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 technology 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 large number of new stylized facts which support this "collateral channel" and broadly suggest that there is a strong empirical link between the rise in intangible capital and the secular trend in corporate cash holdings. A structural model that can successfully replicate the facts suggests that the collateral chan-

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[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)).

nel is also quantitatively important, thus offering a potential resolution of the puzzle for existing theories. Overall, our results indicate that intangible capital is crucial to providing a satisfactory analytic account of the main stylized facts of corporate cash holdings.

Our focus on intangible capital builds on a vast body of evidence spanning several literatures, which shows that over the last decades there has been a shift away from physical capital investments. There is solid evidence at the aggregate level that investments in intangible capital by US firms have picked up substantially since the 1980s (Corrado, Hulten, and Sichel (2009) and Corrado and Hulten (2010)), especially in computerized information and private R&D. There is also evidence that organizational capital is becoming increasingly important (Lev (2001)). This well-documented shift in firms' mode of production is an economy-wide phenomenon, something that the literature has dubbed a general purpose technology (GPT) shock, or the third industrial revolution (Jovanovic and Rousseau (2005)). This body of evidence broadly suggests that fundamental technological changes in the 1980s and 1990s have had a pervasive effect on public corporations.

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 construct a new firm-level measure of intangible capital, which is challenging since intangible assets are not reported on firms' balance sheets. 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)). While these approaches measure intangibles as unexplained (by physical capital) residuals of stock market value or firm productivity, a more direct approach is to construct aggregate measures of the different components of intangible capital, which include the stock of assets created by R&D expenditures, brand equity, and human and organizational capital using NIPA accounts (Corrado, Hulten, and Sichel (2009) and Corrado and Hulten (2010)).

We build on this latter approach and use standard accounting data to construct a new comprehensive firm-level measure of intangible capital for all non-financial firms in Compustat between 1970 and 2010. 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

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and organizational capital capitalizes SG&A expenditures.[2] IT capital is constructed capitalizing expenditures in computer software from BEA.

Using this firm-level measure, we document several new empirical regularities on the link between intangible capital, firm financing, and corporate investment. In particular, 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. Results of a simple out-of-sample forecasting exercise that follows the approach of Bates, Kahle, and Stulz (2006) show that an economically significant part of the overall increase in cash holdings over the last decades can be attributed to increases in intangible capital. 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 the joint determination of firms' financing, risk management, and capital accumulation decisions. 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 arise since debt financing is subject to a collateral constraint, intangible capital cannot be pledged as collateral, and equity financing involves issuance costs; second, there are real frictions that arise since investment in real assets is subject to non-convex adjustment costs, which make it infrequent and lumpy (see Abel and Eberly (1994) for a standard treatment).

In this setting, we show that the interplay of external financing costs and non-convex adjustment costs of investment generates a quantitatively large precautionary demand for cash hoarding because it makes difficult for firms to generate funds by either divesting real assets or raising ex-

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[2]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.

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ternal finance (see Bolton, Chen, and Wang (2009), and Riddick and Whited (2009) for related settings, which abstract from debt and capital heterogeneity; see also Froot, Scharfstein, and Stein (1993) for a seminal model of corporate liquidity management). Intangible assets further boost this precautionary demand for cash by shrinking debt capacity through a tightening of the collateral debt 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. To assess the quantitative importance of this "collateral channel" through which firms' debt capacity and asset tangibility are linked in our model, we develop a stationary general equilibrium analysis of net savings of corporations and households. All else equal, 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 their US averages for the same period. In addition, it 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. Overall, these results suggest that technological change has contributed significantly to recent changes in US corporations' and households' private liquidity decisions.

In addition to offering a potential resolution to important empirical and quantitative puzzles of corporate cash holdings, our results make two other important contributions. On the finance side, while it is well-established that more tangible capital assets support more debt (see Shleifer and Vishny (1992), and Hart and Moore (1994) for seminal contributions, and Rampini and Viswanathan (2010) for recent work), our contribution is to examine the quantitative implications of asset tangibility for liquidity management, which are relatively less well-understood. Our proposed rationale for the secular trend in corporate cash holdings based on technological change is complementary to recent work by Karabarbounis and Neiman (2012) who explore the link with the rise in the labor share.[3] 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 with respect

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[3]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.

to these studies 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.[4] On the macroeconomics side, we contribute to the financial accelerator literature (Kiyotaki and Moore (1997), Bernanke, Gertler, and Gilchrist (1999) and Cooley and Quadrini (2001)) by extending the analysis to the issue of dynamic risk management under financial market frictions in general equilibrium.

2   Intangible Capital and the Rise in Cash Holdings: The Evidence

We begin our analysis by summarizing the stylized facts of the evolution of intangible capital and corporate cash holdings over time, as well as a number of related empirical regularities on intangible capital, firm financing, and corporate investment. 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).

2.1   Measuring Intangible Capital

We construct a measure of intangible capital for each firm-year,[5] which is our empirical proxy for the amount of capital accumulated by past investments in intangible assets. 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.[6] We use annual data on expenses in three broad categories of intangible investment whose importance has been emphasized in the literature on the economics of innovation (Corrado, Hulten, and Sichel (2009) and Corrado and Hulten (2010)): knowledge capital, organizational capabilities, and computerized information and software. Intangible capital is defined as the sum of the stocks of investments in these three categories divided by net book assets.

First, we construct the stock of knowledge capital from past R&D expenses using the perpetual

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[4]Our study also contributes to the small but growing theory literature on dynamic models of corporate savings (e.g., Bolton, Chen, and Wang (2009), Riddick and Whited (2009), Gamba and Triantis (2008), Anderson and Carverhill (2012), and Hugonnier, Malamud, and Morellec (2012)) by showing that a richer production-side is key to improve the quantitative performance of this class of models.

[5]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.

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

inventory method:

$$G_{it} = (1 - \delta_{R\&D}) G_{it-1} + R\&D_{it} \tag{1}$$

where G_t is the end-of-period stock of knowledge capital, $R\&D_{it}$ is the ($1990 real) expenditures on R&D during the year, and $\delta_{R\&D} = 15\%$ (Hall, Jaffe, and Trajtenberg (2000)).[7]

Second, we construct the stock of organizational capital from past sales, general, and administrative (SG&A) expenses also using the same method with $\delta_{SG\&A} = 20\%$ Lev and Radhakrishnan (2005), Eisfeldt and Papanikolaou (2013)). 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.[8]

Third, we construct the stock of computerized information and software by applying again perpetual inventory method with a depreciation rate of 31% as in the BEA data. 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 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.[9] 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 Stylized Facts

We begin our analysis by considering 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

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[7]If R&D expenditures are constant (in real terms), the stock of knowledge capital is $G_t = \sum_{s=0}^{\infty} (1 - \delta)^s R\&D_{t-s} = \frac{R}{\delta}$. We set the initial stock to be equal to the R&D expenditures in the first year divided by the depreciation rate $\delta_{R\&D}$. In addition, we interpolate missing values of R&D following Hall (1993) who shows that this results in an unbiased measure of R&D capital. For firms that do not report R&D, we set R&D to zero.

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

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

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 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 -1. Panels A and C of Table 2 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.[10] 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 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

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[10]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.

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.

2.3 Panel Evidence

In the remainder of this section, we corroborate the stylized facts using panel data analysis. To that end, 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[11], 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 for time variation in cash holdings.[12] We evaluate statistical significance using robust clus-

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[11]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.

[12]See Appendix C for detailed variable definitions.

tered standard errors adjusted for non-independence of observations within firms.

The resulting estimates are reported in Panel A of Table 3 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.[13] The coefficient on intangible capital is robustly positive and statistically significant across the two samples and both specifications.[14]

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 and 1/2 % 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 and 1/2%, suggesting that intangible capital is also an economically significant determinant of the within-firm time-series evolution of cash holdings. Finally, estimates for firms with positive R&D are even larger than those for the entire sample, which suggests that our baseline OLS result is not spurious and that intangible capital is an even more important economic 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 and net indebtedness.[15]

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[13]The results are robust to using 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.

[14]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.

[15]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.

Quantifying the Contribution of Intangible Capital to the Rise in Cash   Figure 1 shows that cash holdings increased by about 10% over the last decades, from about 8% in 1970 to about 20% by 2010. To quantify the importance of intangible capital in explaining the secular trend in cash holdings, we investigate how changes in firm characteristics over time affect cash ratios.[16] The intuition for this exercise is as follows: sample average intangible capital was 0.42 in 1980 and 0.75 in 2000. If the (unscaled) coefficient on intangible capital is 0.087, then we infer that, holding all other variables constant, the average cash ratio increased by 2.8 percentage points from 1980 to 2000 because of the increase in intangible capital, going from 3.7 percentage points (=0.087*0.42) in 1980 to 6.5 percentage points (=0.087*0.75) in 2000.

Panel A of Table 3 shows the results of this analysis that quantifies the contribution to the overall increase in the predicted cash ratio of changes in the firm-level determinants of that ratio. We first estimate the augmented OLS regression specification of Column (1) in the first half of the sample, i.e. the pre-1990 period. Using these coefficient estimates, we construct measures of the contributions of each of the explanatory variables in explaining changes in cash holdings between the 2000s and the pre-1990 period. Changes in intangible capital stand out as the most important driving factor of the rise in cash, with an increase in cash of about 3 (5) percentage points attributable to the increase in intangible capital in the overall sample (in the sub-sample of positive R&D firms). Changes in all other standard determinants have quite limited explanatory power for the rise in cash.

Intangible Capital and Cash Dynamics   We further probe the role of intangible capital in driving the time-series dynamics of corporate cash management by adding a lagged dependent variable to our baseline specification. This new ingredient allows us to do two things: first, though we do not report the coefficient estimates for brevity, we check that our results are robust to allowing for imperfections in cash rebalancing or partial adjustment in cash ratios (Lemmon, Roberts, and Zender (2008)); second, we gather additional evidence on the role of financing frictions. In particular, we examine the hypothesis that intangible capital lowers the speed of adjustment (SOA) of cash: if intangibles make it more difficult to raise external finance, then they should be expected to

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[16]To ease comparison and gauge the relative contribution of intangible capital compared to other standard determinants, we use the approach in Bates, Kahle, and Stulz (2006) and augment the OLS specification with net debt and equity issuance.

increase adjustment costs of cash, thus leading to lower SOA (see Faulkender, Flannery, Hankins, and Smith (2012) for more details on this intuition).

Because there is an ongoing debate in the literature about the proper estimation procedure of SOA, Panel B of Table 3 reports results for a wide battery of SOA estimators. The annual SOA of cash ranges between 0.27 and 0.54 (not shown), suggesting that cash is imperfectly adjusted toward its target. To provide economic intuition, we translate these SOAs into half-lives, the time that it takes a firm to adjust one-half the distance to its target cash after a one unit shock to the error term. The half-life ranges from about 1 to about 2 years. Robustly across the different estimation techniques, SOAs decline monotonically with intangible capital. For example, OLS estimates in Column (1) imply that the half-life of 3 years for firms in the top quartile of the distribution of intangible capital is almost three time larger than for firms in the bottom quartile. These results are consistent with the hypothesis that intangible capital increases adjustment costs of cash.

Corporate Investment and Firm Dynamics   Next, we detail the empirical regularities that pertain to the real side decisions of firms. We ask whether cash holdings are an important source of financing for firm investment and growth and, if so, whether their importance varies systematically with intangible capital. To that end, we regress total investment (the ratio of the sum of capex and R&D to net book assets) and sales growth on lagged cash holdings, while controlling for a set of standard determinants of investment (e.g., Gomes (2001)). We consider both OLS and firm fixed effects versions of this baseline model, with firm-level controls that include industry cash flow volatility, market-to-book ratio, firm size, cash flow, and a dummy for whether the firm pays dividend in any given year, as well as year effects. 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 4 for the overall sample (Columns (1)-(4)) and for the subset of firms that report positive R&D (Columns (5)-(8)). The coefficient on lagged cash holdings is robustly positive and statistically significant across the two samples and both specifications, and is also economically significant. For example, for the baseline OLS specification in Column (1), an increase in lagged cash holdings from their lowest to their highest levels leads to about 7% increase in investment, which is almost as large as the sample mean value of investment of 10%. The estimate declines just a bit in the specification with firm fixed effects,

and is even larger for firms with positive R&D, suggesting that cash holdings are an even more important source of financing growth opportunities for innovative firms.

Panel B of Table 4 shows that intangible capital strengthens the relation between cash holdings and firm investment and growth. In fact, when we run our investment and sales growth regressions separately for each of four bins of our sample depending on quartiles of the empirical distribution of intangible capital, the size of the coefficient on lagged cash holdings increases monotonically and about doubles as we move from the bottom to the top quartile. These findings hold robustly for both investment and sales growth, as well as for both the entire sample and the sub-sample of firms that are active in R&D.

The Role of Financial and Real Frictions In our last set of panel results, we use sample-split analysis to better understand why intangible capital is an economically important determinant of corporate cash holdings. 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 5 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 liquidation value 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

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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 OLS coefficient in Column (1) more than triples when we go from the top to the bottom quartile of the firm size distribution (Rows [1] and [2]).

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); time-series skewness and kurtosis of annual aggregate industry investment, both based on Caballero (1999); and the time-series 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]).

In summary, the empirical regularities on intangible capital, firm financing, and corporate investment are:

- Firm cash holdings (net indebtedness) have increased (decreased) over time, and are positively (negatively) related with intangible capital both in the time series and in the cross section.

