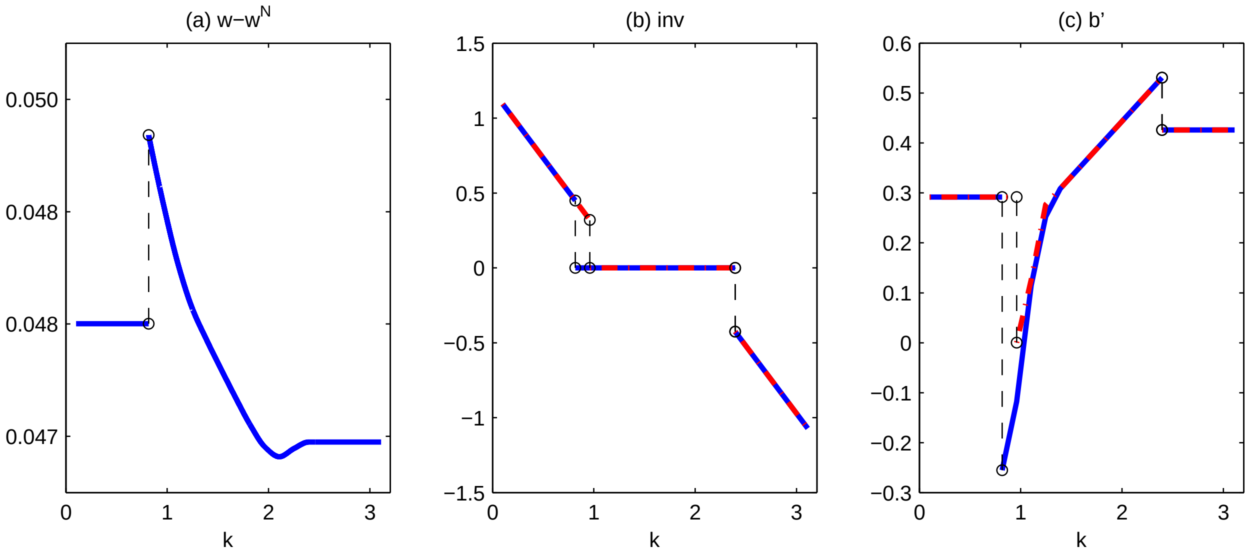
The positive relationship between the Tobin's Q and investment, or more specifically, Tobin's Q being the sufficient statistics of investment is the hallmark of neoclassical investment theory with convex adjustment friction. The lack of strong relationship between these two quantities is often interpreted as indicating the presence of financial friction in the literature (see, for instance, Fazzari, Hubbard, and Petersen [1988] and Chirinko [1993]). As can be seen in the left panels of figure 4, however, on the one hand, Tobin's Q can vary substantially with investment in a complete inaction mode (see the middle part of the figure on the horizontal axis). On the other hand, Tobin's Q can be completely unresponsive to changes in investment (see the left and righ part of the figure, where dis(investment) actions are taken occurs). In the middle of the state space shown in the horizontal axis, Tobin's Q increases in general as the productive capacity depreciates during the inaction period. This negative relationship owes itself to the concavity of the value function, a feature that deviates form the neoclassical investment theory formulated by, for instance, Hayashi [1982].

Once the firm's production capacity is reduced enough, the firm expands its capacity in bulk to its optimum capacity, at which point the Tobin's Q exhibits a large downward jump. In the opposite situation where the firm's capacity-to-technology ratio reaches the upper threshold, the Tobin's Q shows a large upward jump as the firm liquidates a large amount of production capacity. Given these large jumps up and down in investment and corresponding jumps in the Tobin's Q in the opposite directions, we expect the investment and Tobin's Q to be negatively correlated, but the strength of the correlation to be weak owing to the inaction region where the Tobin's Q continuously varies despite dormant investment activity as the capacity depreciates and the technological condition changes.

The right panels show how the financial condition under the capital market friction modifies the relationship between the investment and Tobin's Q. The blue, solid line and the red, dash-dotted line share the same investment fundamental. However, the presence of financial condition forces the firm with weak balance sheet condition to postpone investment action, exapanding the size of inaction region. This makes the link between investment and Tobin's Q even weaker, supporting the view that the presence of financial friction makes investment unresponsive to investment fundamental. By looking at the right panels of figure 4 and the top right panel of figure 3, one can see that both cash holdings and Tobin's Q rise the most near investment action point, i.e., in the part of state space where the firm anticipates the arrival of investment opportunities. Owing to the financial friction and limited debt capacity, the firm finds it costly to finance new investment projects entirely with outside funds. This precautionary saving in anticipation of investment opportunities creates a positive correlation between cash holdings and Tobin's Q. We will test this prediction below using our simulations.

