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Which Investments Do Firms Protect? Liquidity Management and Real Adjustments When Access to Finance Falls Sharply

James R. Brown
Iowa State University, jrbrown@iastate.edu

Bruce C. Petersen
Washington University in St. Louis

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Keywords
Liquidity management, value of cash, financial flexibility, R&D, fixed investment, financial crisis

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James R. Brown, Iowa State University*

Bruce C. Petersen, Washington University in St. Louis†

ABSTRACT

We study how firms engaged in both R&D and fixed investment manage liquidity and adjust real investment during the recent financial crisis. Among firms with positive R&D expenditures, cuts to fixed investment in the crisis are typically far more severe than cuts to R&D. These firms allocate cash reserves to buffer R&D but do not use cash to protect fixed investment. Some firms appear to go so far as to allow the stock of fixed assets to fall to stabilize R&D. The use of cash holdings and fixed assets to protect R&D is particularly strong among firms most likely to face financing frictions at the start of the crisis. We only find evidence that firms use cash to buffer fixed investment when we expand the sample to include firms with no R&D spending to compete for funds. Our study provides direct evidence on the real effects of liquidity management, highlights a key benefit of precautionary cash reserves, and illustrates the adjustments firms make to navigate a financial crisis.

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* Iowa State University, College of Business, Department of Finance, 3331 Gerdin Business Building, Ames, IA 50011-1350; phone: 515-294-4668; jrbrown@iastate.edu.
† Washington University in St. Louis, Department of Economics, Campus Box 1208, One Brookings Dr., St. Louis, MO 63130-4899; phone: 314-935-5643; petersen@wustl.edu. Corresponding Author.

1. Introduction

We explore how firms prioritize across competing real investments when dealing with a severe negative finance shock. Our basic idea is that protecting some investments creates more value for the firm than protecting other investments, in large part because adjustment costs differ substantially across alternative real investments. As a consequence, firms should disproportionately use their cash and liquid assets to stabilize some investments, while permitting potentially sharp reductions in others. We test these ideas by focusing on the differential treatment of R&D and fixed investment during the recent financial crisis. We focus on R&D and fixed investment because they are the primary investments for modern firms and they likely have markedly different adjustment costs.[1] In particular, cutting R&D investment typically entails releasing highly skilled technology workers, and reversing these cuts in the future brings about classic costs of adjustment (e.g., future hiring and training costs). In addition, firing R&D workers exacerbates appropriability problems when fired workers transmit proprietary knowledge to competitors. Since neither of these potential costs has any obvious counterpart when it comes to cuts in the rate of fixed investment, we expect firms facing a sharp decline in access to finance to buffer R&D much more aggressively than fixed investment.

We focus on firms with investment in both fixed capital and R&D in the crisis period. Though our insights extend to any time constrained firms face a firm-specific loss of access to finance, the crisis period is well-suited for testing our ideas because there is arguably a large exogenous negative shock to the availability of all forms of finance (e.g., Bliss et al., 2013; Campello et al., 2010; Duchin et al., 2010). During the crisis, our summary statistics show large declines in the flow of new finance, a very sharp drop in fixed investment and modest declines in R&D. Furthermore, the initial decline in cash stocks is sufficient to offset a substantial portion of the loss of internal and external finance. In addition, simple median-based tests suggest that firms responded to the negative finance shock by protecting R&D much more than fixed investment. For example, at the height of the crisis, the median within-firm annual change in R&D investment is a decline of just 2%, while the corresponding change in fixed investment is -25%. Moreover, among the firms forced to cut both R&D and fixed investment during the crisis, an

[1] While our ideas would readily extend to other investments the firm undertakes, these investments typically are either relatively unimportant (e.g., advertising expenses) or have very low or no adjustment costs (e.g., working capital). We therefore focus on the choice between R&D and fixed investment.

overwhelming majority (84%) cut fixed investment more than R&D (and typically the reductions in fixed investment are far larger).

To formally explore the differential buffering of R&D and fixed investment, we include changes in cash holdings in standard dynamic investment regressions. We are particularly interested in how firms spent stocks of cash holdings to buffer competing investments during the crisis.[2] We employ a "systems" GMM estimator which addresses the potential endogeneity of all financial variables in the regression. In the crisis period, changes in cash holdings share a very strong negative relation with R&D, particularly in the peak two years of the crisis. While there is some limited evidence in our main sample that cash holdings are used to protect fixed investment at the start of the crisis, the association between changes in cash holdings and fixed investment is far weaker (and typically insignificant) compared to the point estimates in the R&D regressions. Thus, for firms doing *both* R&D and fixed investment, our evidence suggests that firms spent much more cash protecting R&D compared to fixed investment. An additional test is motivated by the Campello et al. (2010, p. 471) survey evidence that "the vast majority of financially constrained firms sold assets in order to fund operations in 2008." We find a strong negative relation between changes in the stock of fixed assets and R&D, indicating that some firms so aggressively favored R&D that they allowed the *stock* of fixed capital to fall to provide additional resources to buffer R&D. Finally, when we expand the sample to include large numbers of firms doing little or no R&D, we then find a substantial negative relation between changes in cash holdings and fixed investment. It appears that firms prioritize during a crisis, and when R&D expenditures are not competing for liquidity, firms do in fact allocate some liquidity to protect fixed investment.

We perform a number of robustness and falsification tests. First, we re-estimate our main regressions with alternative controls for investment demand and find that there are no important quantitative changes in our main findings. Second, the need to prioritize across competing real investments in the face of a severe decline in the availability of finance should be strongest among firms

[2] Firms may also use debt capacity, derivatives and credit lines to smooth investment. However, Almeida et al. (2014) note that the literature on liquidity management points to cash holdings as the most important source of liquidity when it comes to downside protection. For example, Acharya et al. (2007) show that financially constrained firms whose financing needs arise mainly in low cash flow periods should build cash holdings as opposed to relying on spare debt capacity. In addition, in a survey of CFOs in 29 countries, Lins et al. (2010) conclude that cash holdings are used to buffer negative cash flow shocks while credit lines are used to undertake new investment opportunities in good times.

most dependent on external finance (e.g., small, young, low-payout, and bank-dependent firms). We in fact find that the firms *a priori* most likely to be affected by the crisis display the strongest evidence of utilizing stocks of cash holdings and fixed assets to buffer R&D investment. Finally, while most of our study focuses on annual data, we reach similar conclusions using quarterly data. In particular, we use a difference-in-differences approach similar to Duchin et al. (2010) and find a significant *increase* in the use of cash for R&D buffering during the quarters covering the crisis period, further supporting our main conclusions.

Overall, our findings indicate that firms confronted with a negative finance shock protect R&D to a much greater extent than fixed investment. To our knowledge, the differential buffering of R&D and fixed investment has not been explored in prior studies, perhaps because until very recently the corporate finance literature has focused almost exclusively on fixed capital investment. Since R&D is now as large (or larger) than fixed investment for a substantial fraction of firms, assessing how firms prioritize across alternative investments is important for understanding liquidity management decisions in modern firms and for evaluating the real effects of negative finance shocks. In particular, by focusing on differences across R&D and fixed investment, our study provides novel insights on the way firms use their cash reserves, highlights the conditions under which precautionary cash holdings are especially valuable, and offers the first detailed exploration of the impact of the financial crisis on R&D in the U.S.

Our findings are especially relevant for the rapidly growing literature on cash holdings and corporate flexibility (see Almeida et al., 2014 and Denis, 2011 for reviews of the literature). A number of studies develop theoretical models where cash holdings are used to transfer liquidity over time when firms have valuable future projects that may be lost due to financing constraints.[3] Almeida et al. (2004) show that constrained firms save more of their cash flow as cash than unconstrained firms and several other studies show that firms most likely to face frictions in capital markets accumulate more cash (e.g., Harford, 1999; Kim et al., 1998; Opler et al., 1999). Furthermore, there is evidence that cash holdings are more valuable for constrained firms (e.g., Denis and Sibilkov, 2010; Faulkender and Wang, 2006; Pinkowitz and Williamson, 2007). But surprisingly few empirical studies explore how firms actually *use* their cash holdings to protect real investment opportunities. Two exceptions are Denis and Sibilkov

[3] For example, see Acharya et al. (2007), Almeida et al. (2004, 2011), Gamba and Triantis (2008), and Han and Qiu (2007).

(2010), who find a strong link between cash holdings and fixed investment for constrained firms, particularly those with high hedging needs, and Brown and Petersen (2011), who show that constrained firms spend cash holdings to smooth R&D. In addition, Duchin et al. (2010) find that firms with more cash reserves have smaller reductions in fixed investment during the early phase of the recent financial crisis. None of these studies, however, explore how firms prioritize their cash holdings across competing investments when navigating a severe negative finance shock.

The use of cash to buffer R&D that we document is an important illustration of firms transferring liquidity into the future to support investment. Corporate liquidity and financial flexibility can support investment either by allowing firms to readily fund valuable new investment projects or by preventing the slashing of key ongoing projects during a period of financial distress, which is clearly the focus of our study. The favorable treatment of R&D over fixed investment sheds light on the types of firms that are most (and least) likely to gain from financial flexibility. In particular, there is an important literature on the agency costs of cash holdings (see Duchin et al., 2010 for a review) and our findings point to the types of firms where the benefits from precautionary cash holdings likely outweigh agency costs. It is also worth pointing out that our findings suggest that studies exploring the precautionary role of cash and focusing *only* on fixed investment may reach incorrect conclusions about the importance of stocks of liquidity for supporting investment and preserving firm flexibility. Finally, our results help explain the finding that R&D intensity, but *not* fixed investment, is strongly positively correlated with the level of cash holdings across firms (Bates et al., 2009) and why cash is more valuable in R&D-intensive firms and industries (Faulkender and Wang, 2006; Pinkowitz and Williamson, 2007).

Since there has been almost no assessment of the impact of the recent financial crisis on R&D, our study also contributes to the literature on the economic effects of the crisis. During the recent crisis, *aggregate* industrial R&D did not decline in 2008 and fell by only 2.9% in 2009, less than one-sixth the percentage decline in business fixed investment.[4] Our micro-level findings go a long way in explaining why aggregate business R&D did not fall more sharply in the face of enormous declines in aggregate internal finance and stock issues. In addition, given the importance of R&D for long-run economic

[4] Nominal R&D figures are from the NSF (12-310). The level of private nonresidential fixed investment fell 17.8% in 2009 (U.S. Bureau of Economic Analysis). The monthly producer price index for capital equipment (from the BLS) rose throughout 2008 and was basically unchanged throughout 2009. Thus, the decline in fixed investment in 2009 can be attributed to a decline in the physical quantity of investment, not the price of investment.

growth, our findings suggest that liquidity management policies by firms likely kept the long-run costs of the financial crisis from being even more severe.[5] A key implication is that precautionary cash reserves not only have important private benefits for R&D-intensive firms, but also *external* benefits that accrue to the broad economy.