- Investment and growth are positively related to cash holdings, especially for firms with greater intangible capital.

- The adjustment dynamics of cash is more sluggish for firms with more intangible capital.

- The link between cash and intangible capital is stronger for the firms that are financially constrained and belong to industries with greater skewness and kurtosis in investment rates.

3 A Structural Model of Corporate Cash Management

This section develops a stationary general equilibrium model in which illiquidity of productive assets and financial market frictions interact with each other to determine firms' optimal liquidity management policies. Our general equilibrium approach has a number of advantages: it allows us to derive the ergodic joint distribution of capital stock, financial assets and liabilities and idiosyncratic technology of heterogeneous firms; it allows us to construct the exact moments of endogenous quantities in a simulation-free environment; it incorporates endogenous feedbacks of market prices in general equilibrium. To save space however, we focus on the description of firm problem in this section. A complete definition of stationary equilibrium and the numerical method can be found in the Appendix.

3.1 Technology

Firms combine labor and capital to produce and sell output in a competitive market. They use two different types of capital: tangible (K_T) and intangible (K_N). In particular, the production technology takes the following Decreasing-Returns-to-Scale (DRS) Cobb-Douglas form:

$$Y = Z^{1-(1-\alpha)\xi} N^{(1-\alpha)\xi} \left[\theta \left(\frac{K_T}{\theta} \right)^{-\rho} + (1-\theta) \left(\frac{K_N}{1-\theta} \right)^{-\rho} \right]^{-\alpha\xi/\rho} - F_O \,, \quad 0 < \xi < 1 \qquad (2)$$

where α is value added share of capital, ξ is the return-to-scale parameter, Z is an idiosyncratic technology shock, and N is labor hours. Production is subject to fixed operation costs, denoted by F_O, which make it possible for the firm to incur operating losses ex post. The idiosyncratic technology shock follows a N_z-state Markov Chain process with a transition function denoted by $Q(Z, dZ')$.[17] With the technological assumption, a static optimization over labor yields the following profit before fixed operation cost:

$$\Pi(K_T, K_N; \theta, \rho) = \eta(w) Z \left[\theta \left(\frac{K_T}{\theta} \right)^{-\rho} + (1-\theta) \left(\frac{K_N}{1-\theta} \right)^{-\rho} \right]^{-\gamma/\rho} \qquad (3)$$

$$\eta(w) \equiv [1 - (1-\alpha)\xi] \left[\frac{(1-\alpha)\xi}{w} \right]^{\frac{(1-\alpha)\xi}{1-(1-\alpha)\xi}} \,, \quad \gamma \equiv \frac{\alpha\xi}{1 - (1-\alpha)\xi}.$$

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[17]The Markov Chain process is adopted to facilitate our analysis of the ergodic distribution of firms' balance sheets in general equilibrium. Later, we generalize this process to a continuous Markov process.

where w is market clearing wage.

Note that we assume that capital service is given by a CRS-CES form with the elasticity of substitution given by $1/(1 + \rho)$. For the baseline specification, we specify $\rho = \infty$, implying Leontief, $\min \{K_T/\theta, K_N/(1-\theta)\}$. In this special case, $K_T/\theta = K_N/(1-\theta) \equiv K$. It is then straightforward to verify that the profit function is simply given by $\Pi(K; \theta, \rho) = \eta(w)ZK^\gamma$. Since the two types of capital are held in a fixed proportion, the assumption preserves tractability by allowing us to essentially eliminate one state variable. This reduces the size of problem considerably, especially in general equilibrium, thus allowing us to develop intuition about the main forces at work in the model. As a robustness check, we later consider the general CES case $\rho < \infty$.

To motivate firms' cash holdings, it is necessary, although not sufficient, to introduce illiquidity of long-lived capital assets. For this reason, we assume that all capital expenditures are only partially reversible (Abel and Eberly (1996)). 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 $0 \leq p_i^- \leq p_i^+$ for $i = T, N$. Since the desire to hold cash arise from the imperfect resale value, we make a simplifying assumption, $p_i^+ = p^+$ for $i = T, N$: the initial purchase prices are identical.

In addition, we also assume that adjustment of capital is costly in either direction because it involves fixed adjustment costs (interchangeably, non-convex adjustment). We assume that both types of capital are subject to the same amount of fixed costs, denoted by F_K. Combining the two assumptions about the illiquidity of capital, we can express the adjustment cost as

$$\Gamma(K_i', K_i) = p_i(K_i', K_i)[K_i' - (1-\delta)K_i] + \nu_K F_K \tag{4}$$

where $\nu_K \equiv \mathbf{1}(K_i' \neq (1-\delta)K_i)$ and the price of capital $p_i(K_i', K_i)$ is given by

$$p_i(K_i', K_i) = \begin{cases} p^+ & \text{if} \quad K_i' \geq (1-\delta)K_i \\ p_i^- & \text{if} \quad K_i' < (1-\delta)K_i \end{cases} \tag{5}$$

for $i = T, N$ with $0 \leq p_N^- \leq p_T^- \leq p^+$. Note that, for simplicity, we assume that the two types of capital have an identical depreciation rate δ.[18]

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[18]In principle, it would be desirable to specify capital-specific depreciation rate and/or fixed cost to match the dynamic patterns of adjustment of the two types of capital in the micro-level data. In our baseline, this would create an additional state variable. However, the alternative specification that we consider later, the general CES case, is flexible enough to incorporate this extension.

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. Next, we detail the debt and equity market frictions in turn.

3.2.1 Debt Market Friction

It is well-established in the literature that more tangible capital assets 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.[19]

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 only tangible capital assets constitute eligible collateral.[20] The resulting risk-free debt contract is subject to the following borrowing constraint:

$$B' \leq B^{\max}(K'_T; p_T^-) \equiv p_T^- \frac{(1-\delta)K'_T}{1+r(1-\tau_i)} = p_T^- \frac{(1-\delta)\theta K'}{1+r(1-\tau_i)} \tag{6}$$

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[19]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 an ongoing concern, commits itself to deliver the human capital to the entity that is obtaining the liquidated part of intangible capital.

[20]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.

where $r(1 - \tau_i)$ is after-tax interest rate. The assumption that intangible assets cannot be used as collateral is also broadly factual.[21] Using a large sample of syndicated loans to US corporations for which a detailed breakdown of type of collateral used is available,[22] we have verified that contractual loan terms state that only assets that can be easily valued represent eligible collateral. 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.

For later reference, we define the financial slack of the firm as $B^{\max}(K'_T; p^-_T) - B'$. A natural interpretation of $B^{\max}(K'_T; p^-_T)$ 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:

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

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, firms never hold 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 $B^{\max}(K'_T; p^-_T)$ 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 $B^{\max}(K'_T; p^-_T) - \max\{0, B'\}$, 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

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[21]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%.

[22]Our loan information comes from a 2011 extract of Loan Pricing Corporation's (LPC) Dealscan database. The data consist 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.

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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, $\varphi(E)$:

$$\varphi(E) \equiv \varphi_0 \nu_E K + \varphi_1 \cdot \max\{0, E\} \tag{8}$$

where $\nu_E \equiv \mathbf{1}(E \geq 0)$. In words, the firm incurs fixed costs when issuing new equity, which are proportional to its size. In addition, the firm also incurs linear costs 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

The flow of funds constraint facing the firm can be expressed as

$$D = (1 - \tau_c) \left[\Pi(K; \theta, \rho) - F_0 \right] - \sum_{i=T,N} \left[\Gamma(K_i', K_i) - \tau_c \delta K_i \right] - [1 + r(B)]B + B' + E - \varphi(E) \tag{9}$$

where D denotes the dividends payout, τ_c is a flat rate corporate income tax.[23] We allow B' to be negative, in which case B' is 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.[24] 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

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[23]For simplicity, we assume no dividend taxation.
[24]The same assumption is made by Bolton, Chen, and Wang (2009).

issue that is not central to the task of explaining the low frequency movement of cash.[25]

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

$$V(K, B, Z) = \min_{\lambda, \psi} \max_{K', B', D, E} \left\{ (1+\lambda)D - E + \psi \left[\frac{p_T^-(1-\delta)\theta}{1 + r(1-\tau_i)} K' - B' \right] \right.$$
$$\left. + \frac{1}{1 + r(1-\tau_i)} \int V(K', B', Z') Q(Z, dZ') \right\} \tag{11}$$

s.t. (4), (8), (9) and (10)

where λ and ψ 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. Note that the firm discounts the continuation value with after-tax risk free rate. While we adopt a general equilibrium framework, we solve for a stationary equilibrium without aggregate shocks. For this reason, we do not use the stochastic discounting factor of the household.

The non-convexity of the value function with respect to capital due to the presence of fixed cost of adjustment makes the analysis of the efficiency condition for capital rather complicated. To detour this complexity, we redefine the firm problem as a discrete choice problem,

$$V(K, B, Z) = \max\{V(K, B, Z | \nu_K = 1), V(K, B, Z | \nu_K = 0)\}$$

Following Abel and Eberly (1994), we proceed in two steps: first, find the optimal investment under the assumption that action ($\nu_K = 1$) is optimal; second, find the condition that $\nu_K = 1$ is optimal. To derive the FOC for capital, we first define the marginal value of capital as

$$q^M(K', B', Z) \equiv \frac{1}{1 + r(1-\tau_i)} \int V_K(K', B', Z') Q(Z, dZ') \tag{12}$$

Note that $\Gamma(K', K)$ is everywhere differentiable with respect to K' except at $K' = (1-\delta)K$. We denote left and right side derivatives of the adjustment cost function at $K' = (1-\delta)K$ by $\Gamma_{K'}^{(-)}((1-\delta)K, K)$ and $\Gamma_{K'}^{(+)}((1-\delta)K, K)$. The FOC for capital stock tomorrow can then be described as[26]

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[25]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.

[26]The condition (13) describes the optimal level of capital stock when *action* is optimal. However, the condition

1. If $q^M(K', B', Z) \notin (q^{M-}, q^{M+})$, K' satisfies

$$K' : (1 + \lambda)\Gamma_{K'}(K', K) = q^M(K', B', Z) + \psi \frac{p^-(1-\delta)\theta}{1 + r(1-\tau_i)} \tag{13}$$

2. If $q^M(K', B', Z) \in (q^{M-}, q^{M+})$, K' satisfies

$$K' : 0 = K' - (1-\delta)K \tag{14}$$

where

$$q^{M-} \equiv (1 + \lambda)\Gamma_{K'}^{(-)}((1-\delta)K, K) - \psi \frac{p^-(1-\delta)\theta}{1 + r(1-\tau_i)}$$

and

$$q^{M+} \equiv (1 + \lambda)\Gamma_{K'}^{(+)}((1-\delta)K, K) - \psi \frac{p^-(1-\delta)\theta}{1 + r(1-\tau_i)}.$$

To build intuition, consider the neoclassical case without financial frictions, i.e., $\lambda = \psi = 0$ always. In this case, the optimality condition on action (13) reduces to $\Gamma_{K'} = q^M$, simply equalizing the marginal cost and benefit of investment. The difference brought about by the financial friction is that the marginal cost and benefit of adjustment are no longer measured by $\Gamma_{K'}$ and q^M, but by $(1 + \lambda)\Gamma_{K'}$ and $q^M + \psi p^-(1-\delta)\theta/[1 + r(1 - \tau_i)]$ as shown by (13).[27] Since the shadow value of internal funds can go above 1 with financial frictions, we can see that these frictions increase the marginal cost of investment to $(1 + \lambda)\Gamma_{K'} \geq \Gamma_{K'}$. However, they also increase the marginal benefit of investment, which is reflected in the fact that $\psi p^-(1-\delta)\theta/[1 + r(1 - \tau_i)] \geq 0$. This last term measures the shadow value of the borrowing constraint: as the firm chooses a greater production capacity, it expands its debt capacity as well. The second term of the marginal benefit of investment measures the marginal value of expanded debt capacity.

The FOC (13) shows that the target capital level chosen by the firm when action is optimal is a function of the financial conditions of the firm. This is in contrast to the neoclassical benchmark in which the target capital stock is a function of investment fundamentals, i.e., the current technology level. In particular, the tangibility of capital assets affects investment directly through the presence of θ in the efficiency condition: only to the extent that the capital assets of the firm are

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itself does not establish the *optimality of action*. This latter optimality is provided by a value matching condition, $V(K, B, Z|\nu_K = 1) \geq V(K, B, Z|\nu_K = 0)$. In the appendix, we provide a further characterization of the value matching condition. This additional condition is necessary due to the presence of the fixed cost of adjustment. If the adjustment friction were only due to the partial irreversibility, the value matching condition would not be required (see Abel and Eberly (1996) and Abel and Eberly (1994)).

[27]The fact that the action/inaction boundaries are affected by the financial condition is also due to the presence of financial friction.

pledgeable against debt financing, capacity expansion leads to the expansion of debt capacity. The secular downward trend in asset tangibility θ affects the trade-off involved in optimal investment decisions by making the marginal cost of investment weigh more than the marginal benefit of investment. One margin firms have to avoid this *de facto* strengthening of financial market frictions is to reduce their dependence on debt financing by holding outright cash assets. Using a quantitative exercise we will provide a test of the strength of this "collateral channel."