Figure 5 shows how the optimal liquidity manament can increase the value of the firm. In order to quantify the effect, we re-solve the model by adding an occasionally binding nonnegativity

Figure 5: Financial Friction and the Value of Option to Hold Liquidity



Note: Left panel shows the difference between the value of equity with and without the option to invest in liquid financial assets. Blue, solid line is the case with a large cash holding and red, dash-dotted line is the case with the average net leverage in the data.

constraint on $\tilde{b}'$ and denote the firm value under this scenario by $w^N(k,b)$. Hence $w(k,b) - w^N(k,b)$ measures the willingness to pay to obtain the option to invest in financial assets when the firm faces capital market frictions. The magnitude of such increase in firm value at the investment burst episode shown in the left panel can be as big as 20 percent of the book value of tangible capital stock, and 6 percent of the book value of total capital stock in this particular example.

The middle panel compares the investment strategies under the two cases. Without the option to invest in liquid financial assets (shown by red, dash-dotted line), the firm is forced to take an investment action earlier at a lower scale than in the case with the option (blue, solid line). In contrast, the option and the resulting cash holdings (shown in the right paenl) provide the firm with a powerful hedging instrument, which allows the firm to optimize the timing and the scale of investment in an environment where the firms face non-convex, real and financial friction. The value of the option also can be thought of as the value of establishing a revolving credit facility with a lead bank, which is essentially equivalent to purchasing a right to borrow. It is not hard to imagine that the value of such option is likely to go up when the firm faces a stronger financial constraint, which may come from the reduced debt capacity of production assets. Below, we qunatify the effects of asset intangibility on the value of lquidity option and cash holding strategy using stochastic simulations in a more general environment with CES technology. We also show how the limiting case of Leontief is related with more general CES cases.

Table 4: Baseline Calibration

Description	Calibration
Technological Parameters	
Curvature of profit function	$\gamma = 0.60$
Depreciation	$\delta = 0.10$
Elasticity of substitution between capital inputs	$\rho = -0.3, 1.0, 5.0$
Purchase price of capital	$p^{+} = 1.00$
Partial irreversibility of tangible capital	$p_T^{-} = 0.95$
Partial irreversibility of intangible capital	$p_N^{-} = 0.90$
Fixed cost of adjustment	$F_i^K = 0.01$, $i = N, K$
Fixed cost of operation	$F_0^O = 0.05$
Volatility of technology shock	$\sigma_z = 0.05$
Financial Parameters	
Risk-free rate	$r = 0.06$
Agency Cost of Cash Holdings	$\kappa = 5$ bps
Fixed cost of issuance	$\varphi_0 = 0.015k^*$
Linear cost of issuance	$\varphi_1 = 0.15$
Interest rate income tax rate	$\tau_i = 0.33$
Corporate income tax rate	$\tau_c = 0.35$

Note: k^* is the steady state level of capital accumulation in a frictionless model.

4 Simulation Results

4.1 Calibration

In this paper, We choose the following calibration strategy. The elasticity of the profit function with respect to capital service (γ) is set equal to 0.6 as in previous studies (for instance, Hennessy and Whited [2007]). We set the depreciation rate equal to 0.10. We calibrate the resale value of capital as $p_T^- = 0.95$ and $p_N^- = 0.90$. These are small discounts, especially compared to 0.8 of Ramey and Shapiro [2001]. However, such a small discount is large enough to generate substantial amount of saving in liquid asset holdings. Going below this level does not affect the simulation results substantially. This is because the firm almost never finds it optimal to liquidate capital if the liquidation value is below this level. While it is possible for a firm to liquidate capital if it has implausibly large volume of capital, such state space is almost never visited by firms during actual simulation when the volatility of the model is calibrated realistically (see Veracierto [2002] on this).