A number of other studies explore financing and investment decisions during the crisis. Campello et al. (2010) survey CFOs in the U.S. (and abroad) and show that a very large fraction of U.S. firms faced binding financing constraints in late 2008. Furthermore, CFOs of firms engaged in a multifaceted approach for dealing with the unfolding crisis: in particular, constrained firms in 2008 burned through a substantial fraction of their cash holdings and engaged in asset sales to raise funds. Campello et al. (2012) report similar evidence from a survey of CFOs in Europe. Our evidence supports these findings and in addition shows that firms were particularly interested in managing their resources to protect R&D. Focusing on the initial phase of the financial crisis (July 2007 to June 2008), Duchin et al. (2010) find that fixed investment falls less for firms holding more cash reserves at the start of the crisis. Our study differs from Duchin et al. (2010) in several ways, most notably our examination of how cash reserves are differentially allocated across competing investments. Kahle and Stulz (2013) argue that their evidence on similarities in investment by bank-dependent and non-bank-dependent firms cast doubts as to whether a credit supply shock played a central role in the recent crisis. We note that for our sample firms, credit finance is unimportant compared to the sharp declines in internal and external equity finance, so credit shocks per se are not the most important finance shock affecting our firms. Furthermore, our findings suggest that firms worked aggressively to protect some types of investment, which they would not do if hit predominantly by a demand shock rather than a finance shock. Finally, Bliss et al. (2013) document substantial cuts in corporate payouts during the crisis, particularly for firms most likely to be susceptible to declines in credit availability, consistent with a negative shock to the availability of finance during the crisis.

[5] The key reason is that R&D is thought to have important spillovers, which is not the case of fixed investment. See the endogenous growth literature beginning with Romer (1990) and Aghion and Howitt (1992).

2. Motivation and Empirical Predictions

2.1. Adjustment Costs for R&D and Physical Investment

R&D investment consists primarily of wage payments to scientists and engineers and there are multiple types of adjustment costs associated with firing/rehiring these workers. One obvious cost is hiring and training expenses which can be very large for highly skilled workers (see the review in Hamermesh and Pfann, 1996). Second, as Hall and Lerner (2010) point out, when the "knowledge created by R&D workers is "tacit" rather than codified, it is embedded in the human capital of the firm's employees, and is therefore lost if they leave or are fired." A final type of adjustment cost, broadly defined, is the loss in firm value arising from fired technology workers transmitting critical proprietary information to competitors.

Of key importance to our arguments and predictions, there are several reasons to believe that adjustment costs rise much faster for R&D than for physical investment. First, the few studies that estimate adjustment costs for *both* R&D and physical investment typically report that R&D adjustment costs are substantially greater (e.g., Bernstein and Nadiri, 1989). Second, recent studies focusing specifically on physical investment report relatively low adjustment cost estimates (e.g., Cooper and Haltiwanger, 2006). Finally, most physical investment is spending on new equipment. Intuitively, this type of investment need not create high adjustment costs as sharp reductions in equipment investment likely do not involve firing skilled workers.

2.2. Formal Intuition

Standard Euler conditions for investment provide insights for how firms should manage liquidity to buffer competing investments in a financial crisis (see the Appendix for a more detailed discussion). Denote investment in fixed capital by I, the stock of fixed capital by K, investment in technology by RD, the stock of technology by T and the prices of the two investments by P^I and P^{RD}. The Euler conditions for fixed investment and R&D are

$$P^I_t + (\partial\Phi/\partial I)_t = \beta_t E_t [\theta_t\{(\partial\Pi/\partial K)_{t+1} + P^I_{t+1} + (\partial\Phi/\partial I)_{t+1} \}] \tag{1}$$

$$P^{RD}_t + (\partial\Omega/\partial RD)_t = \beta_t E_t [\theta_t\{(\partial\Pi/\partial T)_{t+1} + P^{RD}_{t+1} + (\partial\Omega/\partial RD)_{t+1}\}] . \tag{2}$$

Equation (1) is equivalent to the Euler equation for fixed investment in Gilchrist and Himmelberg (1998) and Love (2003), while Equation (2) is the counterpart equation for R&D and is similar to the first-order condition in Hall (1995) and Hall and Lerner (2010). In the Euler conditions, $\partial\Phi/\partial I$ and $\partial\Omega/\partial RD$ are the marginal adjustment costs associated with fixed investment and R&D and $\partial\Pi/\partial K$ and $\partial\Pi/\partial T$ are the marginal "profit" of capital and technology, respectively. θ_t captures the relative value of finance across periods: $\theta_t = (1+\lambda_{t+1})/(1+\lambda_t)$, where λ_t and λ_{t+1} are the shadow values of finance in period t and t+1. The left-hand side of each equation is the marginal cost of investing today; the right-hand side is the discounted marginal cost of postponing investment one period (i.e., the forgone marginal profits, the price of investment, and marginal adjustment costs).

Suppose the firm is confronted with a *one-period* financial crisis that hits in period t and is expected to be over by the beginning of t+1. The crisis drives λ_t above expected λ_{t+1} and thus drives down θ_t on the right-hand side of the Euler conditions. To rebalance the conditions, firms clearly need to shift some investment (both fixed investment and R&D) from period t to period t+1, as such a shift *drives down* the marginal cost of adjustment in period t and *drives up* the marginal cost of adjustment in t+1. Other things equal, if marginal adjustment costs change much more slowly for fixed investment compared to R&D, firms need to make much larger (proportionate) cuts to fixed investment in order to rebalance the Euler conditions. This implies that optimizing firms will disproportionately allocate scarce stocks of liquidity to buffer R&D.

2.3. Estimating Equation

Following Hall and Lerner (2010), we move from the Euler conditions to an estimating equation by assuming a Cobb-Douglas production function and quadratic adjustment costs.[6] The baseline empirical Euler specification is:

$$INV_{j,t} = \beta_1 INV_{j,t-1} + \beta_2 INV_{j,t-1}^2 + \beta_3 Sales_{j,t-1} + d_t + \alpha_j + \nu_{j,t}\,, \qquad (3)$$

where $INV_{j,t}$ is investment (either fixed investment or R&D) for firm j at time t. Lagged investment and investment squared appear on the right-hand side of the regression; the quadratic term (INV^2) appears

[6] Starting with similar Euler conditions, similar baseline specifications appear in Bond and Meghir (1994), Bond et al. (2003), and Love (2003). See Bond and Meghir (1994) and Hall and Lerner (2010) for a discussion of the details on moving from the Euler condition to an estimating equation like we use.

because of quadratic adjustment costs and the expected coefficient is negative. The baseline specification also includes lagged firm sales, a firm-specific effect (α_j) and a time-specific effect (d_t). The firm effect controls for all unobserved time-invariant determinants of *INV* at the firm level (e.g., technology of the firm and industry characteristics) and the year effect controls for aggregate changes that could affect the demand for *INV*.

Similar to Bond and Meghir (1994), Bond et al. (2003), and Brown et al. (2009), we augment the baseline specification with financial variables that capture access to finance. The resulting dynamic investment regression is:

$$\begin{aligned} INV_{j,t} &= \beta_1 INV_{j,t-1} + \beta_2 INV^2_{j,t-1} + \beta_3 Sales_{j,t} + \beta_4 Sales_{j,t-1} + \beta_5 CashFlow_{j,t} \\ &+ \beta_6 CashFlow_{j,t-1} + \beta_7 StkIssues_{j,t} + \beta_8 StkIssues_{j,t-1} + \beta_9 \Delta CashHoldings_{j,t} \\ &+ \beta_{10} \Delta CashHoldings_{j,t-1} + d_t + \alpha_j + v_{j,t}. \end{aligned} \quad (4)$$

In equation (4) we add contemporaneous and lagged values of cash flow (*CashFlow*) and funds from stock issues (*StkIssues*) to measure firm's access to both internal and external finance. We also include changes in cash holdings (*ΔCashHoldings*), which captures the use of cash holdings as a source of liquidity for buffering investment. Finally, we add current sales as an additional control for investment demand. In Section 4 we consider alternative specifications with different demand controls and other sources of liquidity for buffering investment. All regression variables are scaled by the beginning-of-period stock of firm assets.

2.4. Empirical Predictions

If firms are effective at smoothing R&D we expect β_1 to be close to one when *INV* in equation (4) is measured by R&D (which in fact is the case in all of our R&D regressions). In contrast, when *INV* is measured by fixed investment, if firms make little effort to buffer fixed investment during a crisis, we expect β_1 to be well below one (which is the case for nearly all of our fixed investment regressions). Our main prediction concerns the pattern of coefficients for *ΔCashHoldings*. If firms in a crisis disproportionately spend cash holdings protecting R&D, we expect negative coefficients for Δ*CashHoldings* in the R&D regressions that are larger (in absolute value) relative to the estimates in the fixed investment regressions.[7] Furthermore, we expect the largest (absolute value) coefficients for Δ*CashHoldings* in the R&D regressions for the narrow time period that covers the peak of the financing crisis.

An additional prediction concerns cuts in the *stock* of fixed capital to buffer R&D. If firms run low on the amount of cash reserves available for investment buffering in any given period, the sale of non-core assets can also provide funds for buffering R&D. Campello et al. (2010) report that among the constrained firms in their survey, 70% of the CFOs indicated that they sold more assets in the crisis than before.[8] We also note that firms do not have to actually sell fixed capital to obtain extra resources for R&D. Rather, as we discuss later in the paper, resources can be diverted to R&D by cutting fixed investment so aggressively that it does not cover depreciation of fixed capital. In either case, if firms allowed the stock of fixed capital to fall in order to protect R&D in the crisis, changes in the stock of fixed capital (which we add to equation (4) in some regressions) will have a *negative* association with R&D.

Our final prediction is that firms *a priori* most likely to face binding constraints at the start of the crisis should display stronger evidence of managing their liquidity and other assets to protect R&D. Consider, at the start of the crisis, a firm with investment well in excess of cash flows (e.g., a young firm). For such a firm, loss of access to finance will surely necessitate the use of *stocks* of liquidity if any buffering of investment levels is to occur. This need not be the case, however, for a firm whose investment levels are initially well below the flow of internal finance (e.g., mature firm) since a negative finance shock can be absorbed without drawing down stocks of liquidity to buffer investment.

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[7] In addition to showing that firms use cash reserves to buffer investment, finding a negative relation between Δ*CashHoldings* and R&D also suggests that our inferences are not being biased by misspecification or measurement error in the regression equation since these factors, if present, should impart an *upward* bias in the coefficient estimates (i.e., lead to positive coefficient estimates). Fazzari and Petersen (1993) make this point when evaluating the connection between fixed investment and changes in working capital.

[8] This is consistent with a number of previous studies showing that firms in financial distress make substantial use of asset sales to provide liquidity, and that otherwise constrained firms use some of the proceeds from asset sales for investment in fixed capital and R&D (e.g., Hovakimian and Titman, 2006; Borisova and Brown, 2013). See Edmans and Mann (2012) for additional discussion and references.