The efficiency condition for equity issuance can be derived in the same way. We start with the observation that $\varphi(E)$ is everywhere differentiable except at $E = 0$. Let $\varphi'(0)^+$ denote the right hand side derivatie of $\varphi(E)$ at $E = 0$.[28] As in the case of investment problem, we derive an optimality condition based on $\nu_E = 1$ as follows:

1. If $(1 + \lambda)(1 - \varphi'(0)^+) \geq 1$, equity issuance satisfies

$$E : 1 + \lambda = \frac{1}{1 - \varphi'(E)} > 1 \tag{15}$$

2. If $(1 + \lambda)(1 - \varphi'(0)^+) < 1$, equity issuance satisfies

$$E : E = 0 \tag{16}$$

Note that (8) implies $\varphi'(0)^+ = \varphi_1$. Hence, the condition for equity issuance can also be stated as $\lambda \geq \lambda^+ \equiv \varphi_1/(1 - \varphi_1)$. A few remarks are useful to characterize the equity issuance policy. First, (15) implies that equity issuance is associated with $1 + \lambda > 1$. Given the complementary slackness condition $\lambda D = 0$, the condition implies that $D = 0$ when equity issuance is strictly positive, i.e., the firm never issues new shares and pays out dividends simultaneously. Second, $\varphi'(E) = \varphi_1$ in our parametric assumption of equity issuance cost. This means that (15) does not pin down the level of equity issuance. However, since $D = 0$ when $E > 0$, E should be determined by a financing gap,

$$\frac{1}{1 - \varphi_1} \left\{ \varphi_0 + v_K \Gamma(K', K) + (1 + r_B)B - [(1 - \tau_c)\Pi(K, Z; w) + \tau_c \delta K + B'] \right\},$$

which is the amount of equity issuance required to satisfy the flow of funds constraint with $D =$

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[28] A negative issuance, i.e., share repurchase is identical to dividend payout in our model, and hence we do not need to consider the left hand side derivative of $\varphi'(0)^-$.

0. Third, (15) and (16) imply that it may be optimal neither to issue new shares nor to pay out dividends. Even when the shadow value of internal funds is strictly greater than 1, which requires zero dividend payout, it may still be optimal to delay equity financing until the liquidity problem is sufficiently aggravated in the sense of $\lambda \geq \varphi_1/(1 - \varphi_1)$. Fourth, as in the case of real investment problem, condition, (15) itself does not establish the *optimality of action* in equity finance. Owing to the fixed component of equity issuance cost, the optimality of action should be insured by a value matching condition, i.e., $V(K, B, Z|\nu_E = 1) \geq V(K, B, Z|\nu_E = 0)$.

To analyze the efficiency condition for B', we define, in an analogy to Tobin's Q, *financial Q* as

$$q^F(K', B', Z) \equiv -\frac{1}{1 + r(1 - \tau_i)} \int V_B(K', B', Z')Q(Z, dZ'). \tag{17}$$

q^F can be interpreted as the marginal value of corporate *savings*.[29] The efficiency condition for net-debt decision can then be stated as

$$B : 1 + \lambda - \psi = q^F(K', B', Z) \tag{18}$$

When $B' < 0$, the left side of (18) measures the marginal cost of investing in liquid financial asset as the firm forgoes the current cash flow. In this case, the borrowing constraint becomes slack, the efficiency condition simply becomes $1 + \lambda = q^F(K', B', Z)$. The right hand side of (18) should then be interpreted as the marginal value of financial investment. When $B' > 0$, the left hand side of (18) measures the marginal benefit of additional cash flow from borrowing. The right hand side of (18) in this case is interpreted as the marginal cost of borrowing as the borrowing reduces equity value. Depending on the utilization rate of the line of credit, the borrowing constraint may become binding, in which case, the marginal benefit of additional borrowing is reduced by the shadow cost ψ.

In the particular case of non-binding collateral constraint, one can merge (13) and (18) into a single expression,

$$q^F(K', B', Z) = \frac{q^M(K', B', Z)}{\Gamma_{K'}(K', K)}. \tag{19}$$

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[29]Gilchrist and Himmelberg (1995) coined the term, "financial Q". Our definition is not identical, but certainly consistent with theirs. q^F is similar to what Bolton, Chen and Wang (2012) called 'equity value of cash'. In our framework, the marginal value is modified so that it can capture the interaction with the collateral constraint, and hence $q^F = 1 + \lambda - \psi$. When and only when the collateral constraint becomes slack, q^F can be interpreted as the marginal value of cash.

This condition says that at the margin, the firm should be indifferent between physical investment and financial investment (either by investing in financial assets or by reducing debt). This suggests that the information contents of Tobin's marginal Q and financial Q (or corporate cash hoarding) are correlated along any equilibrium path, and more so if the collateral constraint is binding less frequently. In our quantitative exercise, we show that the secular downward trend in asset tangibility leads to a lower frequency of collateral constraint binding as the firms want to hold greater portions of line of credits unused. As a result, we predict that the decline in the asset tangibility leads to a greater correlation between Tobin's Q and cash hoarding, which is a new testable prediction of our theory.

3.4   Properties of Optimal Real and Financial Policies

In this section, before turning to the quantitative analysis we characterize the properties of the optimal policies of the individual firm in partial equilibrium by showing the marginal impact of each state variable. We denote a firm's real investment policy by $K' = g_K(K, B, Z; \theta)$, and net debt policy by $B' = g_B(K, B, Z; \theta)$.

3.4.1   Investment Options, Financial Frictions and Risk Management

The top panels of Figure 3 show how the net leverage policy (B'/K') responds to the current capacity level (K, on the horizontal axis). If the ratio is negative (positive), it means that the firm desires to hold net financial assets (liabilities) for the next period. The left panel shows the case when firms face both non-convex adjustment friction and partial irreversibility, whereas the right panel shows the case with the irreversibility friction only (we follow the same order in subsequent figures).

   The figures assume that the firm's current financial condition (B) is held constant at its steady state level. The three lines for net leverage ratio correspond to the cases with a normal technology level (blue, solid line), 30% above (black, dash-dotted line) and 30 % below (red, dashed line) the normal level. To highlight the properties of liquidity demand, we set $\theta = 0.4$, a relatively low level of tangible capital ratio, which implies a low degree of pledgeability of production assets in borrowing contracts. In fact, as will be shown later, this value of θ is associated with a large

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accumulation of net financial assets by firms on average.

Consider the case with the non-convex adjustment cost and irreversibility. The overall contour of the net leverage policy can be described in the following way: first, the liquidity demand is associated with relatively small firms while debt accumulation is associated with large firms on the scale of the horizontal axis; second, firms tend to accumulate liquid financial assets in anticipation of a large adjustment of production capacity, and then to disburse all liquid financial assets at the moment of exercising investment option (see the bottom left panel together with the top left panel to see the joint dynamics of capacity expansion and liquidity hoarding); third, the duration of cash hoarding tends to be longer with lower technology as the firms desire to keep their investment options alive given the mean reverting process of technology.

The general contour of the leverage policy for the pure irreversibility case is similar, but the overall level of cash hoarding is substantially smaller. The reason for this can be found in the difference in the nature of adjustments of physical capacity. In the bottom panels of the figure, one can see that the size of investment inaction region is greatly reduced without the non-convex adjustment.[30] For example, when the technology level is at its steady state (the case of blue, solid line), the inaction region without the nonconvex adjustment cost is more than 80% smaller than with the non-convex cost, which explains the shorter duration of cash hoarding without the non-convex adjustment friction.

With the non-convex adjustment friction, the size of adjustment is much larger and lumpy. In the figure, the jumps up and down in capacity levels are on the order of 30% of existing capacity, which is what Cooper and Haltiwanger (2006) classify as (dis)investment "spikes" or "lumpy investment." Lumpy investment is what the firm wants to insure itself against by holding extra liquidity in frictional financial markets. Absent this friction, the optimal amount of liquidity insurance is substantially reduced in the top right panel. In fact, in this case, the financial policy can take an extreme form of never-to-invest in liquid financial assets, build up leverage to exploit tax benefits and to pay out the proceeds of debt issuance as dividends especially when the firm's current technology level is unusually high or the firm has a substantial degree of overcapacity as shown by black, dash-dotted line on the upper right panel.

As mentioned earlier in the discussion of FOCs, the financial friction modifies the properties of

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[30]Inaction region is where K' is equalized to $(1 - \delta)K$ along the thin, dashed, purple line in the bottom panels.

the (*S*,*s*) adjustment rule for production capacity. However, as shown in the bottom panels, under the financial friction, the investment targets are not independent of currently installed capital because the amount of financing that can be raised through internal funds and borrowing may not be sufficient to cover investment expenditures if the gap between the target and currently installed capital is too large. As a result, $K' = g_K(K, B, Z; \theta)$ may positively respond to K even when firm's investment mode is active despite the absence of convex adjustment cost.

3.4.2 Financial Frictions and Debt/Cash Dynamics

In this subsection, we show how past financial conditions affect the dynamics of risk management. To that end, we consider hypothetical firms with an identical level of technology (at its steady state), but with different net-debt position (*B*). In the upper panels of Figure 4, we show how firms' liquidity demand changes as their initial financial condition changes. More specifically, we consider three levels of *B* that would imply net debt ratios -0.3 (blue, solid line), 0.0 (black, dash-dotted line), and 0.30 (red, dashed line), relative to the steady state level of total assets (book value of capital plus cash, $B/\bar{A}$), respectively.

The first can be considered as the case of so called *cash cow* firm, a special case with ample financial slack that allows the firm to behave like a financially frictionless firm in most of the state space. The third can be thought of as the firm with weak balance sheet condition, which are potentially subject to financial distress. Roughly, this case matches the net-debt structure of the firms in the 75 percentile of net-leverage distribution in 2012Q4 of Compustat. The second is an intermediate case. For each of these cases, we consider an identical level of asset tangibility at $\theta = 0.4$.

The key takeaway here is that there is a tremendous amount of *inertia* in firm's financial position: firms that have net financial assets (positive net debt) today are more likely to hold net financial assets (positive net debt) tomorrow. In a frictionless world with no adjustment costs of financial assets/liabilities, there is no reason to expect such inertia since equity markets should provide perfect shock absorption. Equity frictions are responsible for making financial variables slow moving. Thus, the inertial dynamics of firms' balance sheet is an indicator of financial frictions.

This is also related to the phenomenon known as the sensitivity of cash to cash flow in the literature (see Almeida, Campello, and Weisbach (2004)). A poor balance sheet condition today is likely to lead to a poor cash flow today, which, in turn, is likely to lead to a poor balance sheet condition tomorrow under frictional financial markets. What is surprising in our results is that it is not only the firms with positive net debt position that exhibit sensitivity to cash flow in their cash/debt policy, but it is also the firms with ample financial slacks that show sensitivity to current financial conditions. This is because the seemingly unconstrained firms have obtained such financial slack to insure themselves against future financial constraints in a forward looking manner.

The lower panels show the same phenomenon from a different angle in (B, B') diagrams, where a purple, dashed line shows 45 degree line, which, when crossed by the policy functions, indicates fixed points $g_B(K, B, Z) = B$. To show the relationship between B and B', we consider three fixed levels of production capacity. In all cases, we set the technology level equal to the steady state, 1.

Consider the case with fixed cost and irreversibility, the lower left panel. The contour of the policy functions can be described as 'S-shape' with two flat regions and an upward sloping region between them. Among the two flat regions, only one of them is the 'target' level of net-debt position, as only the lower plateau crosses the 45 degree line from the above. The upward sloping region is responsible for the sluggish dynamics of cash. It indicates a positive serial correlation between today's and tomorrow's financial condition, which, in turn, is entirely due to the financial friction in our framework rather than to frictions in adjusting balance sheet condition.

Note that the upward sloping region is much smaller when the real adjustment friction is entirely due to irreversibility (the bottom right panel).[31] The inflexibility in the adjustment of physical capital interacts with financial friction to create a greater serial correlation in cash balances. The strength of the interaction crucially depends on the state of the firm, K and Z.

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[31]The irreversibility case also shows that the upward sloping region may lie above or below the 45 degree line. If it is above the 45 degree line, the firm wants to increase (reduce) debt (financial assets). The exact location of the upward sloping part crucially depends on the current technology and over capacity as indicated by the three different policy functions.

3.4.3 Investment Predictability: Cash vs. Tobin's Q

Non-convex adjustment frictions imply that firms adjust their capital infrequently, and investment is lumpy when executed. When a firm anticipates an investment opportunity, but keeps the growth option alive, the value of equity grows due to the option value, but the current capacity shrinks at a constant rate of depreciation. This implies that a firm's Tobin's Q should be high when it nears the exercise of growth option. In contrast, Tobin's Q should be unusually low right after a large expansion of capacity. This pattern can be seen in Figure 5, which shows how Tobin's Q responds to changes in capital accumulation.[32]

If external financing is costly, the same dynamic pattern can be expected for the accumulation of liquid assets: a firm accumulates financial resources in anticipation of its investment opportunities, but decumulates its financial assets rather quickly or even accumulate debt after exercising the options. This suggests that the information contents of Tobin's Q and liquid asset holdings may be highly correlated under financial market friction and nonconvex adjustment friction.