To parametrize the fixed cost of investment, we follow Cooper and Haltiwanger [2006], who estimate the fixed cost of investment as about 0.01 of installed capital. In our adaptation, we set this value proportional to the steady state level of capital accumulation in the frictionless benchmark. The fixed cost of operation (F^O) is set equal to 0.05 following Gilchrist, Sim, and Zakrajsek [2014]. This value helps to match dividend payout ratio in the data given other parameters of the model. For the idiosyncratic technology shock we assume a geometric random work process with $\sigma_z = 0.05$, which is a conservative calibration that goes against our purpose because a greater volatility strengthen the precautionary demand for liquid assets. As for the tangible-to-intangible capital ratio θ, we consider a range of values for comparative statistics. We choose the range such that the model-generated tangible capital ratios cover the range seen in the data over the last 4 decades. We also consider a range of values for the parameter that determines the subsititutibility of heterogeneous capital inputs, namely, ρ from -0.3 to ∞ to study the impact of inflexibility of production technology on the demand for precautionary demand for liquid assets.

The risk free rate is calibrated as 0.06, such that the after tax annual interest rate is about 0.04. We choose the fixed cost of equity issuance to be 1.5 percent of the steady state level of capital stock in a frictionless model. This is slightly higher than in Bolton, Chen, and Wang [2009], for example. For the linear cost of equity issuance, there exists a wide range of estimates/calibrations in the literature from a low of 0.06 (Gomes [2001]) to a high of 0.30 (Cooley and Quadrini [2001]). We choose a value of 0.15 to be on the conservative side of the middle range. Finally, we set the corporate income tax and interest income tax rates as 0.35 and 0.33, respectively. As will be shown, this difference is large enough to create a substantial incentive to accumulate debt without the need to make additional assumptions on firms' discounting factor or death probability. Finally, we specify a very small agency cost of cash holdings, 5bps. This small value is sufficient to circumvent the issue of nonstationarity of cash holdings discussed above.

4.2 Asset Tangibility and Corporate Saving

We take $\rho = -0.3$ as the baseline (implying the elasticity of substitution of 1.43 between the two capitals) and vary θ from 0.8 to 0.5 to 0.3. In the limiting case of Leontief ($\rho = \infty$), θ can be thought of as the tangible capital ratio. In general cases, actual tangible capital ratio can deviate from the central tendency given by θ. However, even in these general cases, as will be shown below, tagible capital ratio does not deviate much from θ because doing so is too costly as the marginal efficiency of one type of capital deteriorates fast. Hence, we can think of θ as a technological constraint in capital choice toward which the composition of heterogeneous types of capital are led in the long run. In this sense, we call θ the long-run share of tangible capital in firms' production. Firms may deviate from this constraint in the short-run as the two types of capital provide different levels of convenience yields: expansion of debt capacity. Below, we study how the two technological parameters, ρ and θ affect firms' net leverage strategy in general, and cash holding in particular.

Table 5 summarizes the main results of our simulation exercises, in which we use random draws of technology shocks of size of $T = 1,100$ and $N = 10,000$ with T and N indicating the numbers of time periods and firms.[34] The first panel of the table shows the impact of changes in θ on financial ratios. $1-\theta = 0.2$ corresponds to the long run intangible capital ratio of 1970s in the data as shown in the left panel of figure 1 whereas $1 - \theta = 0.5$ corresponds to the ratio of 2000s. We consider one

[34] In computing the moments, we delete the initial 100 periods for each firm. The same set of technological shocks are used for all cases shown in Table 5∼7.

Table 5: Asset Tangibility, Corporate Saving and Investment

Technology parameter, θ	0.8	0.5	0.3
Balance sheet ratios			
Tangible capital ratio	0.821	0.501	0.300
Cash-to-tangible assets	0.000	0.150	0.408
Utilization rate of line of credit	0.369	0.095	0.030
Debt-to-tangible assets	0.316	0.079	0.019
Net leverage (rel. to tangible assets)	0.316	-0.071	-0.389
Cash-to-total asset	0.000	0.082	0.172
Tobin's Q	1.689	1.704	1.736
Market-to-book	1.766	1.783	1.813
Mean level of total capital accumulation (A)	0.899	0.862	0.851
	-	0.959 of A	0.947 of A
Cashflow sensitivity of cash and investment			
Corr(investment, cashflow)	0.502	0.608	0.500
Corr(cash ($\tilde{b}'$), cashflow)	-	0.331	0.343
Predictive power cash and Tobin's Q			
Corr(investment, cash)	-	-0.425	-0.596
Corr(investment, lagged cash)	-	0.717	0.502
Corr(investment, Tobin's Q)	-0.718	-0.631	-0.625
Corr(investment, lagged Tobin's Q)	0.587	0.618	0.568
Corr(cash, Tobin's Q)	-	0.890	0.937