3. Data, Summary Statistics, and Median-Based Tests

3.1. Data and Industry Breakdown

We construct the sample from publicly traded U.S. firms with coverage in the Compustat database. We exclude firms with a primary SIC code from a regulated (SIC 4900-4999) or financial (SIC 6000-6999) industry. We then drop any firm-year observation if capital expenditures or sales is negative, total assets are less than $5 million in 2005 dollars, or sales growth is greater than 100%. We also require that firms have seven annual R&D observations and seven fixed investment observations over the time period 2004-2010. We begin in 2004 and insist on a minimum of seven observations in order to have some observations prior to the start of the crisis (changing the start date to 2003 or 2005 has no impact on our findings). In addition, we are interested in the choices *ongoing* firms make when it comes to buffering alternative investments. As such, we need firms engaged in both R&D and fixed investment and do not want our findings contaminated by either entering or exiting firms.[9] That said, we have checked all results for an unbalanced sample using the (weaker) requirement that firms have data covering the period 2006-2009, which is essentially the minimum amount of data needed to estimate the dynamic model for the crisis period. All of our findings and conclusions also hold in this unbalanced sample.

Table 1 gives the industry breakdown (at the 2-digit SIC level) of the 1,009 firms in our main sample. A total of 773 of the firms are contained in five broad two-digit industries: chemicals (28), industrial machinery and computers (35), electronic equipment (36), instruments (38) and business services (73). It is not surprising that the majority of the sample falls into the main high-tech industries in the U.S., in part because the *entire* population of U.S. publicly traded companies is now concentrated in this set of industries. For example, in 2007, 49 percent of all firms with coverage in Compustat are in one of the five high-tech industries. Thus, while the requirement that firms report R&D naturally leads to a sample concentrated in the high-tech sector, *any* broad sample of publicly traded firms will be heavily

[9] A possible concern with insisting on a balanced sample is that the firms most likely to have to cut investment either exit or are acquired by other firms, in which case our sample is composed of relatively successful firms and our findings would overstate the extent to which they can successfully buffer investment. However, this issue would cause us to overstate the buffering of *both* fixed investment and R&D, and cannot explain the differential attention that surviving firms give to R&D investment. Moreover, the issue of differential buffering may not be particularly relevant among firms that do not survive the crisis as *all* investment in these firms may collapse to zero (or near zero).

weighted towards high-tech. At the end of the paper, we discuss some findings for firms in the high-tech sector compared to firms outside of the high-tech sector.

We focus on annual data for three reasons. First, unlike fixed investment, a very large fraction of Compustat firms report R&D *only* at the annual frequency (and these firms tend to be younger and smaller firms). Second, there are a number of problems (e.g., seasonality) encountered in using quarterly data, some of which are discussed in Kahle and Stulz (2013). Third, the literature on investment and financing constraints, particularly studies estimating structural models, rarely employ quarterly data. A likely reason is that there is a non-trivial "time to build" (e.g., Zhou, 2000), which potentially requires a large number of lags of financial variables when quarterly data is employed. In particular, firms hit with a finance shock, even if they respond instantly, cannot immediately cut investment (e.g., within a quarter) because it takes time to receive and install equipment ordered in previous quarters.

Using the rules stated above, our main sample (*Full*) has 1009 firms. As will be apparent in the summary statistics, firms that do both R&D and fixed investment have a tendency to do less fixed investment than R&D. We therefore report some results for a sub-set of the *Full* sample comprised of only firms with average fixed investment-to-assets ratios over 2004 to 2006 (years just prior to the crisis) of at least 0.03. There are 566 firms in this "*HighCap*" sample. We use the 0.03 cutoff for capital spending because it yields a sample of firms having, on average, fairly similar levels of R&D and fixed investment prior to the start of the financial crisis. Our results are completely unaffected for a wide range of alternative minimum cutoff values for fixed investment (e.g., 0.02 to 0.04).

3.2. The Crisis Period and Descriptive Statistics

In our discussion of the summary statistics, we focus on 2008 and 2009, given that it is well known that the severity of the crisis increased dramatically starting in September of 2008.[10] Table 2 reports mean values of the key financing and investment ratios over the 2004-2010 period for both the *Full* and *HighCap* samples. All variables are scaled by beginning of period total assets and we remove the 1% tail of the distribution in order to reduce the impact of outliers. Cash flow is measured as gross of R&D, since R&D is expensed and we want to measure cash flow before expenditures on both R&D and

[10] The three-month LIBOR-OIS spread jumped enormously the second half of 2008, spiking at an all-time high of 364 basis points in October of 2008. Internal finance (cash flows) fell very sharply in 2008, as is evident in our summary statistics. Furthermore, starting in late 2007, stock indexes collapsed (e.g., DOW fell more than 50%), leading to a drastic reduction in new equity issues during much of the crisis.

fixed capital. Net stock issues are computed net of stock buybacks and net debt issues are funds from new long-term debt issues net of long-term debt reductions.

Panel A of Table 2 reports the descriptive statistics for the *Full* sample of 1009 firms. In the first column, compared to 2006 (the last year before the crisis), the mean of R&D is 7.2% lower in 2008 and 2009.[11] In contrast, in the second column, fixed investment (CAP) falls much more sharply: from 0.041 in 2006 to 0.028 in 2009, a decline of approximately 32%. Column three shows that the *stock* of (net) property plant and equipment is approximately 7% lower in both 2008 and 2009 compared to 2006. Turning to the financial variables, there is a severe decline in both internal and external finance in 2008 and 2009. Cash flow falls modestly in 2007 and then drops very sharply in 2008 (a 34% decline compared to 2006) and remains depressed in 2009 before recovering in 2010. Debt issues actually rise in 2007 but decline substantially in 2008 and are negative in 2009, consistent with a modest decline in the stock of total debt (last column) in 2009. Finally, net stock issues become negative in 2008 and recover to some extent in 2009. Importantly for our study, average cash holdings fall modestly in 2007 and then sharply in 2008 (22% decline compared to 2006). The absolute size of this decline in cash holdings in 2008 (0.050) is large enough to potentially offset most of the decline in cash flow and external finance that occurred in that year. In 2009, however, average cash holdings increase, an issue we return to below.

In Panel B of Table 2 we report the same set of summary statistics for the *HighCap* sample. The only noteworthy difference in this subset of firms is the relatively higher level of fixed investment leading into the crisis period. The average fixed investment ratio in the *HighCap* sample starts at 0.058 in 2006, before falling to 0.050 in 2008 (14% percent decline) and 0.036 in 2009 (38% decline compared to 2006). In contrast, the mean R&D ratio falls 14% between 2006 and 2009. While the mean level of R&D is somewhat higher than fixed investment at the start of the crisis, the *median* value of both R&D and fixed investment is 0.048 in 2006 (not reported in Table 2). The patterns of changes in the financial variables mirror those in Panel A.

We briefly elaborate on two issues. One might wonder why cash holdings did not decline even more in 2008. Part of the reason is that cash holdings serve many roles besides buffering investment,

[11] The 2006 value of R&D is substantially above the value in 2004 and 2005 and thus may not be the most appropriate benchmark. An alternative benchmark is the average of 2004-2006; compared to this benchmark, the decline in R&D in 2008 and 2009 is around 4%.

including providing short-term liquidity for day to day transactions. Second, not all firms in our sample face severe constraints, even in the crisis, implying some firms need not turn to cash holdings to buffer investment. Third, firms do not know the exact duration of a financial crisis. In the event of a severe and long-lasting crisis, imprudent firms may run out of liquidity, potentially leading to the demise of the firm, implying a potentially large option value to preserving some cash holdings. Finally, cash holdings in 2008 did in fact fall by a large amount *relative* to the absolute decline in cash flow and external finance, so (on average) the fall in cash holdings in 2008 appears to be large enough to buffer much of the finance shock in that year.

The second issue concerns average cash holdings at the end of 2009. While the overall sample *average* cash holdings ratio is higher at the end of 2009, it is important to point out that for the full distribution of firms (not reported in Table 2), 32% did cut cash and 78% of these firms cut cash by at least 10% while 58% cut cash by at least 20%. Thus, even in 2009, many firms in our sample cut cash holdings, potentially spending cash to buffer investment. In addition, the events in late 2008 and early 2009 undoubtedly caused many businesses to adjust upwards their estimate of the crisis's length and severity. That is, the option value of liquidity in early 2009 likely rose relative to the option value in early 2008, causing some firms to hoard liquidity to protect the firm in the event of being cut off from capital markets for a substantial period of time.

If firms are surprised by the length (or severity) of a crisis and thus seek to rebuild cash holdings before the crisis abates, what does this imply for investment buffering? Suppose a crisis is expected to last one period (period t) but in fact extends into period t+1. Other things equal (e.g., loss of access to finance in t+1 is similar to period t), cuts to *total* investment should be more severe in period t+1 as the change in cash holdings is now *positive.* Nevertheless, firms can continue to buffer R&D even when compelled to *rebuild* cash holdings, and one way to do this is to make very sharp cuts to fixed investment: if firms cut fixed investment *proportionately more* than the negative shock to the availability of finance, the firm can cut R&D *proportionately less* than the shock to finance (and still satisfy the budget constraint).[12] In addition, as noted above, firms can effectively make fixed investment *negative* by selling off assets, providing additional resources to buffer R&D.

3.3. Within-Firm Changes in R&D and Fixed Investment

Given the importance to our study of differences in the relative magnitudes of investment declines, we present more details on the frequency and size of within-firm adjustments to R&D and fixed investment during the crisis. For each firm, we compute the year-to-year percentage changes in R&D and fixed investment. We focus on R&D and CAP ratios (as in Table 2), but the results are very similar if we look at investment *levels* instead. First, Figure 1 shows that the median change in both R&D and fixed investment is small in 2007. More importantly, Figure 1 shows that the median change in R&D is approximately -2% in both 2008 and 2009; in sharp contrast, the median change in fixed investment is approximately -7% in 2008 and -26% in 2009. Thus, at the height of the crisis, the median within-firm change in fixed investment is more than ten times greater than the median change in R&D. Next, we create histograms (with bins at 10% intervals) based on all cuts to R&D (Figure 2a) and fixed investment (Figure 2b) between 2008 and 2009. Figure 2a shows that when firms do cut R&D, the vast majority of cuts are modest (most are less than 20%). In sharp contrast, Figure 2b shows that it is common for firms to make very large cuts in fixed investment, a substantial fraction of which exceed 50%.