To verify this possibility, the bottom panels reproduce the net debt-to-total capital ratios shown in Figure 3. By comparing the upper and lower panels together, one can easily see that Tobin's Q and cash accumulation are perfectly correlated when technology level changes. For instance, in the left panels for the case with the fixed adjustment friction, black, dashed vertical lines indicate the places where the orderings of Tobin's Qs associated with different technology levels change. Tobin's Q for the case of low technology is higher (lower) than the one of high technology exactly when net-debt policy $g_B(K, B, Z_{low})$ is placed lower (higher) than $g_B(K, B, Z_{high})$, suggesting that the ordering of Tobin's Q might be driven by the same mechanism behind the opposite ordering of net-debt policy. To put it more simply, Tobin's Q is higher when the firm's liquidity demand, including unused line of credit, is higher. This confirms our conjecture that cash holdings and Tobin's Q may convey the same information regarding future investments.

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[32]Tobin's Q is formally defined as $q^A \equiv \frac{1}{1+r(1-\tau_i)} \int \frac{V(K',B',Z')+[1+r(B')]B'}{K'} Q(Z, dZ')$. In an empirical context the term $[1+r(B)]B$ should be interpreted as the market value of *net debt* position, i.e., the market value of 'total debt minus cash and cash equivalents'. This means that for some firms, the total value of the firm $(V + [1 + r(B)]B)$ may be *less* than the value of equity (V) as the firm has become *net creditor*.

3.4.4 Asset Tangibility and Cash Accumulation

We now show the effect of changes in asset tangibility on the liquidity management strategy. Figure 6 considers three different values of the tangible capital ratio, $\theta = 0.8$, 0.5 and 0.3 for which we show the corresponding optimal B' policies (upper panels). $\theta = 0.8$ is chosen to match the intangible-to-total tangible assets ratio, 0.25 $(= (1 - \theta)/\theta)$ of early 1970s in the data, shown in the first panel of Figure 1. $\theta = 0.5$ can be interpreted as implying the intangible ratio 1.0 $(= (1 - \theta)/\theta)$ around early 2000s in the data. We then consider one more hypothetical value $\theta = 0.3$, (or 2.3 $= (1 - \theta)/\theta$ in terms of the intangible capital ratio) for a 'projection'. This case also serves as an illustration of the liquidity management strategy for firms operating in intangible intensive industries.[33]

The dramatic increase in liquidity demand in reaction to the decline of asset tangibility is evident in the upper panels. For instance, when the real adjustment friction consists of fixed adjustment cost and irreversibility (the upper left panel), the maximum liquidity demand doubles from 0.25 to 0.5 relative to the book value of capital chosen for tomorrow when θ declines from 0.8 to 0.5. The liquidity demands also doubles to 1.0 relative to the book value of capital when θ further declines to 0.3.

The pure irreversibility case exhibits the same pattern, although in this case the magnitude of cash holdings becomes much smaller relative to the case with non-convex adjustment friction. It is not the fixed cost per se that increases the demand for liquidity. The lumpy investment friction makes it optimal to adjust physical capital only infrequently, increasing the average size of adjustment, which then requires a bulk of liquid financial resources.

Under the frictional financial market, the firm cannot pledge the capital against borrowing due to the reduced debt capacity with the decline in θ. As the growing reliance on intangible capital in production reduces a firm's financial buffer, the firm compensates for the forgone financial flexibility by holding more liquid assets. The bottom panels of the figure show that the marginal

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[33]Care needs to be taken when setting the current financial condition. A straightforward thing to do is setting the initial financial condition at the same level for all cases. However, doing so is somewhat misleading. This is because a particular financial condition that is close to its steady state for a given parameter value (θ in this case) may be far off of another steady state under a different parameter value. For this reason, we set the initial financial condition at the stochastic steady states obtained in a series of partial equilibrium simulations. For this exercise, we simulate the partial equilibrium economy for 250 periods with 10,000 firms with identical set of idiosyncratic shocks. We delete the initial 50 years of observations before we compute the means.

gains from holding liquid assets can be quite substantial. To gauge the contribution of the liquidity management strategy to equity value, we re-solve the equity problem after imposing a constraint that the firm cannot invest in liquid financial assets, i.e. $0 \leq B' \leq B^{\max}(K'_T; p^-_T)$. We denote this equity value by V^O. The difference between V and V^O then measures the value of option to invest in liquid assets. This is equivalent to the *willingness to pay* to obtain the option to invest in liquid assets. The bottom panels show that the option can increase the value of equity more than 5 percent, which can be considered a significant improvement.

4   Results

4.1   Calibration

Our key comparative statics consists in detailing the general equilibrium outcomes of our model for levels of asset tangibility that match their historical counterparts in the US economy over the last decades. The goal of the exercise is to assess whether the model can generate a good match for the high average level of cash holdings we observe in US data for the last decade. The exercise relies on the following calibration. The elasticity of the profit function with respect to capital γ is set equal to 0.6 as in previous studies (for instance, see Hennessy and Whited (2007) for a structural estimate). We set the annual depreciation rate equal to 0.10. We choose the resale value of capital $p^- = p^-_T = p^-_N = 0.95$. This is an upper bound with respect to the available evidence on the resale value of capital (see, for instance, Ramey and Shapiro (2001)), which we choose to show that even a relatively small discount in resale value is sufficient to generate substantial amount of saving in liquid asset holdings.[34] To parametrize the fixed cost of investment, we follow Cooper and Haltiwanger (2006), who estimate a fixed cost of investment of about 1% of installed capital. We set this value to be proportional to the steady state level of capital accumulation in the frictionless benchmark. The fixed cost of operation (F_O) is set to be equal to 5% of steady state profits following Gilchrist, Sim, and Zakrajsek (2010). This value helps to match dividend payout ratio in the data. To calibrate the idiosyncratic technology shock process, we set $\rho_z = 0.8$ and $\sigma_z = 0.3$ (equivalent to 0.15 in quarterly frequency), which is roughly in line with the estimates of Gourio (2008) regarding

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[34]We have tried a range of resale values between 0.60 and 0.95. While a lower resale value of capital generates more cash holdings, we have found that this is not a first order effect. In fact, we choose 0.95 to shut down this additional channel.

the transitory part of idiosyncratic shock process based on Compustat data. As for the tangible-to-intangible capital ratio θ, this is the key parameter for which we provide an extensive set of comparative statistics.

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 the frictionless capital stock. This is slightly higher than in Bolton, Chen, and Wang (2009), for example. For the linear cost of equity issuance, estimates and calibration choices in the literature range from 0.06 (Gomes (2001)) to 0.30 (Cooley and Quadrini (2001)). We choose a relatively conservative value of 0.15, which is roughly in the middle range. Finally, we set the corporate income tax and interest income tax rates as 0.35 and 0.30, respectively. As our results show, 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.

4.2 Comparative Statistics in General Equilibrium

Tables 7−9 summarize our quantitative results on the effect of asset tangibility on real and financial decisions of individual firms and macroeconomic aggregates in stationary equilibrium. We consider 3 different levels of asset tangibility (tangible-to-total capital ratio), starting from $\theta = 0.8$ and going down to $\theta = 0.5$, a range that roughly covers its empirical counterpart for the US economy since 1970s shown in Figure 1 and Table 2. For the sake of comparison and to further highlight the quantitative implications of the model, we also report model-implied moments for an even lower hypothetical level of $\theta = 0.3$. We report the results for the non-convex adjustment cost and irreversibility case in the first three columns and the results for the irreversibility only case in the last three columns of each table.

First, consider the economy with real frictions involving both non-convex adjustment and irreversibility in Table 7. The first row shows that as the tangible capital ratio declines from 0.8 to 0.5, the cash-to-tangible asset ratio (book value of tangible capital, profits and cash holdings) increases by 16ppt from 2% to 18%. This result shows that, in line with our reduced-form estimates, an increase in firms' precautionary demand for liquid assets in response to a decline in the pledge-

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ability of production assets goes a long way toward explaining a substantial part of the observed secular trend in US cash holdings.

In fact, over the 1970-2010 period, the cash ratio in the data increased by 12ppt from 9% to 21% (the second row), suggesting that our model with non-convex adjustment frictions not only can resolve the quantitative puzzle in the literature, but if anything it actually overshoots the data. The third column of the table suggests that if asset tangibility had declined to 0.3, the model would have predicted that almost more than 40% of corporate balance sheets would consist of liquid financial assets, which represents a radical departure form the conventional notion of a public corporation which relies mostly on external finance. While this result may be surprising and the parameter choice is out of range when the benchmark is the entire US economy, it does have some relevance for firms operating in technology intensive industries.

In contrast, the right panel of Table 7 shows that the irreversibility friction by itself is not sufficient to match the magnitudes of liquid assets seen in the data: as the tangible capital ratio goes down from 0.8 to 0.5, cash-to-tangible asset ratio only goes up 5ppt from zero to 5% (the first row). While the hypothetical decline in the tangible ratio to 0.3 can generate 20% cash ratio, these results indicate that the interplay of both financial and real frictions is key to explaining the magnitude of liquidity hoardings we see in the data.[35]

The fourth row of the table shows that asset tangibility has a dramatic impact on net-leverage, a result that mirrors the rise in precautionary savings and further corroborates our "shrinking debt capacity" mechanism. The last row of the table shows that the decline in asset tangibility also greatly reduces the usage of debt capacity: the limited pledgeability not only reduces the debt capacity of firms, but leads them to hold greater slack in borrowing capacity. As we mentioned earlier, the model penalizes cash holding in two ways: tax disadvantage and agency costs. The precautionary saving motive in the face of rising intangible capital is potent enough to overcome these disadvantages. For instance, the economy with both non-convex cost and irreversible frictions is characterized by a reduction in net-leverage by 30ppt from 47% to 17% as asset tangibility

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[35]Increasing the degree of resale discount certainly helps with generating greater cash hoardings in irreversible investment models. We have experimented with substantially lower resale values up to $p^- = 0.5$. However, we could increase the cash ratio only by 3ppt all else equal, thus confirming a fundamental limitation to generating precautionary saving through this channel. One reason for this failure is that once the resale value of capital goes down below 0.85, firms in the model never disinvest capital for liquidity reason (see Veracierto (2002)), making no material difference for liquidity hoarding.

declines from 0.8 to 0.5.

Figure 7 shows how the joint distribution of capital and net-debt positions also responds to the decline in the tangible capital ratio from $\theta = 0.8$ (blue bars) to 0.5 (red bars) to 0.3 (light blue bars). As the tangible capital ratio declines, the distribution moves to the left in such a way that more probability mass is allocated to the negative portion of the support on the net-debt dimension. In fact, with $\theta = 0.3$, the stationary distribution allocates more probability mass to the negative support than to the positive support, which means that the corporate sector moves toward becoming a net creditor sector. The third column of the fourth row confirms this result. The flip side of this transformation is that households turn into a net borrowing sector, supplying liquid financial assets to the corporate sector.

Table 8 shows several additional model-implied moments, including how asset tangibility affects the sensitivity of investment and cash holdings to cash flows (Rows [1]-[2]), and the comovement between investment, cash and Tobin's Q (Rows [3]-[4]), and the properties of distribution of investment rates (Rows [5]-[6]). As predicted, asset tangibility generally increases the sensitivity of investment and cash to cash flow. This is another manifestation of the shrinking debt capacity. As shown in Row [3], the contemporaneous correlation between investment and Tobin's Q is negative due to the nature of the (S,s) adjustment in capacity. Notably and in line with our earlier discussion of investment predictability, the contemporaneous correlation between cash and Tobin's Q is positive, and more importantly, increasing with the degree of intangibility. For instance, consider the case with irreversibility friction only, shown in Row [3] of right panel. When $\theta = 0.8$, the correlation is essentially zero. However as θ drops to 0.5, the correlation jumps to 0.83. The increase in the contemporaneous correlation is less dramatic when capacity adjustment involves non-convex adjustment cost as it jumps from 0.6 to 0.88. These results confirm our prediction that cash and Tobin's Q become more highly correlated as the share of tangible assets declines and firms are led to rely increasingly on internal sources of funding.

Finally, Table 9 shows that the decline in asset tangibility can have sizable, adverse consequences for the overall level of capital accumulation, output and consumption. Depending on the specification of the adjustment cost friction, a transition from $\theta = 0.8$ to $\theta = 0.3$ can have an impact on capital accumulation and consumption of an order of magnitude up to -2.3% and -1.2%, respectively. As the production technology shifts toward intangible assets, capital assets

lose a substantial part of their eligibility as collateral, which leads to a tightening of the debt constraint. Surprisingly, however, there is virtually no impact on total firm value, as shown in the last row. This result implies that firms are able to almost perfectly neutralize the impact of declining asset tangibility by switching to liquidity management strategies that rely more heavily on cash. Nevertheless, the results on real economic activity point to an inefficiency in that the limited pledgeability of capital assets hinders efficient capital allocation, a result that could have been avoided if the debt contracts had been fully enforceable.

4.3 Alternative Specification: A General CES Case

Our baseline model uses the special case of CES capital aggregator when $\rho = \infty$, which implies no substitutability between tangible and intangible capital inputs. It is important to assess the extent to which our results owe to this specific assumption. To address this question, we consider the case of a general CES capital aggregator. However, we have to face a classical curse of dimensionality issue that arises in this case due to the fact that with this more general technology we need to track the two types of capital as separate state variables.