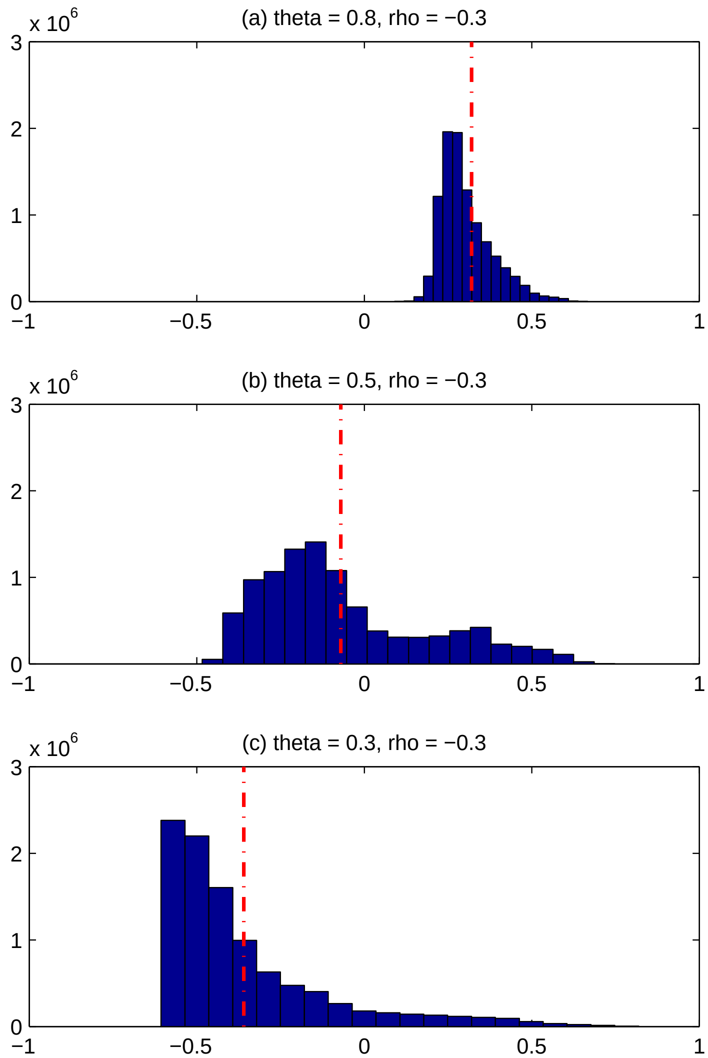
Note: The table shows the moments of simulation for endogenous variables udner the partial irreversibility and fixed adjustment cost. The simulation uses a set of ramdom draws of the size of T=1,100 and N=10,000.

more case as a hypothetical situation in which the long-run share of intangible capital stock rises up to 70 percent of total capital stock ($1 - \theta = 0.7$). The first row of the table shows the mean tangible capital ratios (relative to total capital stock) for different values of θ, and confirms that θ indeed determines the central tendency of capital choice in the long-run.

The most important results can be seen in the second row of the table: When the most of capital stock is pledgeable as collateral asset owing to the technological property ($\theta = 0.8$), the firms do not hold liquid financial assets at all. The management of risks, which mainly come from the arrival of investment opportunities and financing needs of operating costs, is done by varying the amount of unused line of credit.

One can get a more concrete sense of such risk by considering the size of the adjustment in production capacities in the model. During our simulations, on average, there are always $25 \sim 35$ of firms in a complete inaction mode, in which the firms do not actively adjust their capital stock. When we define an investment burst episode as an sdjustment that increases capital stock more than 20 percent, we find that $20 \sim 30$ percent of all positive investment episodes are accounted for

Figure 6: Asset Tangibility and Net Leverage Distribution



Note: Panel (a), (b) and (c) show the histograms of net leverage ratio (b/k) relative to total capital stock evaluated at the book value using a stochastic simulation of size T=1,100 and N=10,000. The red, dash-dotted line shows the mean of the simulation.

by these 'burst' episode, a close match with the property of Census-LRD (Longitudinal Reserch Databases, and see Cooper and Haltiwanger [2006] for more details). The high pledgeability of production capacity allows the firms to cope with such large liquidity risk entirely through the management of borrowing capacity. As shown in the 8th of row of the table, the firms use only about 37 percent of their maximum debt capacity on average when $\theta = 0.8$, and that is enough to hedge liquidity risks. As the firms do not hold any financial claims, the net leverage ratio is equal to their debt-to-tangible asset ratio at about 32 percent.