Finally, we compare the relative size of the cuts in R&D and fixed investment among the firms cutting *both* R&D and fixed investment between 2008 and 2009. For each of the 452 firms with cuts to both investments we divide the percent change in fixed investment by the percentage change in R&D, thereby comparing relative changes in fixed investment and R&D for the *same* firm. The full distribution of this measure is illustrated in Figure 3. For only around 16% of the firms (74 firms) is the ratio less than one, indicating that, in percentage terms, very few firms cut R&D more than fixed investment. Furthermore, firms typically cut fixed investment much more than R&D, with 59% of the firms cutting fixed investment more than twice as much as R&D, and 24% cutting fixed investment at least five times as much.

[12] For example, suppose in the last pre-crisis period, cash flow = 150, fixed investment = 90 and R&D = 60, but in the crisis period cash flow falls to 100 (33% decline): a *disproportionate* reduction in fixed investment from 90 to 45 (50% decline) diverts enough resources to nearly fully buffer all of R&D investment. As we note below, our summary statistics do in fact suggest a disproportionately large cut in fixed investment (relative to the flow of finance) for many firms over the interval 2008 to 2009.

4. Main Results

4.1. GMM Estimation Approach

We estimate equation (4) with the "system" GMM estimator developed for dynamic panel models by Arellano and Bover (1995) and Blundell and Bond (1998). This approach jointly estimates equation (4) in differences and in levels, using lagged levels as instruments for the regression in differences and lagged differences as instruments for the regression in levels. The sys-GMM estimator addresses the potential endogeneity of all financial variables as well as the dynamic panel bias induced from including the lagged dependent variable in a regression with a firm fixed effect and the approach is widely used to estimate dynamic panel regressions (e.g., Bond et al., 2003; Flannery and Hankins, 2013). We report one-step GMM estimates using lagged levels dated *t*-3 and *t*-4 as instruments for the regression in differences and lagged differences dated *t*-2 for the regression in levels. To assess instrument validity we report a Hansen *J*-test of the null that the over-identifying restrictions are valid, a difference-in-Hansen test that evaluates the validity of the instruments used in the levels equation, and an *m2* test for second-order autocorrelation in the first-differenced residuals. These tests generally indicate no major problems with our primary instrument set, particularly in the most important specifications. In all estimates we compute standard errors robust to heteroskedasticity and within-firm serial correlation.

4.2. Estimates for R&D and Fixed Investment

Table 3 reports estimates of equation (4) for both R&D and fixed investment. We use the *Full* sample and report results for four different time periods: i) 2004-2010, ii) 2007-2009, iii) 2007-2008 and iv) 2008-2009. The longer time period includes years before and after the crisis and is used mainly for comparison purposes. The 2007-2009 period, which we refer to as the "crisis period," contains the key crisis years as well as 2007, the first, and mildest, year of the crisis. While 2007-2008 and 2008-2009 cover very brief periods, they provide additional insights into liquidity management as the crisis unfolded. We are able to estimate dynamic regressions for relatively short periods because we use lagged values from the pre-crisis period as instruments. While Table 3 reports coefficient estimates on both current and lagged financial variables, to simplify the discussion we focus on the *sum* of the coefficients for each financial variable. The chi-squared tests for the statistical significance of these sums are reported at the bottom of the table, together with test statistics evaluating instrument validity.

The results for R&D (first four columns) are in line with our expectations. In all four time periods, the point estimate for lagged R&D is near one. Furthermore, the coefficient on lagged R&D-squared is negative and statistically significant (except for the 2008-2009 period), consistent with our maintained assumptions concerning adjustment costs. For all four time periods, the sum of cash flow coefficients and stock issues coefficients is substantial and statistically significant.[13] Most importantly, the sum of the *ΔCashHoldings* coefficients is negative (and significant) in all four time periods. Specifically, across the four time periods, the sum of the *ΔCashHoldings* coefficients is, respectively: -0.145, -0.186, -0.226 and -0.417. Thus, changes in cash reserves share the strongest (negative) relation with R&D in 2008-2009, the most severe period of the crisis.

The results for fixed investment (columns 5-8) are very different than those for R&D. In all four time periods, the coefficient for lagged fixed investment is well below one, suggesting that, compared to R&D, fixed investment in period *t* is much less tightly connected to fixed investment in *t*-1. Of central importance to our exploration of liquidity management and investment protection during the financial crisis, the sum of the coefficients for *ΔCashHoldings* is far smaller (in absolute value) than in the R&D regressions. There is some evidence of limited use of cash holdings to buffer fixed investment in the 2007-2008 period, which supports the findings in Duchin et al. (2010) of an association between cash holdings (at the start of the crisis) and the level of fixed investment in the first year of the crisis. In the 2008-2009 period (when *ΔCashHoldings* coefficients are the largest in the R&D regression) the sum of the coefficients for *ΔCashHoldings* in the fixed investment regression is essentially zero. The coefficients on the other financial variables (cash flow and stock issues) are also quantitatively small, though often statistically significant or close to being significant at conventional levels. It thus appears that the hit on fixed investment during the financial crisis is mainly captured in our regressions by the low coefficient on lagged fixed investment.

4.3. Alternative Controls for Demand

The empirical literature on financing constraints uses a variety of different measures to control for investment demand, including both Q and sales growth. In Table 4, we replace current and lagged sales

[13] The finding that R&D investment is sensitive to stock issues during the crisis period is consistent with the equity-dependent nature of R&D emphasized in several recent studies (e.g., Brown and Petersen, 2009; Brown et al., 2013; Hall and Lerner, 2010).

with Q and sales growth and report the results for the same time periods utilized in Table 3. For the sake of readability, Table 4 (and subsequent tables) reports the *sums* of the coefficients (current and lagged), together with *p*-values from chi-squared tests that the sum is equal to zero. In addition, we do not report coefficients for lagged R&D and fixed investment, which are similar to coefficients in the corresponding regressions in Table 3. The point estimates for Q are fairly large in most regressions (and typically somewhat larger in the R&D regressions) and the estimates are significant for both R&D and fixed investment regressions in the 2004-2010 and 2007-2009 periods. While the Q coefficients are also substantial in the 2007-2008 and 2008-2009 periods, they are not significant, which is not surprising given the smaller number of observations in these shorter time periods. Most importantly, the sums of coefficients for *ΔCashHoldings* in Table 4 are very similar to the corresponding sums in Table 3. Once again, for R&D, the *ΔCashHoldings* coefficients are quantitatively large (and significant), particularly in the peak years of the financial crisis. For fixed investment, the *ΔCashHoldings* coefficients are quantitatively small in all time periods and only statistically significant in the 2004-2010 regression. So, using alternative controls for demand (as reported in Table 4) has no impact on the main findings in Table 3.

4.4. Additional R&D Regressions

In Table 5, we consider modifications to the baseline specification to evaluate a different channel through which firms can buffer R&D. To economize on space, we only report results for the 2004-2010 and 2007-2009 periods. Results for the shorter crisis intervals (2007-2008 and 2008-2009) are consistent with the results for the 2007-2009 interval. We note that in all regressions, the coefficients on the lagged R&D terms are consistent with the estimates reported in Table 3. In columns 1 and 2, we add the change in the stock of capital (ΔK) to our baseline specification. If firms reduce the *stock* of fixed capital to increase available liquidity for buffering R&D, the estimated coefficient on ΔK will be negative. The sum of the coefficients on ΔK is near zero for the 2004-2010 period (column 1). In contrast, the sum of coefficients on ΔK is negative, statistically significant, and large in absolute value (-0.420) during the crisis period (column 2). The lack of a ΔK finding in the broad 2004-2010 period, together with the sizable negative coefficient for ΔK in the narrow crisis period is logical: the use of fixed assets to buffer R&D is surely rather costly and is unlikely to be widely used *except* in a severe crisis.

In columns 3 and 4, we check the robustness of the specification in columns 1 and 2 to the alternative demand controls used in Table 4 (Q and sales growth in place of levels of sales). There are no quantitative changes in the sum of coefficients for either *ΔCashHoldings* or *ΔK*. In columns 5 and 6, we eliminate lags of financial variables from equation (4), but do maintain the lagged R&D variables. So the point estimates reported are not the sums, but rather the coefficients for contemporaneous financial variables. The coefficient estimates in columns 5 and 6 are similar to the sums reported in columns 3 and 4. In particular, for the crisis period (column 6), the point estimate for *ΔCashHoldings* is -0.151 and the point estimate for *ΔK* is -0.452 (both are highly statistically significant).

4.5. Results for Firms a priori Most Likely to Face Binding Constraints

We next explore splits of the data based on proxies commonly used in the literature to separate firms into groups that are *a priori* more or less likely to face binding financing constraints. We sort firms based on age, size, payout level and "bank dependence" in the years immediately preceding the start of the crisis. Age is an especially attractive way to sort firms because age is less endogenous than other splitting criteria (Fee et al., 2009; Hadlock and Pierce, 2010). Furthermore, young firms are more likely to have total investment in excess of the flow of internal finance, forcing them to make greater adjustments in the event of a collapse in access to external finance. We compute firm age as the number of years since the firm first appears in Compustat with a non-missing stock price and consider firms young if their average age in the 2004 to 2006 period is 15 or less, and mature otherwise, the same age cutoff used in Brown et al. (2009). To sort firms based on size and payout we first find firm averages of the book value of total assets and the net payout (dividends plus stock buybacks minus stock issues) ratio over the 2004 to 2006 period. We then consider firms small (low payout) if their average assets (net payout ratio) is in the bottom 70th percentile of sampled firms and large (high payout) otherwise. Finally, our bank dependence measure is motivated by Duchin et al. (2010). We consider firms "bank dependent" if they have no bond rating reported in Compustat and an average debt-to-assets ratio of at least 1% during the pre-crisis period (2004-2006). All other firms are put in the "not bank dependent" group, which includes firms with a bond rating or with trivial levels of debt going into the crisis.

Table 6 reports regression results using the four alternative ways to sort constrained and unconstrained firms. We focus on the 2007-2009 time period and we report sums of the financial coefficients as we did in Tables 4 and 5. For young, small, low-payout and bank-dependent firms (columns 1, 3, 5 and 7), the sums of coefficients for *ΔCashHoldings* range from -0.200 to -0.302 and are always statistically significant, while the sums of coefficients for *ΔK* range from -0.377 (p = 0.053) to -0.563 (p = 0.038). In contrast, for the corresponding groups of "unconstrained" firms, the sums of coefficients for *ΔCashHoldings* range from 0.099 to -0.147 and are only statistically significant for mature firms, while the sums of coefficients for *ΔK* are always smaller (in absolute value) compared to "constrained" firms and are insignificant in all regressions with the exception of large firms (p-value = 0.073).

Overall, the findings in Table 6 show that the firms *a priori* most likely to face binding constraints during the crisis period display the strongest evidence of utilizing stocks of cash holdings and fixed assets to buffer R&D investment. Moreover, these results provide additional evidence against a demand-side interpretation of our findings in Tables 3-5. The logic is that demand shocks should impact all firms, while our findings for R&D buffering with cash holdings and stocks of fixed capital are concentrated among firms *a priori* more likely to be impacted by loss of access to finance during the crisis.