A final contribution of the paper is to show that one can overcome this problem and recover tractability by adopting the following setup: (i) the idiosyncratic technology follows a geometric random walk, $\log Z = \log Z_{-1} + \epsilon$, $\epsilon \sim N(-0.5\sigma_\epsilon^2, \sigma_\epsilon^2)$; (ii) the profit function is homogeneous of degree 1 in the technology and capital service, i.e., $\Pi(K_T, K_N; \theta, \rho) = \eta(w)Z^{1-\gamma}\Phi(K_T, K_N; \theta, \rho)^\gamma$; (iii) the fixed costs of operation, the fixed costs of capital adjustment, and the fixed cost of equity issuance are proportional to the current technology level. Under these assumptions, the equity value function is homogeneous of degree 1 in $(K_T, K_N, B, K_T', K_N', B', Z)$ as the capital aggregator is homogeneous of degree 1 in (K_T, K_N, Z) and so is the profit function in Z and $\Phi(K_T, K_N; \theta, \rho)$. Using this property, we can normalize the value function by the current technology level Z, and

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solve the following 'normalized' value maximization problem:

$$v(k_T, k_N, b) = \min_{\lambda, \psi} \max_{\tilde{k}'_T, \tilde{k}'_N, \tilde{b}', d, e} \left\{ (1+\lambda)d - e + \psi \left[p_T^- \frac{(1-\delta_T)\tilde{k}'_T}{1+r(\tilde{b}')} - \tilde{b}' \right] \right.$$

$$\left. + \frac{1}{1+r(1-\tau_i)} \int \exp(\epsilon') v \left(\frac{\tilde{k}'_T}{\exp(\epsilon')}, \frac{\tilde{k}'_N}{\exp(\epsilon')}, \frac{\tilde{b}'}{\exp(\epsilon')} \right) dF(\epsilon') \right\} \tag{20}$$

s.t.

$$d = (1-\tau_c)[\pi(k_T, k_N) - F_o] - \sum_{i=T,N} [\Gamma(\tilde{k}'_i, k_i) - \tau_c \delta_i k_i] \tag{21}$$

$$-[1+r(b)]b + \tilde{b}' + e - \varphi(e)$$

where the normalized profit function is given by

$$\pi(k_T, k_N) = \eta(w) \left[(1-\theta) \left(\frac{k_T}{1-\theta} \right)^{-\rho} + \theta \left(\frac{k_N}{\theta} \right)^{-\rho} \right]^{-\gamma/\rho}$$

and $k_T \equiv K_T/Z$, $k_N \equiv K_N/Z$, $b \equiv B/Z$, $\tilde{k}'_T \equiv K'_T/Z$, $\tilde{k}'_N \equiv K'_N/Z$, and $\tilde{b}' \equiv B'/Z$.

Even with the normalization, solving for $v(k_T, k_N, b)$ requires tremendous computing resources. For this reason, we do not solve for a stationary general equilibrium, but solve for the individual firm problem, and then simulate the model economy with a set random draws for idiosyncratic technology shocks in partial equilibrium with 250 periods and 10,000 firms.[36] While not ideal, our results indicate that we do not lose much insight by adopting this partial equilibrium setting.

Table 10 reports moments from this simulation exercise. In interpreting these results, it is important to keep in mind that the value of θ is no longer identical to the tangible-to-total capital ratio since firms can now freely deviate from this value. The idea of the exercise is to see if firms still react to changes in θ in the same way they did in our baseline results. With more flexible technology, firms may not have as strong an incentive to hoard liquid assets, since they now gain an extra margin from being able to substitute between the two types of real assets.

The first and second rows show the impact of technological change on the ratios of cash-to-tangible assets and net debt-to-tangible assets. Firms do not hold liquid assets when $\theta = 0.8$. Relative to the Leontief case firms can now can use the more flexible technology as another risk management tool: when facing investment opportunities, firms can choose a higher ratio of

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[36]When computing moments, we delete the initial 50 periods.

tangible-to-intangible capital ratio to expand their borrowing capacity despite lower technological efficiency. $\rho = -0.3$ means that the marginal cost of deviating from the technologically efficient ratio is not big and, as a result, it reduces the amount of liquidity demand. However, as θ decreases to 0.5 and to 0.3, liquidity demand picks up significantly since the efficiency loss involved in the adoption of higher tangible capital ratios becomes higher and, as a result, firms are led to use their financial side for risk management and hold more liquid assets. As in the baseline case, the net leverage ratio declines monotonically as θ goes down. This result, together with those on cash ratio, confirms that our baseline conclusions are not driven by the Leontief assumption. The extended model also shows that the information content of Tobin's Q and cash holdings is almost identical as these variables are nearly perfectly correlated (row [3]).

The last row of the table reports the correlation between net leverage and tangible asset ratios. This correlation increases as θ goes down. This result shows that when firms find it optimal to choose higher leverage ratios they tend to choose higher levels of tangible capital ratios. In the model, causation runs in both directions. Firms can borrow more because they have more tangible capital as collateral. However, at the same time, more vulnerable balance sheet conditions also lead firms to hold more pledgeable assets in their balance sheet since these assets expand borrowing capacity for a long period of time and since it is costly to strengthen their balance sheet conditions by holding liquid assets in the short run.

Finally, an advantage of the CES extension is that it offers a setting that can be used to explore additional channels, over and above the collateral one that constitutes the main focus of our paper. For example, it would be interesting to explore whether lower asset tangibility also leads to higher cash holdings when intangible assets have lower depreciation rates or adjustment costs. However, these additional channels are beyond the scope of the present paper and constitute a potentially interesting avenue for future work.

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 model where intangible capital matters for firms' cash management decisions through a "collateral channel" 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 and macroeconomics, which to date had eluded standard explanations.

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Figure 1: Intangible Capital, Cash Hoardings and Leverage
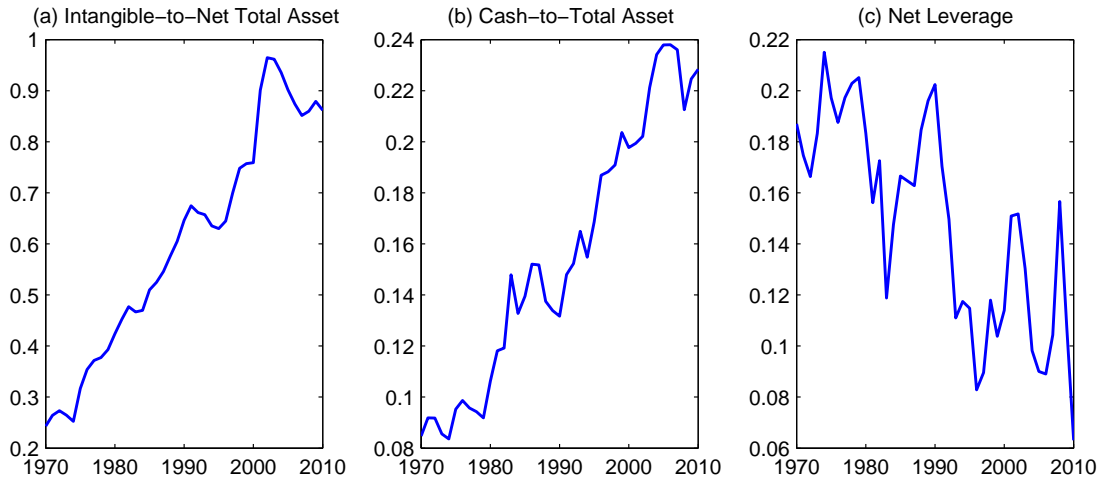
Note: Panel (a), (b) and (c) show intangible capital ratio relative to total (tangible) assets, cash-to-total (tangible) assets and net-debt-to-total (tangible) assets, respectively. The sample includes all Compustat firm-year observations from 1970 to 2010 with positive values for the book value of 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.

Figure 2: Changes in Intangible Capital and Cash: Cross-Industry, Cross-Firm Variation
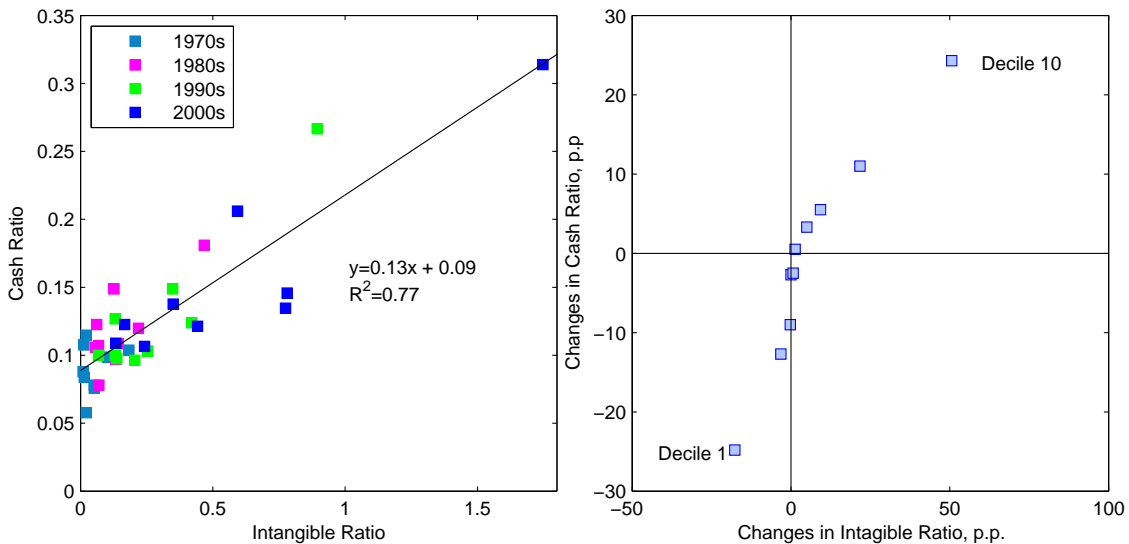
Note: The sample includes all Compustat firm-year observations from 1970 to 2010 with positive values for the book value of total assets and sales revenue for firms incorporated in the United States. Financial firms (SIC code 6000-6999) and utilities (SIC codes 4900-4999) are excluded from the sample, yielding a panel of 176,877 observations for 18,535 unique firms. Variable definitions are provided in the Appendix Table 1 also shows the levels of each combination of cash ratio and intangible ratio across time and industry.

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Figure 3: Investment Opportunities, Optimal Cash and Capacity