As the long-run share of taginle capital declines from 0.8 to 0.5, the cash-to-tangible asset ratio rises to 15 percent. While the initial starting values are different, the amount of increase is almost

Table 6: Corporate Saving: the Case of Low Non-convex Adjustment Cost

Technology parameter, θ	0.8	0.5	0.3
Balance sheet ratios			
Tangible capital ratio	0.809	0.500	0.292
Cash-to-tangible assets	0.000	0.005	0.314
Utilization rate of line of credit	0.473	0.248	0.041
Debt-to-tangible assets	0.402	0.218	0.028
Net leverage (rel. to tangible assets)	0.402	0.212	0.011
Cash-to-total asset	0.000	0.003	0.116
Tobin's Q	1.618	1.5364	1.624
Market-to-book	1.698	1.616	1.704
Mean level of total capital accumulation (A)	0.906	0.899	0.906
	-	0.992 of A	1.000 of A
Cashflow sensitivity of cash and investment			
Corr(investment, cashflow)	0.567	0.548	0.604
Corr(cash ($\tilde{b}'$), cashflow)	-	0.237	0.201
Predictive power cash and Tobin's Q			
Corr(investment, cash)	-	-0.211	-0.561
Corr(investment, lagged cash)	-	0.283	0.606
Corr(investment, Tobin's Q)	-0.748	-0.761	-0.735
Corr(investment, lagged Tobin's Q)	0.623	0.542	0.604
Corr(cash, Tobin's Q)	-	0.362	0.918

Note: The table shows the moments of simulation for endogenous variables udner the partial irreversibility and fixed adjustment cost. The simulation uses a set of ramdom draws of the size of T=1,100 and N=10,000. The initial 100 observations for each firm are deleted in computing these moments.

exactly matched by the empirical counterpart in Compustat data over the last 40 years (shown in the middle panel of figure 1). The transition from $\theta = 0.8$ to 0.5 also produces a reduction in net leverage ratio of about 37 percentage point.

These are not mechanical results of using tangible assets as denominators in constructing these ratios. In principle, the ratios can go down without actual increase in liquid asset holdings because the size of the denominator may go down by construction if tangible capital ratio itself declines.[35] However, the sixth row of the table shows that this is not the case: as the long run tangible capital ratio declines from 0.8 to 0.5, the cash-to-total asset (including tangible capital, intangible capital and cash holdings) also substantially increases from 0 percent to 8.2 percent.

When the long-run share of tangible capital ratio further declines to 0.3, something remarkable happens: the cash-to-tangible asset ratio jumps to 41 percent while the cash-to-total asset ratio leaps to 17 percent. More strikingly, the net leverage ratio jumps to -39 percent and the coportate

[35]This is because 'tangible asset' includes only tangible capital stock and liquid financial claims, and if the former declines more than the latter increases, the size of the denominator may decline in these ratios.

sector transforms itself into a large, net creditor in the economy.[36] This result is robust against equilibrium setting. The results of the current paper are derived in partial equilibrium. However, Falato, Kadyrzhanova, and Sim [2013] show essentially identical results in general equilibrium. In a closed economy, this means that the household sector becomes a net borrowing sector without any changes in preferences, only the results of changes in the tangibility of assets in the economy.

Figure 6 shows this transformation in more detail, showing the transition of the distribution of the net leverage ratio. In this picture, two things stand out. First, as the long-run tangibility of production asset declines, the mean and the support of the distribution move to the left as more firms find optimal to hedge liquidity risk by reducing debt or increasing financial claims. This is because the growing share of intangible assets reduces the debt capacity of firms. Second, the dispersion of net leverage ratio increases with the decline of long-run tangible capital ratio. When the share of tangible asset is high, the scope for risk management is not high, which reduces the dispersion of net leverage ratio. As mentioned earlier, the risk hedging is mainly achieved through the management of unused line of credit. Row 8 shows the utilization rate of the maximum debt capacity. However, when θ declines to 0.3, the utilization rate drops to mere 3 percent as an average firm wants to keep almost entire debt capacity unused to manage liquidity risk. While seemingly extreme, this is not surprising given the limited debt capacity when $\theta = 0.3$. As the pledgeability of production capacity declines, the firms adopt more active risk hedging strategies by investing in financial assets, and the dispersion of net leverage ratio endogenously increases.