4.6. Quarterly Data and Difference-in-Differences Estimates

We discussed earlier why we focus on annual data and not quarterly data. However, one particular advantage of quarterly data is that we can zero in on narrow episodes of the recent financial crisis. In particular, Duchin et al. (2010) use quarterly data and examine 2007Q3-2008Q2, or the initial phase of the crisis. While this initial phase is a less severe financial shock than what came in late 2008 and 2009, they point to the initial phase as predominantly a "supply phase." They find that firms with larger stocks of cash at the start of the crisis exhibit a significantly smaller decline in fixed investment during the 2007Q3-2008Q2 phase of the crisis.[14] We therefore proceed in two ways. First, we re-estimate our main regressions (augmented with *ΔK*) for the 2007Q3-2008Q2 time period for all firms in our sample that report quarterly R&D data. The estimates of our main specification using quarterly data

[14] They find a weaker (and insignificant) connection between stocks of cash holdings and fixed investment for a later phase of the crisis (2008Q3-2009Q1). They offer a number of explanations, including a weakening of their "instrument" as cash stocks are measured in 2006 and there were substantial declines in cash holdings in 2007 and 2008 in their data. A complementary explanation, suggested by our findings, is that as the crisis became more severe, tighter liquidity constraints forced firms to allocate virtually all available cash holdings to protect R&D, consistent with our very large sum of coefficients for *ΔCashHoldings* in the 2008-2009 time period.

(available on request) are qualitatively similar to the results reported above. For example, when the regression contains current and three lags of quarterly financial variables, the sum of *ΔCashHoldings* coefficients in the R&D regression is approximately -0.100, statistically significant, and much larger than the corresponding sum of *ΔCashHoldings* coefficients in the fixed investment regression.[15]

Second, quarterly data also allows us to estimate a difference-in-differences regression motivated by the approach in Duchin et al. (2010). They estimate a standard Q-model of investment and include an interaction between firm cash holdings prior to the start of the crisis and a dummy variable equal to one for all crisis quarters. Their interest is identifying whether fixed investment during the crisis is higher for firms with larger cash reserves at the start of the crisis. We can build on this approach to explore whether firm *use* of cash reserves for R&D buffering is higher during the crisis period compared to the pre-crisis period, as our arguments would suggest. We construct an indicator variable (*EarlyCrisis*) that is equal to one for the four quarters 2007Q3-2008Q2 and zero otherwise. We then interact the *EarlyCrisis* dummy variable with firm *ΔCashHoldings*, and it is this interaction which captures whether there is a *difference* in firm use of cash holdings for investment between the 2007Q3-2008Q2 and the pre-crisis period. We also explore the use of cash for investment buffering deeper into the crisis (following Table 10 in the Duchin et al. (2010) study). To do this we include observations from the 2008Q3-2009Q2 interval and construct a new indicator variable (*LateCrisis*) that equals one in each of these quarters and zero otherwise. In each case we use observations from 2006Q3-2007Q2 for the pre-crisis period.

In Table 7, we report the difference-in-differences estimates for R&D in the first three columns, and fixed investment in the last three columns. We start with a specification that includes only Q, Cash flow, *ΔCashHoldings*, and the interaction between *ΔCashHoldings* and *EarlyCrisis*. The *EarlyCrisis* indicator variable does not enter separately because we include dummy variables for each quarter. Other than our focus on quarterly changes in cash holdings (*ΔCashHoldings*) rather than the pre-crisis level of cash, this specification follows the main difference-in-differences regression in Duchin et al. (2010). While they use a standard within-firm estimator, we continue our approach of instrumenting all financial

[15] As expected, if we use fewer lags of financial variables, the sum of *ΔCashHoldings* coefficients is smaller, but the qualitative pattern of findings does not change. For example, with only one lag of financial variables, the sum of *ΔCashHoldings* coefficients is -0.051 (and significant) in the R&D regression and -0.023 (and insignificant) in the fixed investment regression.

variables with lagged values, an issue that is more important in our setting given our focus on changes in cash during the crisis period and our inclusion of firm stock issues in some specifications.

The estimates for R&D in column (1) show a significant negative coefficient on the interaction variable Δ*CashHoldings*EarlyCrisis*. This indicates that, within-firms, there is differentially more R&D buffering per dollar of cash spent in the early crisis interval (2007Q3-2008Q2) than in the pre-crisis interval (2006Q3-2007Q2). In column (2) we include *Stock issues* and our estimate of the differential effect is even stronger. Notably, the estimates in column (2) show a coefficient on *ΔCashHoldings* of -0.032 during the pre-crisis quarters and -0.093 during the early crisis quarters (-0.032 + -0.061), the latter of which is consistent in both sign and magnitude with the quarterly regression results noted above. In column (3), we interact each of the three financial variables with the *EarlyCrisis* dummy variable and continue to find a significant negative coefficient on the *ΔCashHoldings*EarlyCrisis* interaction.[16] Moreover, the estimates in column (3) indicate that *ΔCashHoldings* is the only financial factor that increases in importance for R&D when moving from the pre-crisis to early-crisis quarters. Finally, in column (4) we use data from 2006Q3-2009Q2 and estimate a specification that includes both the *ΔCashHoldings*EarlyCrisis* and the *ΔCashHoldings*LateCrisis* interaction variables. The estimates in column (4) show a negative and significant coefficient on both of these interaction terms. In fact, the coefficient estimate is larger (in absolute value) for the *ΔCashHoldings***LateCrisis* interaction, which is consistent with the very large *ΔCashHoldings* estimates we find using annual data for the 2008-2009 period in Table 3.

In the final three columns we report a similar set of regressions for fixed investment. In sharp contrast to the results for R&D, the difference-in-differences results suggest that firms do not allocate more cash to fixed investment during the crisis, consistent with earlier evidence (in particular Table 3). Overall, the findings in Table 7, which are based on a very different empirical approach than used earlier in the paper, support our conclusions that firms doing both R&D and fixed investment allocated cash to protect the later and not the former during the recent crisis.

[16] We have estimated similar regressions using the annual data and draw identical conclusions about the *increasing* allocation of cash reserves to R&D during the crisis. For example, if we run the difference-in-differences regression with 2007-2009 as the "crisis" period and 2004-2006 as the pre-crisis period, the coefficient estimate on the *ΔCashHoldings***Crisis* interaction is -0.239 (*p*-value=0.046). If we exclude 2007 from the regression since this is the mildest year of the crisis, the coefficient estimate on the *ΔCashHoldings***Crisis* interaction is -0.277 (*p*-value=0.041).

5. Additional Tests

In this section we provide some tests of robustness by exploring different instrument sets as well as splits of the main sample into high-tech and low-tech firms. We also provide some additional findings for fixed investment using alternative samples, including a broad sample that is made up primarily of firms not reporting R&D. All results not reported in a table are available on request.

5.1. Different Instrument Sets

The GMM estimator we use relies on lagged values of the regression variables for instruments. We use lags *t*-3 to *t*-4 in our main results for two reasons: i) overall, the specification tests indicate no major problems with this instrument set, and ii) using all available lags as instruments results in a proliferation of instruments that potentially weakens the specification tests and overfits the endogenous variables (e.g., Roodman, 2009). Nonetheless, because there can be efficiency gains from including more of the available lags as instruments and to explore the robustness of our results, we estimated all main regressions with deeper lags included in the instrument set and get very similar results. For example, focusing on the *Full* sample and the 2007-2009 time period, if we estimate the R&D regression using all available lags as instruments (starting with *t*-3), the estimate on *ΔCashHoldings* is -0.148 and significant at the 1% level, whereas the corresponding estimate in the CAP regression is essentially zero. We also get similar results if we start the instruments one period *sooner* (*t*-2), though in this case the specification tests weaken considerably in some regressions.

5.2. High-Tech vs. Low-Tech Splits of Data

Table 1 shows that the majority of our sample falls within five broad two-digit high-tech industries. A logical question is whether our findings on the use of cash during the crisis are driven only by high-tech companies protecting R&D, or if they extend to R&D activities in other sectors as well. When we re-estimate our main regressions for the "high-tech" portion of the sample only, the sum of coefficients on *ΔCashHoldings* is -0.157 (p-value=0.026). In the "low-tech" firms, the corresponding estimate is -0.121 (p-value=0.121). Moreover, among the low-tech firms with substantial R&D expenditures (R&D ratio of at least 0.05 during the pre-crisis interval), the estimate on *ΔCashHoldings* is very similar in magnitude to the estimate for the high-tech sample (-0.159). Thus, though our estimates for the low-tech sample are not as precisely estimated due to the smaller sample size, our results suggest that both high-tech and non-high-tech companies were interested in protecting R&D during the crisis period, particularly those non-high-tech companies with substantial R&D activities to protect.

5.3. Additional Fixed Investment Regressions: Alternative Samples

The results in Tables 3 and 4 suggest that firms doing both R&D and fixed investment allocated little or no cash holdings to protect fixed investment during the financial crisis. It is possible that we find relatively little evidence of firms using *ΔCashHoldings* for fixed investment in these regressions because the level of fixed investment is smaller than the level of R&D in the *Full* sample (see Panel A of Table 2). We explore this possibility by estimating regressions for the *HighCap* sample, where fixed investment and R&D levels are similar (see the discussion of Panel B, Table 2). The first two columns of Table 8 report fixed investment results using equation (4). For the 2004-2010 and the 2007-2009 periods, the sum of coefficients for *ΔCashHoldings* is small (-0.033 and -0.034) and statistically insignificant. These point estimates are very similar to the corresponding estimates for the full sample in Table 3.

In columns 3 and 4 of Table 8 we add new long-term debt issues to the regression and also drop lags of financial variables. (The intermediate step – where we include debt issues in a specification with lags of all financial variables – yields very similar results.) Since fixed investments provide much more collateral value than R&D, it is reasonable to explore the impact of adding debt financing in the fixed investment regressions. For both the 2004-2010 and the 2007-2009 periods, the coefficient on new debt issues is positive and statistically significant, but, once again, the coefficient for *ΔCashHoldings* remains small and insignificant. Thus, our findings on the use of *ΔCashHoldings* for fixed investment are similar whether we focus on the *Full* or *HighCap* sample of firms doing R&D.

In the second half of Table 8 we consider an entirely new sample (*BroadCap*) that includes firms we initially excluded from the sample due to lack of information on R&D. Many firms report information on fixed investment but no information on R&D. Absence of R&D information likely means that R&D is zero or trivial, since firms that fail to report R&D are typically in industries that traditionally do little R&D. To construct the *BroadCap* sample we simply drop the requirement that firms report R&D. The idea is that when R&D is not competing for scarce stocks of liquidity, firms may be more willing to allocate cash holdings to protect fixed investment. As Table 8 shows, including firms doing little or no

R&D increases the sample size a great deal, and thus the *BroadCap* sample is heavily weighted towards firms doing little or no R&D.