(a) Bnew/Knew: IRR+FIX

z = 1.0
z = 1.3
z = 0.7

capital, K

(c) Bnew/Knew: IRR

z = 1.0
z = 1.3
z = 0.7

capital, K

(b) Knew: IRR+FIX

z = 1.0
z = 1.3
z = 0.7

capital, K

(d) Knew: IRR

z = 1.0
z = 1.3
z = 0.7
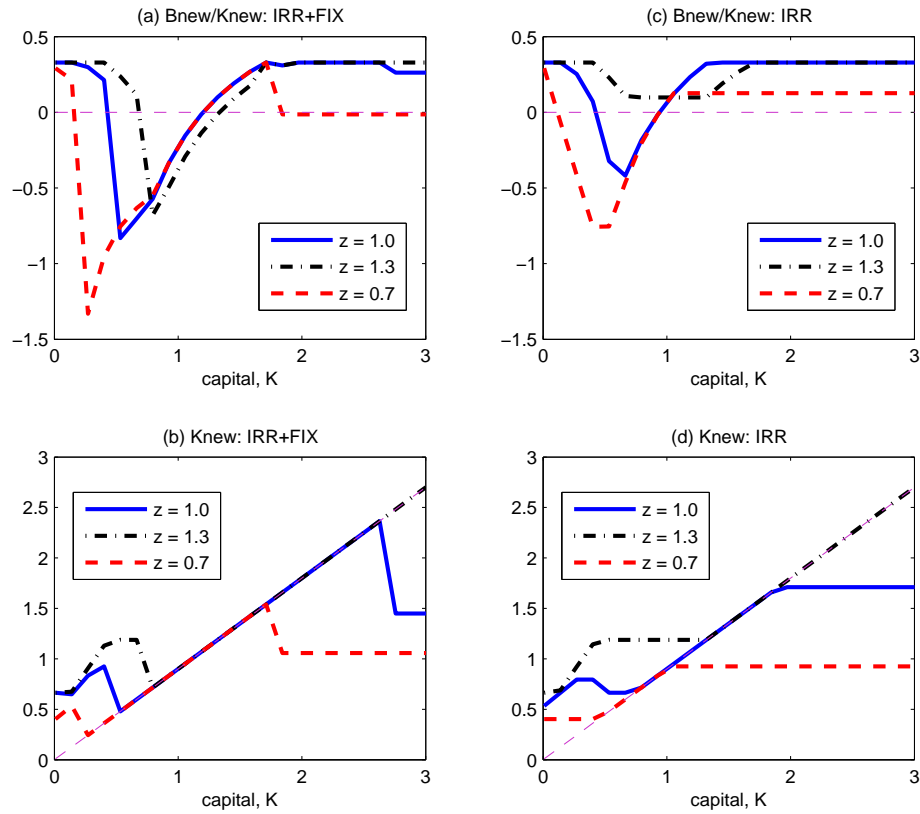
capital, K

Figure 4: Financial Condition and the Dynamics of Cash

(a) Bnew/Knew: IRR+FIX

b/E(k) = −0.3
b/E(k) = 0.0
b/E(k) = 0.3

capital, K

(c) Bnew/Knew: IRR

b/E(k) = −0.3
b/E(k) = 0.0
b/E(k) = 0.3

capital, K

(b) Bnew: IRR+FIX

k/E(k) = 0.58
k/E(k) = 0.72
k/E(k) = 0.86

capital, B

(d) Bnew: IRR

k/E(k) = 0.58
k/E(k) = 0.72
k/E(k) = 0.86

capital, B

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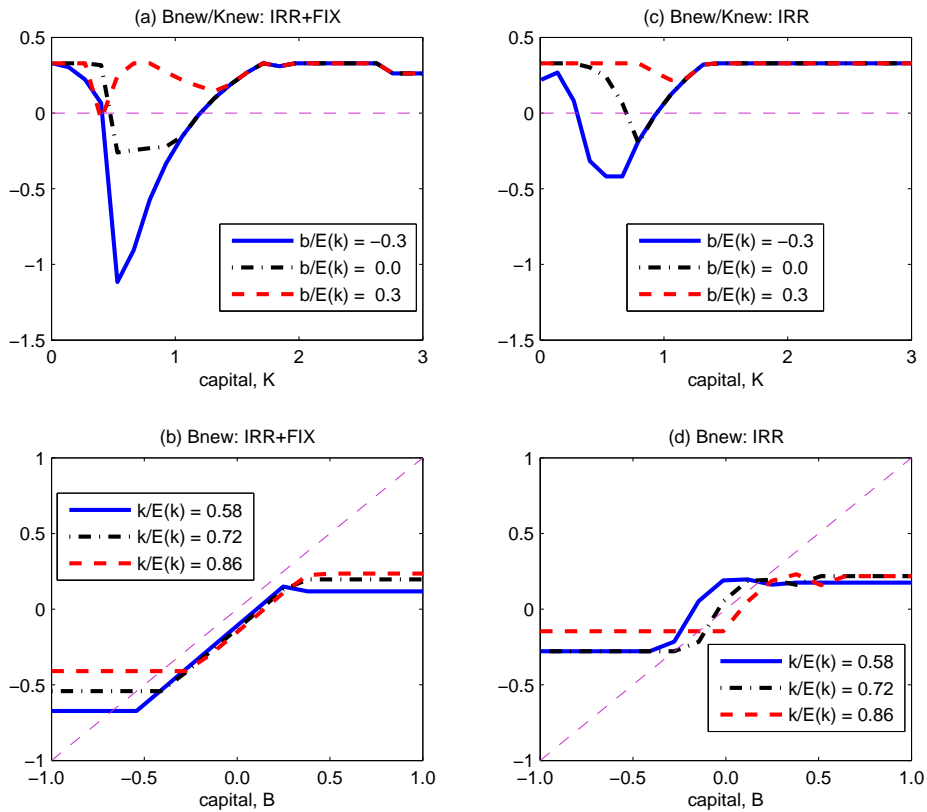
Figure 5: Tobin's (Average) Q and Cash Holdings

(a) Average Q: FIX+IRR

(c) Average Q: IRR

(b) Bnew/Knew: FIX+IRR

(d) Bnew/Knew: IRR
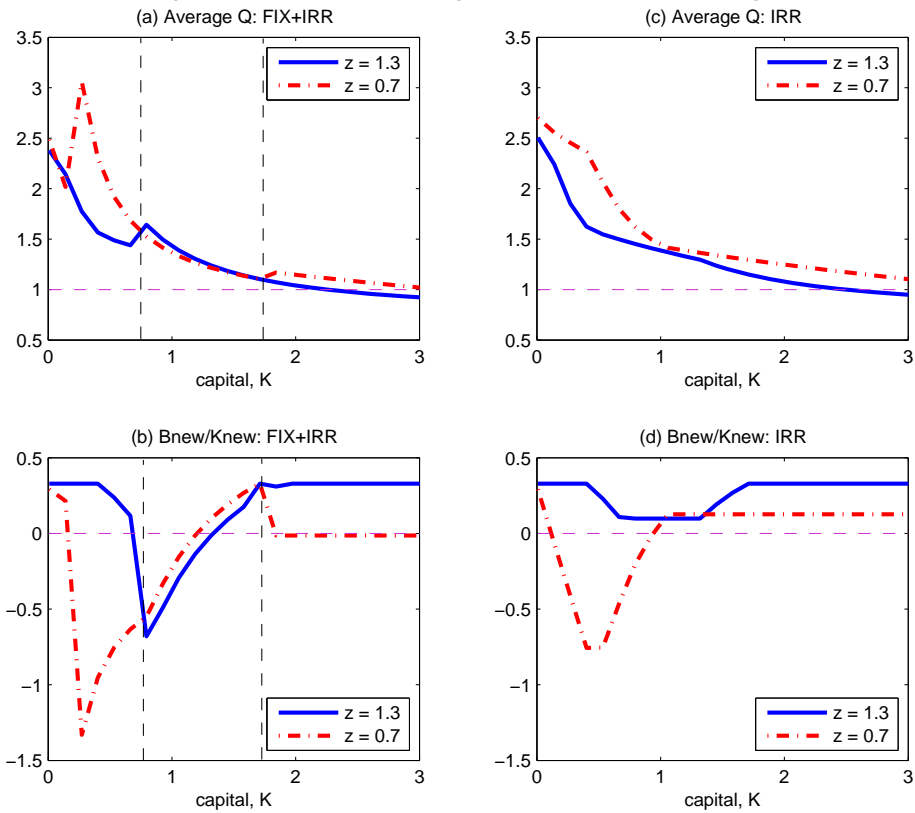
Figure 6: Asset Tangibility, Value of Liquidity and Cash Holdings

(a) Bnew/Knew, FIX+IRR

(c) Bnew/Knew, IRR

(b) $100 \times \Delta\log(V/V^O)$, FIX+IRR

(d) $100 \times \Delta\log(V/V^O)$, IRR
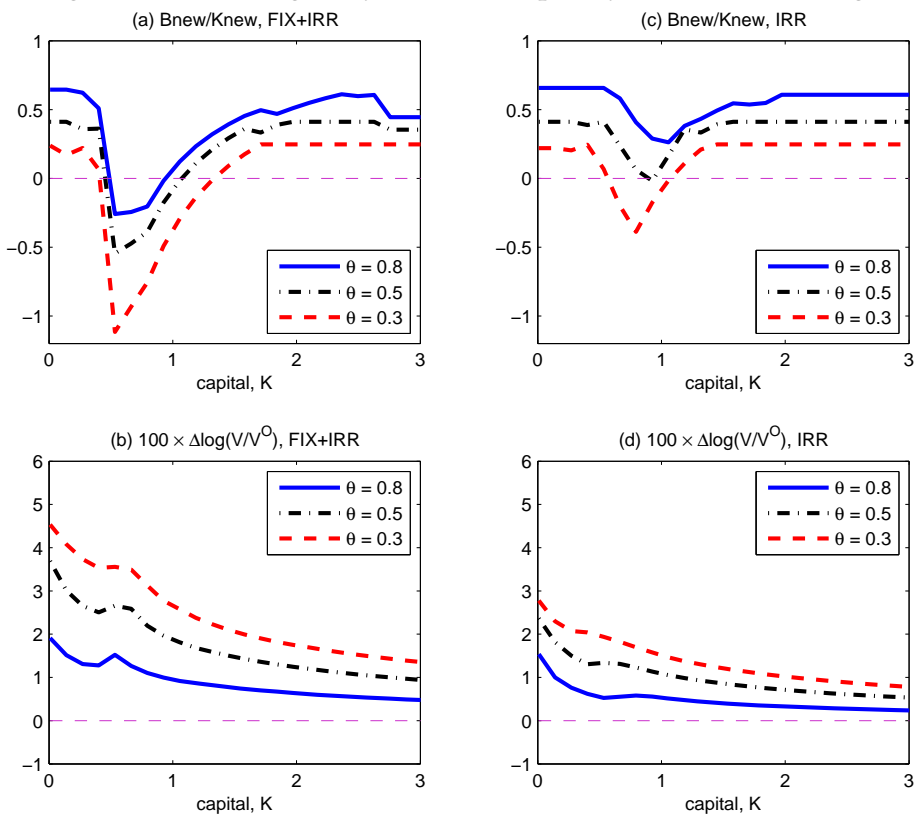
Figure 7: Asset Tangibility and Stationary Distribution of Capital and Net-Debt
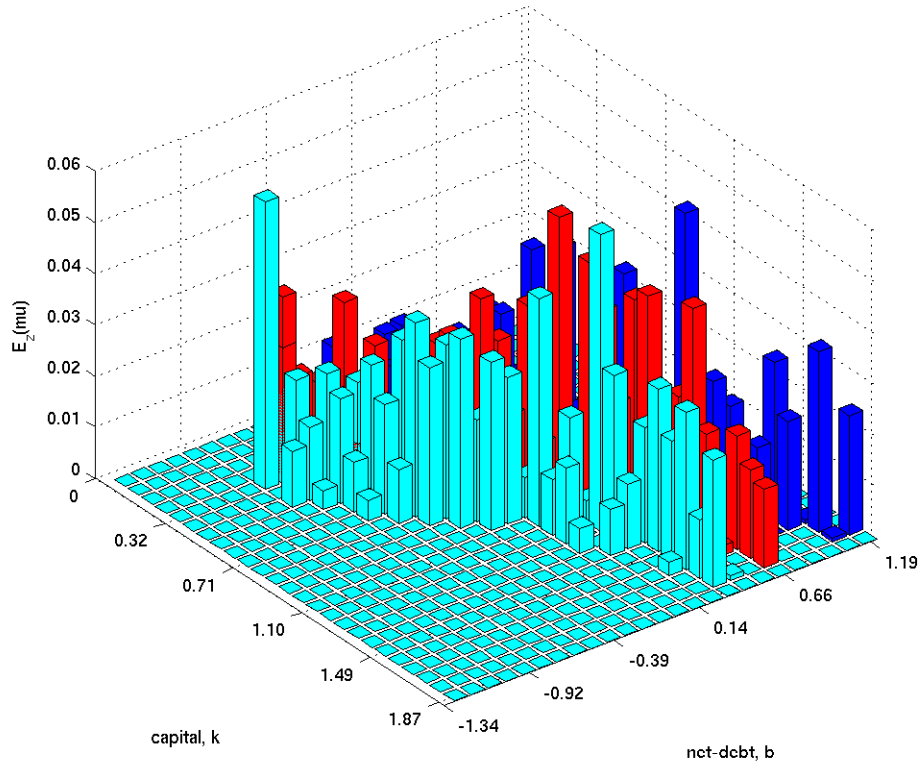
Note: Blue, red and cyan bars are the cases with $\theta = 0.8$, 0.5 and 0.3, respectively. $E_z[\mu]$ is the marginal distribution of (K, B).

Table 1: Evolution of Industry-level Cash Hoarding and Intangible Capital

	1970s		1980s		1990s		2000s	
	Cash	Intgbl K	Cash	Intgbl K	Cash	Intgbl K	Cash	Intgbl K
Hlth	0.10	0.13	0.25	0.71	0.34	2.33	0.41	5.07
BusEq	0.10	0.18	0.18	0.47	0.27	0.89	0.31	1.75
Durbl	0.08	0.05	0.11	0.14	0.10	0.25	0.15	0.78
Chems	0.10	0.10	0.12	0.22	0.12	0.42	0.13	0.77
Other	0.11	0.02	0.15	0.13	0.15	0.35	0.21	0.59
Manuf	0.08	0.05	0.10	0.13	0.10	0.21	0.12	0.44
Telcm	0.06	0.02	0.08	0.07	0.13	0.13	0.14	0.35
NonDur	0.08	0.01	0.11	0.07	0.10	0.14	0.11	0.24
Enrgy	0.11	0.01	0.12	0.06	0.10	0.13	0.12	0.17
Shops	0.09	0.01	0.11	0.06	0.10	0.07	0.11	0.13

Note: Cash ratio is defined as cash and equivalents relative to total (tangible) assets and intangible ratio (Intgbl K) is defined as intangible-to-tangible asset ratio.

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Table 2: 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 Appendix C..

Table 3: Panel Evidence on Intangible Capital and Firm Financing

	Whole Sample				R&D>0 Firms			
Panel A: Intangible Capital, Cash, and Net Indebtedness								
	Cash		Net Debt		Cash		Net Debt	
	OLS	FE	OLS	FE	OLS	FE	OLS	FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intangible								
Capital$_{t-1}$	0.086***	0.061***	-0.111***	-0.047***	0.104***	0.067***	-0.125***	-0.067***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
% Predicted Rise	42.5%				43.4%			
Predicted Rise	0.069				0.075			
Year fixed 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$_{it}$ = α_0+ $(1 - \alpha)$ *Cash$_{it-1}$ +$\beta * X_{it-1}$ + ϵ_{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 α. 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 ϵ, ln(0.5)/ln(1 - α). 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 Appendix C.