Table 5 also shows that Tobin's average Q monotinically declines as the long-run tangible asset ratio falls. The reason for this can be found in the fact that the average level of capital accumulation is negatively affected by the decline in the asset tangibility as shown in the last two rows of the first panel in the table. The more tangible asset support the more debt, which increases the total value of firm owing to the tax benefit of debt. This creates a positive feedback loop between investment in production capacity and accumulation of debt. As a consequence, the decline of the long-run tangible capital ratio declines from 0.8 to 0.3, overall capital accumulation falls about 5 percent, an economically significant reduction. The decreasing returns-to-scale implies that Tobin's average Q must rise as a result (and this applies to a similar measure, market-to-book ratio shown in the next row).

The second and third panels of table 5 display contemporaneous and dynamic relationship among cashflow, cash, investment and Tobin's Q. Not surprisingly, investment in both production and financial assets exhibit cashflow sensitivity owing to the financial friction.[37] While investment may be sensitive to cashflow for reasons other than the financial friction, for instance, the curvature in the profit function (see Cooper and Ejarque [2003]), the sensitivity of cash investment to cashflow is undoubtedly a direct result of the financial friction in our environment since it is suboptimal otherwise not to maximize the tax benefit of debt without financial friction. More importantly,

[36] As shown by the table, the corporate sector turning itself into a net credit sector already happens at $\theta = 0.5$, but a much smaller scale.

[37] Cashflow is defined as the sum of net operating income after tax and depreciation, and net cash inflow due to financial debts or claims.

Table 7: Capital Substitutibility, Corporate Saving and Investment

Technology parameter, ρ	-0.3	1.0	5.0	∞
Balance sheet ratios				
Tangible capital ratio	0.300	0.303	0.302	0.300
Cash-to-tangible assets	0.408	0.438	0.443	0.561
Utilization rate of line of credit	0.030	0.032	0.019	0.007
Debt-to-tangible assets	0.019	0.009	0.011	0.003
Net leverage (rel. to tangible assets)	-0.389	-0.420	-0.431	-0.558
Cash-to-total asset	0.172	0.187	0.191	0.273
Tobin's Q	1.736	1.672	1.693	1.602
Market-to-book	1.813	1.751	1.770	1.689
Mean level of total capital accumulation (A)	0.851	0.844	0.841	0.823
	-	0.992 of A	0.988 of A	0.967 of A
Cashflow sensitivity of cash and investment				
Corr(investment, cashflow)	0.500	0.522	0.467	0.600
Corr(cash ($\tilde{b}'$), cashflow)	0.343	0.185	0.234	0.272
Predictive power cash and Tobin's Q				
Corr(investment, cash)	-0.596	-0.705	-0.722	-0.565
Corr(investment, lagged cash)	0.502	0.530	0.469	0.574
Corr(investment, Tobin's Q)	-0.625	-0.655	-0.635	-0.649
Corr(investment, lagged Tobin's Q)	0.568	0.631	0.599	0.599
Corr(cash, Tobin's Q)	0.937	0.926	0.906	0.960

Note: The table shows the moments of simulation for endogenous variables udner the partial irreversibility and fixed adjustment cost. The simulation uses a set of ramdom draws of the size of T=1,100 and N=10,000. The initial 100 observations for each firm are deleted in computing these moments.

investment is negatively correlated with cash contemporaneously, but positively correlated with lagged cash. Given the financial constraint, investment in capital and investment in financial claims are competing uses of financial resources, hence the negative, contemporaneous correlation. In contrast, the lag of cash investment becomes a component of cash inflow today as the investment earns a gross return, and not surprisingly, is positively correlated with contemporaneous investment. In the discussion of policy functions, we conjectured that the information content of cash might be closely related with that of Tobin's Q. As conjectured, table 5 shows that investment is negatively correlated with contemoraneous Tobin's Q, but positively correlated with lagged Tobin's Q in an exact parallel with the relationship between investment and cash. In fact, Tobins' Q and cash are contemporaneously correlated and the strength of correlation increases to 0.94 when the asset tangibility is particularly low, for instance, when $\theta = 0.3$. This pattern arises because both cash and Tobin's Q rise in anticipation of investment opportunities in the context of financial friction and both drop immediately after the execution of investment projects, which are carried out in lumps in the presence of non-convex adjustment costs. The equivalence of information content of cash and Tobin's Q is a feature that would not exist without the specific combination of the real and financial friction in the model.