Columns 5 and 6 report estimates of our baseline regression for the 2004-2010 and 2007-2009 periods. Of particular interest, the coefficient estimates on *ΔCashHoldings* are statistically significant and fairly substantial (-0.132 and -0.149). In column 7 we continue to focus on the 2007-2009 period and report estimates of the specification that includes debt issues but drops lags of the financial variables. The coefficient estimates on cash flow, stock issues and debt issues are positive and statistically significant. More importantly, the coefficient on *ΔCashHoldings* (-0.104) remains sizeable and statistically significant. However, as with the regressions in columns 5 and 6, the test statistics evaluating instrument validity are poor for the *BroadCap* results reported in column 7. We therefore estimate the regression using difference GMM instead of system GMM and report the results in column 8. The results using this alternative estimator also show a substantial negative (-0.171) and significant relation between *ΔCashHoldings* and fixed investment. Furthermore, the Hansen *J*-test indicates no problems with instrument validity. Thus, the *BroadCap* results in Table 8 suggest that during the recent crisis some firms – namely firms where R&D is not a competing use of funds – did protect fixed investment with cash reserves.[17]

We note that these findings for the *BroadCap* sample provide additional evidence against a demand-side interpretation of our overall findings. Suppose the only reason we find evidence that firms protect R&D far more than fixed investment during the crisis is because: i) demand fell more for fixed investment than for R&D, and ii) our demand-side controls are inadequate. If this demand-side story is the principal explanation, we should not find evidence of cash holdings being used to protect fixed investment in *any* samples of firms. Instead, once the sample consists primarily of firms where R&D is not competing for scarce stocks of liquidity, we find that firms do in fact use cash reserves to buffer fixed investment.

[17] If we divide the *BroadCap* sample into those firms doing R&D (our main sample) and those firms not in our main sample (low or no R&D), we find evidence of fixed investment smoothing only in the low/no R&D firms. Specifically, the coefficient estimate (*p*-value) on *ΔCashHoldings* is -0.237 (0.065) in the low/no R&D subsample and -0.045 (0.074) for R&D firms. This is precisely what we expect, given the fact that in our main sample, we found no evidence of fixed investment smoothing for firms reporting R&D information.

6. Conclusion

We study how firms prioritize across competing real investments when they encounter a severe negative finance shock. Since adjustment costs for R&D likely increase much faster than those for fixed investment, we expect firms to allocate a disproportionate amount of available liquidity to R&D during periods when access to finance declines sharply. We study the recent financial crisis and find strong support for this idea. First, we find that the large majority of firms engaged in both fixed investment and R&D cut the former far more than the latter. Second, we estimate dynamic investment regressions that include the *changes* in cash holdings, allowing us to directly explore how firms spend liquidity to support investment. These regressions show that firms allocate a disproportionate share of cash holdings to buffer R&D and even take the extreme step of allowing their stock of fixed capital to fall in order to support R&D. This favorable treatment of R&D compared to fixed investment is particularly pronounced in the firms who *a priori* were likely to face the most severe financing constraints during the crisis. We also find that firms engaged in no (or very little) R&D – and thus where R&D is not a competing use of funds – do allocate cash holdings to buffer fixed investment. Overall, our findings demonstrate that when firms must prioritize among competing real investments during a crisis, they allocate liquidity primarily to protect R&D. Based on these findings, we conclude with some final thoughts on the private and public benefits of cash holdings.

In the recent crisis, *aggregate* industrial R&D did not fall in 2008 and declined by 2.9% in 2009 (in nominal terms), far less than aggregate fixed investment. Given how dramatically internal finance and stock issues fell, it is hard not to conclude that *collectively* firms were rather successful at protecting R&D. Since our sample contains a large fraction of total corporate R&D, our findings suggest that cash holdings played an important role in protecting aggregate R&D, which arguably mitigated some of the long-run costs of the crisis. The rationale is that unlike fixed investment, there are large "spillovers" from new knowledge creation, suggesting that the social returns to R&D can be very large (see the reviews in Griliches, 1992, and Hall et al., 2010), making R&D a critical driver of economic growth (e.g., Romer, 1990; Aghion and Howitt, 1992).

Bates et al. (2009) report that cash holdings (per dollars of assets) was at an all-time high just before the recent crisis, which to many observers in the financial press seemed like an excessive level of liquidity.[18] Duchin et al. (2010) explore the connection between cash holdings and investment during the recent crisis and conclude (p. 423) that "seemingly excess cash may in fact benefit firms in times of dislocation in markets for external finance." Our results support this view, but with the important qualification that cash holdings in times of dislocation appear to be most beneficial to R&D-intensive firms compared to more traditional companies. Moreover, to the extent that R&D buffering has the economy-wide benefits discussed above, cash holdings can produce substantial benefits that are *external* to the firm. This implies that for many R&D-intensive firms, "seemingly excess cash" from a private point of view may in fact be closer to what is socially optimal.

[18] See for example Ian McDonald, "Capital Pains: Big Cash Hoards," *The Wall Street Journal*, July 21, 2006, p. C1.

Appendix

We modify the standard dynamic optimization model used in Love (2003) and a number of other studies (e.g., Whited, 1992; Gilchrist and Himmelberg, 1998). Similar to Hall (1995), one modification is that output is a function of both fixed capital (K) and technology (T), rather than just fixed capital and we follow the literature in assuming a one-period time to build lag for both investments. Quantity of investment in fixed capital is denoted by I and investment in technology is denoted by RD and prices of these two investments are P^I and P^{RD}. A second modification is that we allow the firm to have positive cash holdings, which can be used (drawn down) to partially relax financing constraints during a crisis. To simplify, we ignore debt finance (as does Love (2003)), which has no impact on the first-order conditions considered below.

Managers are assumed to maximize the expected present value of dividends subject to the capital accumulation and financing constraints. Equations (A1)-(A6) characterize the problem:

$$V_t(K_t, T_t, \xi_t) = \max_{\{I_{t+s}, RD_{t+s}\}_{s=0}} \{ D_t + E_t[\sum_{s=1}^{\infty} \beta_{t+s-1} D_{t+s}]\} \tag{A1}$$

subject to

$$D_t = \Pi(K_t, T_t, \xi_t) - P^I_t I_t - P^{RD}_t RD_t - \Phi(I_t, K_{t-1}) - \Omega(RD_t, T_{t-1}) - \Delta CH_t \tag{A2}$$

$$K_{t+1} = K_t + I_t \tag{A3}$$

$$T_{t+1} = T_t + RD_t \tag{A4}$$

$$CH_{t+1} = CH_t + \Delta CH_t \tag{A5}$$

$$D_t \geq 0. \tag{A6}$$

In equation (A1), ξ_t is a productivity shock, D_t is the dividend paid to shareholders, β_{t+s-1} is a discount factor from period *t+s* to period *t* and E_t is the expectation conditional on information known at time *t*. Equation (A2) is the "sources and uses" condition and determines the size of dividends. As is standard in the literature, adjustment costs for fixed investment ($\Phi(I_t, K_{t-1})$) are assumed to be convex and depend on the level of both I and K (e.g., typical to assume Φ depends on I/K). Symmetrically, we assume the adjustment costs for R&D ($\Omega(RD_t, T_{t-1})$) are convex and depend on the level of both R&D and T (e.g., Hall, 1995; Hall and Lerner, 2010). In equation (A2), ΔCH_t is the change in the level of cash holdings (CH), which can be either positive (use of funds) or negative (source of funds). Equations (A3), (A4) and (A5) describe the path of accumulating fixed capital, technology and cash holdings, ignoring depreciation (which adds no additional insights to the analysis).

Equation (A6) introduces financing constraints in the manner commonly done in the literature (e.g., Love, 2003): there is a non-negativity constraint on dividends (i.e., no new share issues). The multiplier on this constraint, λ_t, is the shadow value to the firm of being able to obtain equity finance by paying negative dividends (or generating additional internal equity finance). Within this framework, one way to think of a financing crisis is as a sharp decline in the availability of *internally* generated finance (i.e., sharp fall in $\Pi(K_t , T_t)$), which was a major feature of the 2007-2009 crisis. Alternatively, one could assume that firms face perfect capital markets and can issue new external equity during normal times ($\lambda = 0$) and Equation (A6) is only present during a financing crisis ($\lambda > 0$). The Euler conditions for the constrained maximization problem are given in equations (1) and (2) in Section II of the paper.

It is important to point out the key role of cash holdings in equation (A2) for relaxing financing constraints during a crisis. Suppose a crisis occurs in period *t*, shutting down all access to external finance. Spending down cash holdings makes it possible for

$$P^I I_t + P^{RD} RD_t > \Pi (K_t , T_t) - \text{adjustment costs}$$

without necessarily violating equation (A6). Given that Π_t often becomes negative during a financing crisis, firms with no cash reserves could be forced to cut total investment to zero and possibly still not satisfy equation (A6), short of selling assets.

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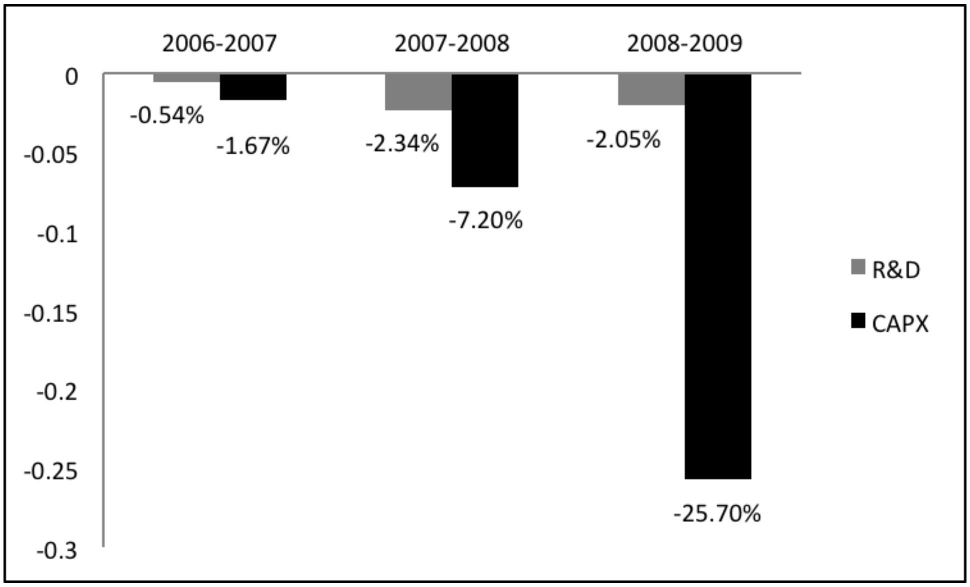

Figure 1. Median within-firm percentage change in R&D and fixed investment. The reported value is the median across the entire sample of 1009 firms. The sample is described in Table 1.