Table 4: Panel Evidence on Intangible Capital, Corporate Investment, and Firm Dynamics

	Whole Sample				R&D>0 Firms			
Panel A: Sensitivity to Cash Conditions								
	Investment		Sales Growth		Investment		Sales Growth	
	OLS	FE	OLS	FE	OLS	FE	OLS	FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CDF(Cash$_{t-1}$)	0.071***	0.059***	0.145***	0.125***	0.076***	0.059***	0.166***	0.132***
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted R^2	0.459	0.595	0.105	0.295	0.390	0.515	0.102	0.291
Panel B: Sensitivity to Cash Conditions By Quartiles of Intangible Capital								
	Investment		Sales Growth		Investment		Sales Growth	
	OLS	FE	OLS	FE	OLS	FE	OLS	FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Q1	0.049***	0.045***	0.145***	0.109***	0.054***	0.059***	0.145***	0.106***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Q2	0.055***	0.053***	0.151***	0.118***	0.055***	0.061***	0.155***	0.148***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Q3	0.062***	0.059***	0.165***	0.130***	0.062***	0.069***	0.190***	0.160***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Q4	0.096***	0.078***	0.280***	0.268***	0.106***	0.089***	0.303***	0.283***
	(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. b. Panel A reports estimates from panel regressions of total corporate investment (capex + R&D) and annual sales growth on the empirical cumulative distribution function (CDF) of lagged cash to book assets ratio for OLS and firm fixed effects specifications. Reported coefficients are the change in the dependent variable associated with a change from the lowest to the highest values of lagged cash. 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 same regressions as in Panel A for different sub-samples based on quartiles of the distribution of intangible capital. d. Year dummies as well as firm-level controls for standard determinants of corporate investment are included in all regressions. p-values are in parentheses and are clustered at the firm level. e. Detailed variable definitions are in Appendix C.

Table 5: Why does Intangible Capital Matter? Panel Evidence on Financial and Real 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 sub-sample 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 sub-sample 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 - |Capex/book assets|<.01 (Rows [1] to [2]), and whether in the industry there are investment spikes - |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 Appendix C.

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Table 6: Baseline Calibration

Description	Calibration
Parameters of Technology and Preferences	
Returns-to-scale	$\xi = 0.83$
Value-added share of capital	$\alpha = 0.30$
Depreciation	$\delta = 0.10$
Elasticity of substitution between capital inputs	$\rho = \infty, -0.3$
Purchase price of capital	$p^+ = 1.00$
Partial irreversibility	$p^- = 0.95$
Fixed cost of adjustment	$F_k = 0.01k^*$
Fixed cost of operation	$F_0 = 0.05k^*$
Persistence of technology shock	$\rho_z = 0.80$
Constant relative risk aversion	$\sigma = 1.00$
Volatility of technology shock	$\sigma_z = 0.30$
Inverse of Frisch elasticity of labor supply	$\phi = 1.00$
Financial Parameters	
Risk-free rate	$r = 0.06$
Agency Cost of Cash Holdings	$\kappa = 5\,\text{bps}$
Fixed cost of issuance	$\varphi_0 = 0.015k^*$
Linear cost of issuance	$\varphi_1 = 0.15$
Interest rate income tax rate	$\tau_i = 0.30$
Corporate income tax rate	$\tau_c = 0.35$

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

Table 7: Asset Tangibility, Cash Hoardings and Net-Leverage

	FIX+IRR			IRR		
Technological parameter θ	0.80	0.50	0.30	0.80	0.50	0.30
Cash-to-tangible assets (model)	0.02	0.18	0.42	0.00	0.05	0.20
Cash-to-tangible assets (data)[a]	0.09	0.21	-	0.09	0.21	-
Net debt-to-tangible assets (model)	0.47	0.17	-0.24	0.60	0.43	0.13
Net debt-to-tangible assets (data)[a]	0.18	0.05	-	0.18	0.05	-
Utilization of debt capacity (model)	0.57	0.46	0.29	0.76	0.61	0.50

Note: The table shows the moments of endogenous variables in the economy with irreversibility and fixed adjustment cost, using stationary distribution. The stationary distribution $\mu^*(K, B, Z)$ is discretized on a space (50,50,5). a. Data moments are average values of 1970s and 2000s.

Table 8: Asset Tangibility and Cash Flow Sensitivity of Cash and Investment

	FIX+IRR			IRR		
Technological parameter θ	0.80	0.50	0.30	0.80	0.50	0.30
Corr (Investment, Cash flow)	0.28	0.30	0.33	0.21	0.25	0.30
Corr (Cash, Cash flow)	0.49	0.76	0.75	0.05	0.61	0.71
Corr (Investment,Tobin's Q)	-0.20	-0.21	-0.20	-0.31	-0.32	-0.31
Corr (Cash, Tobin's Q)	0.60	0.88	0.91	0.05	0.83	0.86
Skewness (Investment)	2.19	2.27	2.27	0.68	0.38	0.41
Kurtosis (Investment)	8.10	8.47	8.22	5.23	4.69	5.11
Tobin's Q (Mean)	1.63	1.62	1.61	1.64	1.66	1.66

Note: The table shows the moments of endogenous variables in the economy with irreversibility and fixed adjustment cost, using stationary distribution. The stationary distribution $\mu^*(K, B, Z)$ is discretized on a space (50,50,5).

Table 9: Asset Tangibility and Real Economy in Stationary Equilibrium

	FIX+IRR			IRR		
Technological parameter θ	0.80	0.50	0.30	0.80	0.50	0.30
Capital Accumulation ($\times 10$)	9.85	9.74	9.75	10.0	9.85	9.77
Consumption ($\times 10$)	5.57	5.54	5.55	5.64	5.59	5.57
Output ($\times 10$)	6.54	6.51	6.52	6.62	6.57	6.55
Hours ($\times 10$)	4.71	4.70	4.70	4.74	4.72	4.72
Total Value of Firm	1.96	1.96	1.97	2.01	2.01	2.01

Note: The table shows the moments of endogenous variables in the economy with irreversibility and fixed adjustment cost, using stationary distribution. The stationary distribution $\mu^*(K, B, Z)$ is discretized on a space (50,50,5).

Table 10: Comparative Statics: the Case of CES

Technological parameter, θ	0.80	0.50	0.30
Cash-to-tangible assets	0.00	0.12	0.25
Net debt-to-tangible assets	0.46	-0.04	-0.23
Corr (Cash, Tobin's Q)	n/a	0.94	0.97
Corr (Net leverage ratio, Tangible asset ratio)	0.33	0.41	0.59

Note: The table shows the moments of endogenous variables in the economy with irreversibility and fixed adjustment cost, using actual simulation of size T=200 and N=10,000. The Markov Chain in the baseline is replaced with a Gauss-Hermite quadrature with same number of grids.

Appendices

A Stationary Equilibrium

The model economy consists of a continuum of firms that combine capital and labor to produce final outputs, and a continuum of households that provide labor hours to firms to earn market wages, consume final outputs and invest in firm's shares and debts to accumulate wealth. For the description of the firm problem, see the main text.

A.1 Stationary Distribution

The presence of persistent idiosyncratic shocks, DRS production technology and financial market friction imply a non-degenerate joint distribution of technology, capital accumulation and financial balances. We denote the joint distribution by $\mu(K, B, Z)$. At any point in time, the joint distribution satisfies the following of motion[37]:

$$\mu'(\mathbf{K} \times \mathbf{B} \times \mathbf{Z}) = \int \mathbf{1}(g_k(K, B, Z; \mu) \in \mathbf{K}) \cdot \mathbf{1}(g_b(K, B, Z; \mu) \in \mathbf{B}) \cdot Q(Z, \mathbf{Z})\mu(dK, dB, dZ) \quad (22)$$

where $g_k(K, B, Z; \mu)$ and $g_b(K, B, Z; \mu)$ are the optimal capital and financial policies that solve the program (11). Note that the distribution next period μ' is determined by today's optimal policies, which then depends on today's distribution μ via market clearing wage. The stationary distribution is the fixed point solution to the above functional equation: $\mu' = \mu = \mu^*$. The stationary distribution can be used to compute exact moments of any order as well as *aggregates*.[38]

A.2 Households

Since our focus is on firms' investment and financial policies, we assume the existence of a representative agent for the household sector. The household is assumed to maximize the expected present value of utility flows discounted at $\beta < 1$: $\max \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(C_t, H_t)$. The utility flow is strictly increasing and concave in consumption, and is strictly decreasing and concave in labor hours. For ease of interpretation of general equilibrium effects, we adopt a utility form that is nonseparable in consumption and hours following Greenwood, Hercowitz, and Huffman (1988). More specifically, we specify

$$u(C, N) = \frac{1}{1-\sigma}\left[\left(C - \frac{\zeta}{1+\phi}N^{1+\phi}\right)^{1-\sigma} - 1\right]. \quad (23)$$

Such specification abstracts from wealth effects on labor supply, thus making it straightforward to interpret the effects of technological changes on capital accumulation.

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[37] See Stokey, Prescott, and Lucas (1989) for theoretical discussion, and Gourio and Miao (2010) for a computational example.

[38] In principle, it is conceivable that the firm may want to exit owing to the presence of fixed costs of operation. For this reason, we allow the firms to have an exit option during our simulation such that the value of equity is truncated below by a certain threshold value $\bar{V}$. This can be achieved by replacing $V(K', B', Z')$ with $\max\{\bar{V}, V(K', B', Z')\}$ in the continuation value term. However, exit does not occur in our simulation with baseline calibration of the model in which we set $\bar{V} = 0$. If, however, the outside option of the firm, $\bar{V}$ is substantially greater than zero the firms may want to exit in certain circumstances. For simplicity, we adopt an implicit assumption that the sunk costs of entry are given such that that the value of outside option remains at a low value, and the value of new firm entry is no greater than the required gross return on the costs of entry, i.e., $\mathbb{E}[V(0, 0, Z_0)] - [1 + r(1 - \tau_i)]F_S \leq 0$.where Z_0 is an initial draw from the erogodic distribution of Z and F_S is the sunk entry costs, which can be interpreted as a natural entry barrier.

The household earns competitive market wage w per work hour, and saves by investing in shares and debt issued by the firms. The budget constraint of the household is given by

$$C + \int (P_S S' + B') \mu(dK, dB, dZ) = wN + T_G + T_F \tag{24}$$
$$+ \int \{(D + \tilde{P}_S)S + [1 + r(1 - \tau_i)]B\} \mu(dK, dB, dZ).$$

where P_S is the (ex-dividend) value of equity today, $\tilde{P}_S$ is the (ex-dividend) value today of existing shares outstanding yesterday. S and S' are the number of shares outstanding yesterday and today, respectively. We assume that the proceeds of interest and corporate income taxes are transferred to the household in a lump sum, denoted by T_G. We also assume that all fixed costs of operation and investment are transferred to the household in the same way, denoted by T_F. The two value terms P_S and $\tilde{P}_S$ are linked to each other by an accounting identity,

$$P_S S' = [\tilde{P}_S + E - \varphi(E)]S \tag{25}$$

This identity simply says that the total value of equity today is the sum of the total value of shares outstanding yesterday and the value of new shares issued today. Substituting (25) in (24) and imposing stock market clearing condition $S = S' = 1$ yields

$$C + \int B' \mu(dK, dB, dZ) = wN + T_G + T_F \tag{26}$$
$$+ \int \{D - [E - \varphi(E)] + [1 + r(1 - \tau_i)]B\} \mu(dK, dB, dZ).$$

A few remarks are in order. First, by substituting (9) in (26), one can see that the term $E - \varphi(E)$ vanishes. This makes it clear that the costs of issuing equity take the form of discount sales of new shares such that the dilution costs to the old shareholders are exactly offset by the gains of new shareholders in general equilibrium, thus leaving the resource constraint of the economy intact. Second, we use the same notation B to denote the debt issued by a firm and held by the household. When B is positive, this means that the household has a financial claim on a firm. When B is negative, this implies that the household owes money to a firm. Finally, we assume that the differential tax treatment of interest incomes and expenses applies only to the firms, but not to the household. This implies that the after-tax interest rate is equalized to the time discount rate of the household in the stationary equilibrium, $1 + r(1 - \tau_i) = \beta^{-1}$.

A.3 Government

The government follows a balanced budgeting rule, collecting taxes and then transferring them to the household. The budget constraint is given by

$$T_G + T_F = \int \left[\tau_c[\Pi(K, Z) - F_0] - \tau_c \delta K - (\tau_c - \tau_i) \max\{0, B\} \right] \mu(dK, dB, dZ) \tag{27}$$

When a firm holds a strictly negative financial balance B, the taxes on interest incomes and the deduction on interest expenses of the household are offset.