To show the influence of the non-convex adjustment friction in generating precautionary demand for liquid financial assets under financial friction, in table 6, we redo the simulation with the non-convex adjustment costs calibrated as half the size of the baseline, i.e., 0.5 percent of each capital stock. Overall patterns in the relationship among endogenous variables remains the same. However, the absolute amount of corporate saving is reduced substantially. The second row of the table shows that in each case of the long-run tangible capital ratios considered in table 5 and 6, the cash-to-tangible asset ratio declines about 10 percentage points from the baseline, except that the cash ratio is identically zero at $\theta = 0.8$ in both cases. However, even in this case, one can see in row 3 and 4 that both debt-to-tangible asset ratio and the utilization rate of the debt capacity are lower about 10 percentage points compared with those of table 5. Higher costs of non-convex adjustment increase the precautionary demand for liquidity not just for the financing needs directly related with the cost. It is because the higher non-convex adjustment costs make it optimal to make infrequent, but large amount of adjustment in production capacity. It is in this sense that a greater inflexibility of the firm's real sidemakes a greater financial flexibility more desirable. This result isbroadly consistent with the stylzed facts about the relationship beween investment friction and cash holdings in the data shown in table 3.

As in table 5, the second and third panels of table 6 show the cashflow sensitivity of cash and investment, and the dynamic properties of cash and Tobin's Q in the relationship with investment. Broadly speaking, all the major properties identified in 5 remain unaffected by the change in the size of the fixed costs of adjustment: investment is highly sensitive to cashflow, and investment in financial clains is positively, but weakly correlated with cashflow; investment is negatively correlated with both cash and Tobin's Q contemporaneously, but correlated positively with lagged cash and Tobin's Q; cash and Tobin's Q are positively correlated with each other contemporaneously as in the baseline case, though the correlation is now much weaker when $\theta = 0.5$ than in the baseline.

Finally, in table 7, we show how robust this finding is against different degrees of substitutibility of heterogeneous capital inputs. Holding the long-run tangible capital ratio fixed at 0.3, we investigate how the cash holding change when ρ changes from -0.3 to 1.0 to 5.0 to ∞. As mentioned earlier, the greater the value of ρ, the smaller the substitutibility. As shown by the second row of the table, the firms accumulate enormous amount liquid financial assets on their balance sheet when the tangibility of production assets is low ($\theta = 0.3$) regardless of the substitutibility of heterogeneous capital inputs in all cases.

Nevertheless, the flexibility in production technology as measured by the inverse of ρ has important bearing on the liquidity management strategy. As ρ increases from -0.3 to ∞, the cash-to-tangible asset ratio increases about 38 percent from 0.41 to 0.56. Similarly, the cash-to-total asset ratio increases about 60 percent from 0.17 to 0.27. The results show that the firms try to compensate for foregone flexibility in their capital choice by holding extra liquidity. In principle, a more flexible technology allows firms to use tangible capital stock more intensively than implied by the long-run average because doing so provide a greater debt capacity. Such convenience yield allows the firms to economize its liquidity risk management, lowering the precautionary demand for cash.

Table 7 also shows that all the main results in table 5 continue to hold: investment and cash exhibit cashflow sensitivity; investment is negatively correlated with contemporaneous cash and Tobin's Q; investment is positively correlated with lags of cash and Tobin's Q; cash and Tobin's Q is highly correlated contemporaneously. Overall, the results in table 7 together with those in table 5 and 6 establish a robustness for the link between asset tangibility and liquidity demand in the context of real anf financial friction.

5 Conclusion

We have presented new evidence and theory which support the hypothesis that the rise in intangible capital can explain the secular increase in US corporate cash holdings over the last four decades. Our empirical evidence shows that intangible capital is a key empirical determinant of cash holdings. In addition, the evidence suggests that both financial and real frictions contribute to explain why intangible capital matters so much. Next, we built a structural dynamic corporate finance model where intangible capital matters for firms' cash management decisions because of the interplay between financial and investment frictions. All else equal, our model generates an outsized increase in the demand for corporate cash in response to an increase in intangible capital. We conclude that intangible capital is a crucial ingredient to providing a satisfactory analytic account of key stylized facts in corporate finance, which to date had eluded standard explanations.