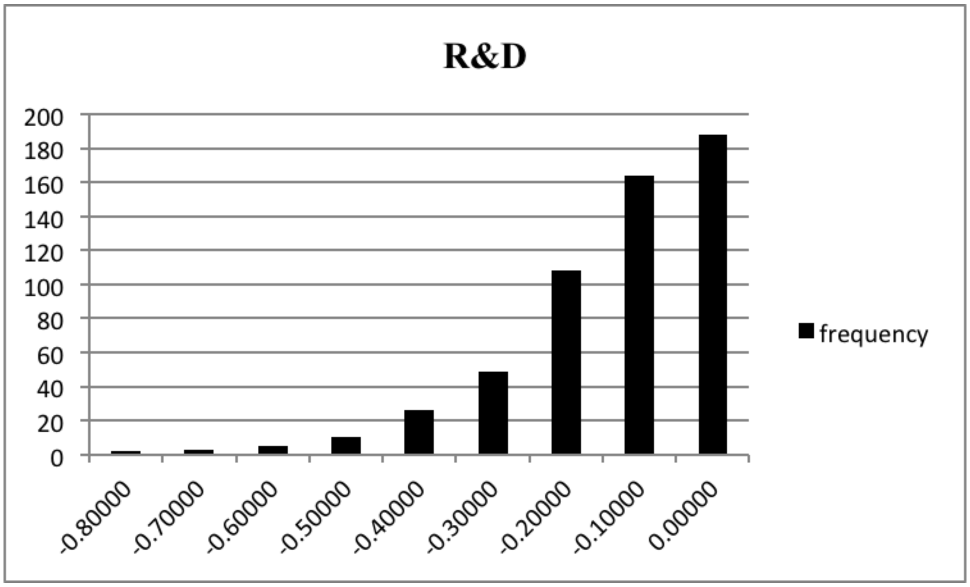

Figure 2a. Histogram of the percentage size of firm cuts to R&D (2008-2009). Reported for the 543 sampled firms with cuts to R&D between 2008 and 2009. The full sample is described in Table 1.

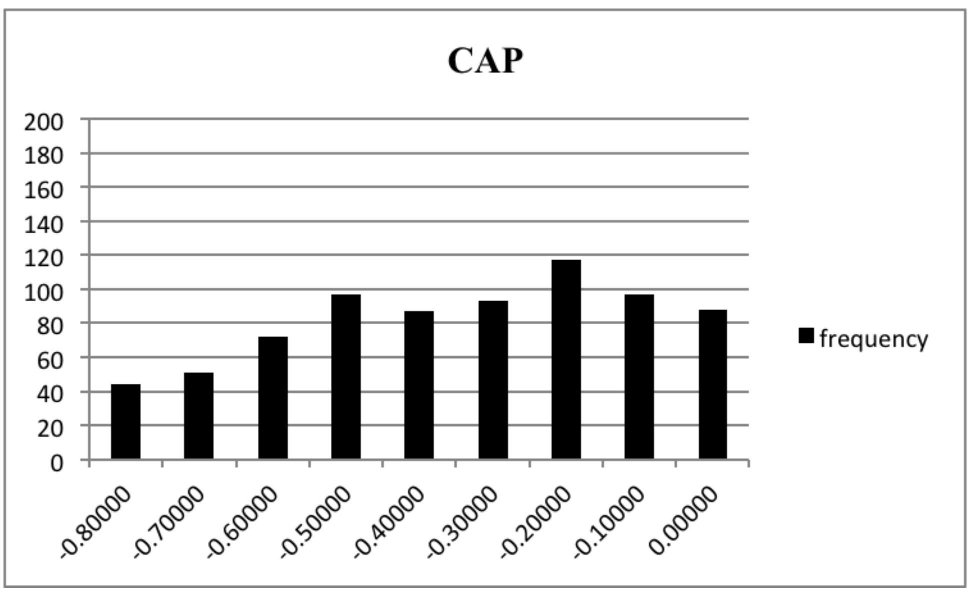

Figure 2b. Histogram of the percentage size of firm cuts to fixed investment (2008-2009). Reported for the 746 sampled firms with cuts to fixed investment between 2008 and 2009. The full sample is described in Table 1.

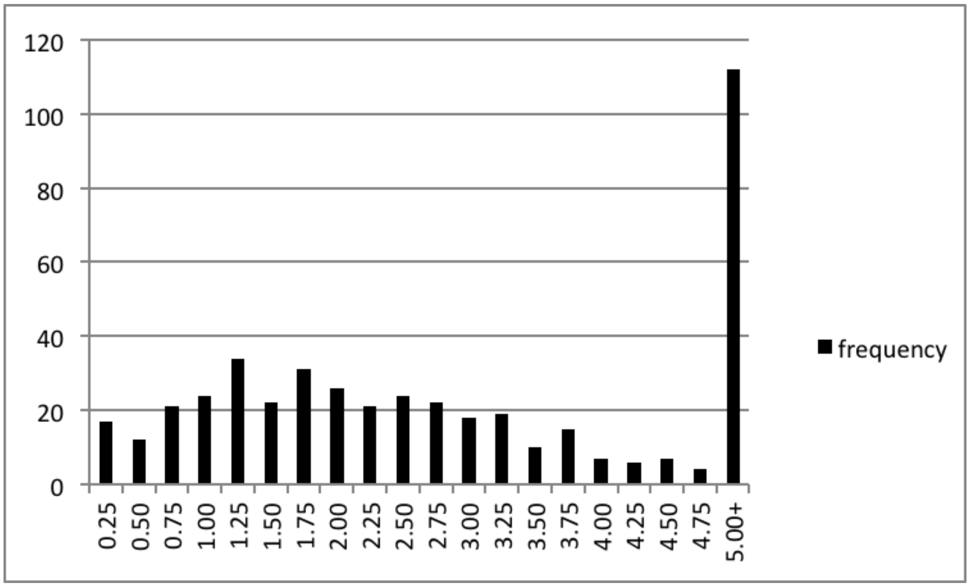

Figure 3. Distribution of the percent change in fixed investment divided by the percent change in R&D (2008-2009). Reported for the 452 sampled firms with cuts to both fixed investment and R&D from 2008 to 2009. The full sample is described in Table 1.

Table 1: Firm count by industry

The table reports the number of firms by 2-digit SIC code. The sample is constructed from publicly-traded firms with coverage in the Compustat database during 2004-2010. Firms with a SIC code from a regulated or financial industry (SIC 4900-4999 or 6000-6999) are excluded. Firm-year observations are excluded if capital expenditures or sales are negative, total assets are less than $5 million (in 2005 dollars), or if sales growth is greater than 100%. Firms without seven R&D observations and seven fixed investment (CAP) observations over 2004-2010 are excluded.

Industry	2-digit SIC codes	Firm count	Share of sample
Ag, Mining, and Construction	01-17	7	0.007
Food	20	12	0.012
Tobacco	21	4	0.004
Textiles	22	2	0.002
Apparel	23	1	0.001
Lumber and wood	24	3	0.003
Furniture	25	13	0.013
Paper	26	18	0.018
Printing and publishing	27	2	0.002
Chemicals	28	137	0.136
Petroleum	29	6	0.006
Rubber and plastics	30	13	0.013
Leather	31	2	0.002
Pottery and glass	32	9	0.009
Primary metals	33	12	0.012
Fabricated metal products	34	23	0.023
Machinery and computers	35	124	0.123
Electronics	36	209	0.207
Transportation equipment	37	48	0.048
Instruments	38	164	0.163
Misc manufacturing	39	16	0.016
Transportation and communications	40-49	10	0.010
Wholesale and retail trade	50-59	14	0.014
Non-business services	70-72, 74-89	21	0.021
Business services	73	139	0.138
High-tech industries	28, 35, 36, 38, 73	773	0.766
Full sample	All	1009	1.000

Table 2: Sample characteristics by year

The table reports average values of key investment and financing variables for each year from 2004 to 2010. Panel A (1009 firms) reports average values for the full sample of firms (*Full sample*), and Panel B (566 firms) reports average values for a sub-set of the full sample comprised of firms with average fixed investment-to-assets ratios over 2004-2006 of at least 0.03 (*HighCap sample*). All averages are computed after excluding the 1% tails. All variables are scaled by beginning-of-period total assets. The sample is described in detail in Table 1.

	R&D	CAP	Fixed Assets	Cash Flow	Stock Issues	Debt Issues	Cash Holdings	Total Debt
				Panel A: Full sample				
2004	0.081	0.038	0.191	0.153	0.035	0.004	0.282	0.211
2005	0.077	0.040	0.178	0.149	0.014	0.004	0.277	0.209
2006	0.083	0.041	0.181	0.154	0.016	0.010	0.271	0.215
2007	0.080	0.040	0.175	0.148	0.003	0.012	0.262	0.217
2008	0.077	0.038	0.168	0.102	-0.013	0.009	0.212	0.213
2009	0.077	0.028	0.168	0.107	0.011	-0.007	0.255	0.202
2010	0.080	0.032	0.170	0.150	0.011	0.002	0.272	0.202
				Panel B: HighCap sample				
2004	0.079	0.054	0.242	0.173	0.037	0.006	0.253	0.206
2005	0.076	0.058	0.232	0.168	0.012	0.005	0.241	0.213
2006	0.080	0.058	0.239	0.171	0.018	0.011	0.239	0.218
2007	0.075	0.053	0.228	0.162	0.003	0.015	0.237	0.219
2008	0.072	0.050	0.220	0.120	-0.011	0.012	0.186	0.223
2009	0.069	0.036	0.217	0.114	0.012	-0.004	0.226	0.208
2010	0.072	0.041	0.218	0.162	0.010	0.004	0.245	0.209

Table 3: R&D and fixed investment regressions during the financial crisis

The table reports estimates of equation (4) with R&D as the dependent variable in the first four columns and fixed capital investment (CAP) as the dependent variable in the last four columns. Estimation is by systems GMM with lagged levels dated *t*-3 to *t*-4 used as instruments for the equation in differences and lagged differences dated *t*-2 used as instruments for the equation in levels. Fixed firm and time effects are included in all regressions. The regression sample is the *Full sample* described in Table 1. Standard errors robust to heteroskedasticity and within-firm serial correlation are reported in parenthesis. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level.