A.4 Stationary Equilibrium

The stationary equilibrium consists of a constant market wage w, the stationary distribution μ^*, the individual policy rules of the firms, $K' = g_K(K, B, Z; \mu^*)$, $B' = g_B(K, B, Z; \mu^*)$, $E = g_E(K, B, Z; \mu^*)$,

$D = g_D(K, B, Z; \mu^*)$, $H^D = H^D(K, Z, w; \mu^*)$, $I = p(g_K(K, B, Z; \mu^*), K) \cdot [g_K(K, B, Z; \mu^*) - (1 - \delta)K] \equiv g_I(K, B, Z; \mu^*)$, the policy rules of the representative household, $C = C(w; \mu^*)$, and $H^S = H^S(w; \mu^*)$ such that labor and goods markets clear[39]:

$$H^S(w; \mu^*) = \int H^D(K, Z, w; \mu^*) \mu^*(dK, dB, dZ) \tag{28}$$

$$C(w; \mu^*) = \int [Y(K, Z, w; \mu^*) - g_I(K, B, Z; \mu^*) + \kappa \min\{0, g_B(K, B, Z; \mu^*)\}] \mu^*(dK, dB, dZ). \tag{29}$$

B Investment with a Non-Convex Cost with Financial Friction

To analyze under what condition an active (dis)investment is warranted, we reformulate the program (11) as a discrete choice problem, $V(K, B, Z) = \max\{V(K, B, Z | \nu_K = 1), V(K, B, Z | \nu_K = 0)\}$ where the two auxiliary value functions can be defined as

$$V(K, B, Z | \nu_K = 1) = \min_{\lambda, \psi} \max_{K', B', E, \nu_E} \left\{ (1 + \lambda)D - E + \psi \left[\frac{p^-(1 - \delta)\theta}{1 + r(1 - \tau_i)} K' - B' \right] \right. \tag{30}$$
$$\left. + \frac{1}{1 + r(1 - \tau_i)} \int V(K', B', Z')Q(Z, dZ') \right\}$$

s.t.

$$D = (1 - \tau_c)\Pi(K, Z; w) + \tau_c \delta K - \Gamma(K', K) - [1 + r_B(B)]B + B' + \nu_E[E - \varphi(E)]$$

$$V(K, B, Z | \nu_K = 0) = \min_{\lambda, \psi} \max_{B', E, \nu_E} \left\{ (1 + \lambda)D - E + \psi \left[\frac{p^-(1 - \delta)\theta}{1 + r(1 - \tau_i)} (1 - \delta)K - B' \right] \right. \tag{31}$$
$$\left. + \frac{1}{1 + r(1 - \tau_i)} \int V((1 - \delta)K, B', Z')Q(Z, dZ') \right\}$$

s.t.

$$D = (1 - \tau_c)\Pi(K, Z; w) + \tau_c \delta K - [1 + r_B(B)]B + B' + \nu_E[E - \varphi(E)]$$

The investment action is warranted if and only if $V(K, B, Z | \nu_K = 1) - V(K, B, Z | \nu_K = 0) > 0$. After substituting in complementary slackness conditions, we can express the condition as

$$\Gamma(K', K) \leq -[B' - B'^{(0)}] + \{\nu_E[E - \varphi(E)] - \nu_E^{(0)}[E^{(0)} - \varphi(E^{(0)})]\} \tag{32}$$
$$+ \frac{1}{1 + r(1 - \tau_i)} \int [V(K', B', Z') - V((1 - \delta)K, B'^{(0)}, Z')]Q(Z, dZ')$$

where we make distinctions between $\{B', E', \nu_E\}$ and $\{B'^{(0)}, E'^{(0)}, \nu_E^{(0)}\}$ to distinguish the solutions for (30) and (31). By construction $K'^{(0)} = (1 - \delta)K$. Note that holding $B', E, \nu_E, B'^{(0)}, E^{(0)}$ and $\nu_E^{(0)}$ constant, both sides of the inequality are strictly increasing in K'. We denote the level of capital stock tomorrow that satisfies (32) with an equality by $\hat{K}$. Such a capital stock may not exist. The derivative of the right hand side is given by $q^M(K', B', Z)$ since all terms except $V(K', B', Z')$ does not depend on K'. The derivative of the left side is given by $\Gamma_{K'}(K', K)$. We summarize the optimal investment strategy in the following proposition.

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[39]The last term in the goods market clearing condition is due to the agency cost of cash holdings, which we view as an efficiency loss to the economy. The goods market clearing conditions can be derived by adding up three flow of funds constraints of the firms, the representative household and the government.

Figure 8: Illustration of Investment Problem: A Neoclassical Case
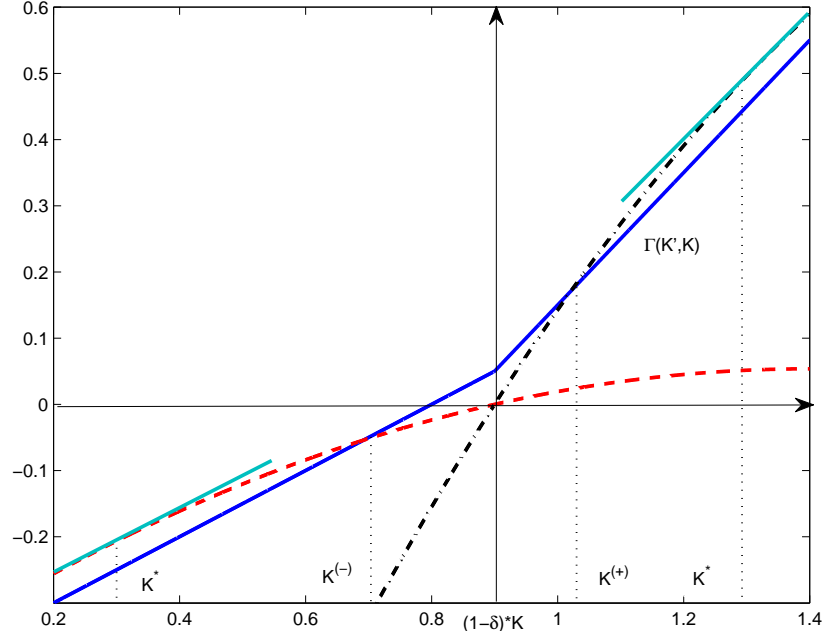
Note: The horizontal line measures the level of capital stock tomorrow and the vertical line measures the corresponding values of adjustment cost and the expected gains from adjustment. Blue, solid line depicts the shape of the adjustment cost function, black, dhash-dotted line and red, dash line illustrate possible shapes of expected gains from adjustment as a function of capital stock chosen for tomorrow. The two green line segments depict the slopes of the expected gain functions.

Proposition 1 *If (i) $\hat{K}$ exists, (ii) $q^M(\hat{K}, B', Z) \geq \Gamma_{K'}(\hat{K}, K)$, and (iii) $K^*(K, B, Z) \geq \hat{K}$, then the capital stock tomorrow is determined by (13), i.e., $K' = K^*(K, B, Z) > (1 - \delta)K$; if (i) $\hat{K}$ exists, (ii) $q^M(\hat{K}, B', Z) \leq \Gamma_{K'}(\hat{K}, K)$ and (iii) $K^*(K, B, Z) \leq \hat{K}$, then the capital stock tomorrow is determined by (13), i.e., $K' = K^*(K, B, Z) < (1 - \delta)K$; Otherwise, inaction is optimal, i.e., $K' = (1 - \delta)K$.*

Note that in case where V can be shown to be strictly concave with respect to K' in $[\hat{K} - \epsilon, K^* + \epsilon]$ for a finite real number $\epsilon > 0$, the third conditions, $K^*(K, B, Z) \geq \hat{K}$ for the expansion problem, and $K^*(K, B, Z) \leq \hat{K}$ for the contraction problem, are not required to establish the optimality of action.

To build intuition, it is useful to consider a neoclassical case without financial distortions. If $\varphi(E) = 0$ for all E and $\tau_i = \tau_c$, the value matching condition (32) is simplified into

$$\Gamma(\hat{K}, K) = \frac{1}{1 + r(1 - \tau_i)} \int [V(\hat{K}, Z') - V((1 - \delta)K, Z')] Q(Z, dZ') \tag{33}$$

The right hand side of the above, which measures the expected gain from adjustment, is strictly increasing in K' as it depends on K' only through $V(K', Z')$. Furthermore, the right hand side is equal to zero at $K' = (1 - \delta)K$. This means that at $K' = (1 - \delta)K$, the right hand side of (33) stays strictly below the left hand side as $\Gamma((1 - \delta)K, K) = F_k > 0$.

Figure 8 illustrates the investment problem for a frictionless neoclassical firm. Solid blue line depicts the adjustment cost function $\Gamma(K', K)$. The horizontal axis measures K' and the vertical axis shows the corresponding values of the left and right hand sides of (33). Due to the asymmetry of purchase and resale prices, the function is kinked at $K' = (1 - \delta)K$. The fixed component of the adjustment cost places the function strictly above zero at $K' = (1 - \delta)K$. Black, dash-dotted line

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and red, dash line depict two possible contours of the right hand side of (33). As noted before, the right hand side is strictly increasing in K' and passes through the point, $((1-\delta)K, 0)$.

Consider the case of black, dash-dotted line. The line intersects the adjustment cost at $K' = K^{(+)}$. Note that the slope of the black, dash-dotted line is measured by q^M. As the line cuts through the adjustment cost function from *below*, one can see that the second condition of Proposition 1, $q^M(\hat{K}, Z) \geq \Gamma_{K'}(\hat{K}, K)$ is satisfied. On the left side of the vertical line $K' = K^{(+)}$, the expected gain from adjustment is strictly less than the cost of adjustment. On the right side of the vertical line, a strictly positive adjustment is warranted as the gain dominates the cost. In the latter case, the optimal level of capital stock tomorrow K^* is determined such that the FOC $q^M(K^*, Z) = \Gamma_{K'}(K^*, K)$ is met. The green line segment located in the northeast corner of the figure depicts the slope of the gain from adjustment, the slope of which coincides with $q^M(K^*, Z)$. Note that $q^M(K^*, Z) = \Gamma_{K'}(K^*, K)$ is a necessary condition for adjustment, but not a sufficient condition as it may be satisfied with the expected gain from adjustment stays below and never crosses the adjustment cost function. Using the same logic, one can see that K^* located at the southwest corner of the figure corresponds to the case of contraction when the expected gain function is given by the red, dash line. It is important that the expected gain function (the right hand side of (33)) may never intersect the blue, solid line. In such a case, *inaction*, i.e., $0 = K' - (1-\delta)K$ is optimal.

C Details of Variable Definition

The variables used in the analysis are defined as follows:

- Cash to book asset – our main dependent variable – 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 indices 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 |Capex/book assets|<.01, |Capex/book assets|≥.01, and |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 procedure 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 procedure 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 firm-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.

D   Details of Regression Results in Panel A of Table 2

Table A-1: Details of Regression Analysis of Intangible Capital and Corporate Financing

	Whole Sample				R&D>0 Firms only			
	Cash		Net Debt		Cash		Net Debt	
	OLS	FE	OLS	FE	OLS	FE	OLS	FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Intangible Capital	0.086	0.061	-0.111	-0.047	0.104	0.067	-0.125	-0.067
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Industry sigma	0.037	-0.007	-0.062	0.022	0.041	-0.001	-0.064	0.037
	(0.000)	(0.190)	(0.000)	(0.000)	(0.000)	(0.739)	(0.000)	(0.000)
Market-to-book	0.023	0.011	-0.032	-0.010	0.028	0.016	-0.037	-0.009
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Firm size	-0.024	-0.039	0.025	0.011	-0.022	-0.032	0.005	0.067
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
Cash flow	0.031	0.017	-0.096	-0.091	0.037	0.023	-0.109	-0.108
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Capex	-0.008	-0.012	0.017	0.005	-0.011	-0.011	0.018	0.002
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.038)
Dividend	-0.011	0.007	-0.037	-0.036	-0.023	0.005	-0.016	-0.033
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.007)	(0.000)	(0.000)
Acquisitions	-0.010	-0.008	0.034	0.018	-0.012	-0.009	0.036	0.023
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Year fixed effects	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

The table reports detailed parameter estimates for the control variables included in the cash and net-debt regressions reported in Panel A of Table 2.

E   Numerical Method

The numerical procedure can be thought as an inner-outer loop iteration.

1. Initiate the procedure assuming a uniform distribution for the joint distribution of technology, capital and net debt, denote by μ^0.

2. We then look for a market clearing wage $w^0 = w(\mu^0)$ that solves (29) using a numerical root finder.

3. In the inner loop problem, an individual firm solves its value maximization problem taking as given the stationary joint distribution, and hence the market clearing wage. This procedure updates the policy functions, $g_k(K, B, Z; \mu^0)$ and $g_b(K, B, Z; \mu^0)$.

4. We then move to the outer loop where we iterate (22) until convergence to obtain μ^1. We then look for a new market clearing wage $w^1 = w(\mu^1)$ that solves (29) using a numerical root finder.

5. Check if $w^1 = w^0$. If yes, stop. If no, go back to step 3 and iterate the steps using w^1 as a new initial guess.

For the inner loop problem, we use an adaptive grid point method for value function iteration. We proceed in two stages. In the first stages, we specify $30 \times 40 \times 5$ grid points in state dimension for (K, B, Z). We use Markov chain process to discretize the technology shock. In the choice dimension for (K', B'), we use 300×300 grid points. We then iterate on Bellman equation to obtain the first stage value function. We denote the optimal choice of capital and net debt by (K^*, B^*).

In the second stage, we allocate all grid points for (K', B') in $([K^* - \delta_K, K^* + \delta_K] \times [B^* - \delta_B, B^* + \delta_B])$, i.e., in a rectangle around the optimal policies obtained in the first stage Bellman iteration. This way we allocate all computing resources around the region where the optimal choices are mostly likely to exist. In each time we update the value function in the second stage, $([K^{*\prime} - \delta'_K, K^* + \delta'_K] \times [B^{*\prime} - \delta'_B, B^{*\prime} + \delta'_B])$ is also updated with $\delta'_K, \delta'_B < \delta_K, \delta_B$ such that we focus on finer and finer grid points. This allow us to construct a fairly smooth policy functions. It is important to make sure that for each grid point K in state dimension, $(1 - \delta)K$ is always included in the choice dimension such that the program allows for inaction exactly.

For the outer problem, we use a fixed $(50 \times 50 \times 5)$ grid points for $\mu(K, B, Z)$. This means that we need to use interpolation to evaluate policy functions at points off the grid points used in the value function iteration. For speed, we use linear tensor product interpolation.