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Appendices

A Details of Variable Definition

The variables used in the analysis are defined as follows:

- Cash to book asset – our main dependent variaible – is defined cash and marketable securities (data item #1) divided by book assets (#6)
- Other cash measures (robustness): Cash to Net Book Assets is cash and marketable securities (#1) divided by book assets (#6) minus cash and marketable securities (#1); Cash to Market Value of Assets is cash and marketable securities (#1) divided by long-term debt (#9) plus debt in current liabilities (#34) plus market value of equity.

- Net-Leverage is the ratio of long-term debt (#9) plus debt in current liabilities (#34) minus cash and marketable securities (data item #1) to book assets (#6).
- Industry sigma (cash flow risk) is the standard deviation of industry cash flow to book assets. Standard deviation of cash flow to book assets is computed for every firm-year using data over the previous ten years. We then average these cash flow standard deviations over 2SIC industries and each year.
- Market-to-book ratio is the ratio of the book value of assets (#6) minus the book value of equity (#60) plus the market value of equity (#199 * #25) to the book value of assets (#6).
- Firm size is the natural logarithm of book assets (#6) in 1990 dollars (using CPI).

- Cash flow is earnings after interest, dividends, and taxes before depreciation divided by book assets ((#13 – #15 – #16 – #21) / #6).
- Capital expenditures is the ratio of capital expenditures (#128) to book assets (#6).
- Dividend is a dummy variable equal to one in years in which a firm pays a common dividend (#21). Otherwise, the dummy equals zero.
- Acquisitions is the ratio of acquisitions (#129) to book assets (#6).
- Net working capital is the ratio of net working capital (#179) minus cash (#1) to book assets (#6).
- Leverage is the ratio of long-term debt (#9) plus debt in current liabilities (#34) to book assets (#6).
- Net debt (equity) issuance is annual total debt (equity issuance minus debt retirement (equity repurchases), divided by book assets.
- R&D (flow) is the ratio of R&D expenditures (#46) to book assets (#6).
- Asset Tangibility is the ratio of net PPe (#8) to book assets (#6) minus cash and marketable securities (#1).
- High-tech industries are defined following Loughran and Ritter (2004) as SIC codes 3571, 3572, 3575, 3577, 3578, 3661, 3663, 3669, 3674, 3812, 3823, 3825, 3826, 3827, 3829, 3841, 3845, 4812, 4813, 4899, 7370, 7371, 7372, 7373, 7374, 7375, 7378, and 7379.
- WW-Index is based on Whited and Wu (2006) and is as follows: WW-Index=-0.091*CashFlow -0.062*Dividend +0.021*Leverage -0.044*Size +0.102*Industry Growth -0.035*Growth, where Industry Growth is the 4-SIC industry sales growth, Growth is own–firm real sales growth, and the other variables are as defined above.
- Asset liquidation value is based on Berger et al. (1996) and is the sum of 0.715*Receivables(#2), 0.547*Inventory(#3), and 0.535*Capital(#8).
- Industry asset redeployability index is based on Balasubramanian and Sivadasan (2009) and is the fraction of total capital expenditures in an industry accounted for by purchases of used (as opposed to new) capital, computed at 4-digit SIC level and constructed using hand-collected US Census Bureau data. Since these data are available only once every 5 years and not for more recent years, we compute a time-invariant index by averaging the available quinquennial indeces at the 4-SIC level. This measure is only available for a restricted sample of manufacturing firms.

- Investment inaction, small investments, and investment spikes are defined at the firm level based on Cooper and Haltiwanger (2006) as those firm–year observations corresponding to $|\text{Capex/book assets}|<.01$, $|\text{Capex/book assets}|\geq.01$, and $|\text{Capex/book assets}|>.2$, respectively. Industry is 4-SIC. In each industry-year, we compute frequency as number of observations involving investment inaction (small investment) to total number of observations in the industry. This prodecure results in a time-invariant cross-sectional ranking of 4-SIC industries.

- Time-series skewness and kurtosis of annual aggregate industry investment are based on Caballero (1999) and calculated as the skewness and kurtosis of average annual Capex to book assets ratios in each (4-SIC) industry. In every year, we calculate annual averages in each industry as industry-year means of individual firm-year Capex to book asset ratios.This prodecure results in a time-invariant cross-sectional ranking of 4-SIC industries.

- Time-series standard deviation of aggregate industry operating costs is calculated after aggregating fim-level operating costs by taking annual means at the 4-SIC industry level. For each industry, the measure is the standard deviation of these annual industry means of operating costs. Operating costs are costs of good sold (#41). This measure gives a time-invariant cross-sectional ranking of 4-SIC industries.