Dep. Variable	*R&D*				*CAP*			
	2004-2010	2007-2009	2007-2008	2008-2009	2004-2010	2007-2009	2007-2008	2008-2009
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
INV_{t-1}	1.024	1.110	1.313	1.036	0.685	0.610	0.762	0.625
	(0.072)***	(0.131)***	(0.208)***	(0.167)***	(0.119)***	(0.234)***	(0.381)**	(0.289)**
INV^2_{t-1}	-0.453	-0.942	-1.702	-0.493	-0.637	0.316	-0.562	1.260
	(0.184)**	(0.403)**	(0.627)***	(0.471)	(0.746)	(1.507)	(2.237)	(1.880)
$Sales_t$	0.028	-0.003	-0.004	-0.024	0.036	0.032	0.024	0.065
	(0.014)**	(0.021)	(0.028)	(0.031)	(0.008)***	(0.018)*	(0.021)	(0.017)***
$Sales_{t-1}$	-0.030	-0.005	-0.015	0.010	-0.030	-0.023	-0.017	-0.063
	(0.014)**	(0.020)	(0.025)	(0.023)	(0.008)***	(0.018)	(0.020)	(0.016)***
$CashFlow_t$	0.068	0.178	0.224	0.148	0.008	0.023	0.027	-0.013
	(0.035)**	(0.068)***	(0.092)**	(0.091)	(0.022)	(0.044)	(0.051)	(0.060)
$CashFlow_{t-1}$	0.012	-0.065	-0.078	-0.006	0.026	0.023	0.013	0.067
	(0.034)	(0.054)	(0.082)	(0.045)	(0.017)	(0.035)	(0.044)	(0.029)**
$StkIssues_t$	0.128	0.284	0.329	0.261	0.026	0.040	0.052	-0.012
	(0.041)***	(0.054)***	(0.081)***	(0.072)***	(0.017)	(0.033)	(0.050)	(0.051)
$StkIssues_{t-1}$	-0.037	-0.085	-0.035	0.009	0.009	0.016	0.011	0.045
	(0.037)	(0.055)	(0.079)	(0.076)	(0.016)	(0.024)	(0.035)	(0.032)
$\Delta CashHoldings_t$	-0.057	-0.131	-0.163	-0.249	-0.009	-0.015	-0.011	-0.020
	(0.041)	(0.054)**	(0.066)**	(0.070)***	(0.021)	(0.034)	(0.050)	(0.043)
$\Delta CashHoldings_{t-1}$	-0.088	-0.055	-0.063	-0.168	-0.011	-0.024	-0.060	0.019
	(0.028)***	(0.047)	(0.071)	(0.081)**	(0.016)	(0.025)	(0.044)	(0.040)
Sum CashFlow	0.003	0.029	0.038	0.075	0.027	0.087	0.251	0.277
(p-value from Chi-squared test)								
Sum StkIssues	0.079	0.014	0.008	0.016	0.030	0.062	0.165	0.494
(p-value from Chi-squared test)								
Sum ΔCash	0.003	0.015	0.019	0.002	0.459	0.311	0.134	0.995
(p-value from Chi-squared test)								
m2	1.650	0.260			-0.390	-2.000		
Hansen J-test	0.397	0.590	0.837	0.866	0.015	0.215	0.873	0.405
Diff-Hansen	0.497	0.240	0.545	0.318	0.007	0.318	0.705	0.568
Obs	7,001	3,027	2,018	2,018	7,001	3,027	2,018	2,018
Firms	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009

Table 4: R&D and fixed investment regressions: Alternative demand controls

The table reports estimates of equation (4) with Q and sales growth used as demand controls in place of current and lagged sales. R&D is the dependent variable in the first four columns and fixed capital investment (CAP) is the dependent variable in the last four columns. Estimation is by systems GMM with lagged levels dated *t*-3 to *t*-4 used as instruments for the equation in differences and lagged differences dated *t*-2 used as instruments for the equation in levels. Fixed firm and time effects are included in all regressions. The regression sample is the *Full sample* described in Table 1. The table reports the sum of the coefficients on current and lagged financial variables. The values in italics are *p*-values from Chi-squared tests of the null hypothesis that the coefficient estimates are equal to zero after adjusting standard errors for heteroskedasticity and within-firm serial correlation.

Dep. Variable	*R&D*				*CAP*			
	2004-2010	2007-2009	2007-2008	2008-2009	2004-2010	2007-2009	2007-2008	2008-2009
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Q	0.005	0.006	0.005	0.002	0.003	0.004	0.003	0.004
p-value	*0.014*	*0.033*	*0.131*	*0.526*	*0.018*	*0.002*	*0.133*	*0.071*
Sales growth	-0.035	-0.057	-0.068	-0.004	0.024	0.028	-0.009	0.050
p-value	*0.048*	*0.057*	*0.220*	*0.869*	*0.024*	*0.079*	*0.678*	*0.000*
Cash flow	0.072	0.093	0.097	0.068	0.024	0.038	0.037	-0.011
p-value	*0.007*	*0.032*	*0.131*	*0.203*	*0.137*	*0.112*	*0.184*	*0.761*
Stock issues	0.098	0.224	0.321	0.218	0.009	0.012	0.051	-0.006
p-value	*0.010*	*0.001*	*0.003*	*0.009*	*0.592*	*0.676*	*0.242*	*0.892*
ΔCashHoldings	-0.199	-0.244	-0.280	-0.356	-0.052	-0.035	-0.033	-0.030
p-value	*0.000*	*0.000*	*0.001*	*0.000*	*0.027*	*0.314*	*0.417*	*0.574*
m2	1.46	-0.50			-1.39	-1.61		
Hansen J-test	0.187	0.345	0.638	0.592	0.003	0.233	0.473	0.606
Diff-Hansen	0.143	0.084	0.439	0.059	0.018	0.749	0.208	0.514
Obs	6,993	3,024	2,016	2,016	6,993	3,024	2,016	2,016
Firms	1,008	1,008	1,008	1,008	1,008	1,008	1,008	1,008

Table 5: R&D regressions: Alternative specifications

The table reports alternative specifications of the dynamic R&D regression. Estimation is by systems GMM with lagged levels dated *t*-3 to *t*-4 used as instruments for the equation in differences and lagged differences dated *t*-2 used as instruments for the equation in levels. Fixed firm and time effects are included in all regressions. The regression sample is the *Full sample* described in Table 1. In columns (1)-(4) the table reports the sum of the coefficients on current and lagged financial variables. The model in columns (5) and (6) excludes lags of the financial variables and reports the coefficient estimate on the contemporaneous term only. The values in italics are *p*-values from Chi-squared tests of the null hypothesis that the coefficient estimates are equal to zero after adjusting standard errors for heteroskedasticity and within-firm serial correlation.

	Add change in stock of fixed assets		Use alternative demand controls		Drop lags of financial variables	
	2004-2010	2007-2009	2004-2010	2007-2009	2004-2010	2007-2009
	(1)	(2)	(3)	(4)	(5)	(6)
Cash flow	0.087	0.161	0.076	0.122	0.069	0.138
p-value	*0.002*	*0.002*	*0.003*	*0.005*	*0.015*	*0.003*
Stock issues	0.113	0.260	0.106	0.238	0.124	0.310
p-value	*0.021*	*0.000*	*0.004*	*0.000*	*0.041*	*0.000*
ΔCashHoldings	-0.163	-0.224	-0.199	-0.254	-0.051	-0.151
p-value	*0.000*	*0.002*	*0.000*	*0.000*	*0.230*	*0.012*
ΔK	-0.005	-0.420	0.012	-0.424	-0.155	-0.452
p-value	*0.962*	*0.028*	*0.905*	*0.027*	*0.122*	*0.010*
m2	1.49	-0.33	1.44	-0.90	1.52	-0.60
Hansen J-test	0.583	0.785	0.367	0.415	0.051	0.540
Diff-Hansen	0.636	0.415	0.294	0.113	0.004	0.113
Obs	7,001	3,027	6,993	3,024	7,001	3,027
Firms	1,009	1,009	1,008	1,008	1,009	1,009

Table 6: R&D regressions: Sample splits

The table reports separate estimates of equation (4) for groups of firms sorted on the *ex ante* likelihood they face binding financing constraints. Firms are sorted based on characteristics in the pre-crisis (2004-2006) interval. Estimation is by systems GMM with lagged levels dated *t*-3 to *t*-4 used as instruments for the equation in differences and lagged differences dated *t*-2 used as instruments for the equation in levels. Fixed firm and time effects are included in all regressions. The regression sample is the *Full sample* described in Table 1 and the sample period is 2007-2009. The table reports the sum of the coefficients on current and lagged financial variables. The values in italics are *p*-values from Chi-squared tests of the null hypothesis that the coefficient estimates are equal to zero after adjusting standard errors for heteroskedasticity and within-firm serial correlation.

	Age		Size		Payout		Bank dependence	
	Young	Mature	Small	Large	Low	High	Yes	No
	(1)	(2)	(3)	(4)	(5)	(6)	(5)	(6)
Cash flow	0.176	0.142	0.151	0.233	0.154	-0.093	0.155	0.066
p-value	*0.001*	*0.078*	*0.002*	*0.006*	*0.006*	*0.094*	*0.014*	*0.210*
Stock issues	0.299	0.154	0.243	0.156	0.260	-0.026	0.303	0.090
p-value	*0.000*	*0.089*	*0.000*	*0.106*	*0.000*	*0.579*	*0.001*	*0.377*
ΔCashHoldings	-0.241	-0.147	-0.205	0.006	-0.200	0.099	-0.302	-0.081
p-value	*0.000*	*0.042*	*0.000*	*0.964*	*0.004*	*0.216*	*0.001*	*0.249*
ΔK	-0.563	-0.184	-0.377	-0.331	-0.456	0.341	-0.489	-0.004
p-value	*0.038*	*0.265*	*0.053*	*0.073*	*0.030*	*0.129*	*0.056*	*0.977*
m2	-0.180	-1.000	-0.240	0.200	-0.470	0.940	-0.29	0.79
Hansen J-test	0.929	0.566	0.784	0.056	0.906	0.962	0.847	0.581
Diff-Hansen	0.614	0.736	0.478	0.001	0.466	0.503	0.113	0.044
Obs	1,605	1,422	2,118	909	2,118	909	2208	819
Firms	535	474	706	303	706	303	136	273

Table 7: Difference-in-differences regressions

The table reports estimates of difference-in-differences regressions using quarterly data. In the first four columns R&D-to-total assets is the dependent variable and in the last three columns fixed investment-to-total assets is the dependent variable. The sample is all firms in the *Full sample* with sufficient quarterly data. *EarlyCrisis* is a dummy variable equal to one for each quarter between 2007Q3 and 2008Q2, and zero otherwise. *LateCrisis* is a dummy variable equal to one for each quarter between 2008Q3 and 2009Q2, and zero otherwise. In all columns except (4), the sample period is 2006Q3-2008Q2. In column (4) the sample period is 2006Q3-2009Q2. Estimation is by systems GMM with lagged levels dated *t*-3 to *t*-8 used as instruments for the equation in differences and lagged differences dated *t*-2 used as instruments for the equation in levels. Fixed firm and quarterly time effects are included in all regressions. Standard errors robust to heteroskedasticity and within-firm serial correlation are reported in parenthesis. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% level.

Dep. Variable	*R&D*				*CAP*		
	Baseline diff-n-diff	Add stock issues	Full set of interactions	Early vs. late	Baseline diff-n-diff	Add stock issues	Full set of interactions
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Q	0.011	0.010	0.010	0.008	0.001	0.001	0.001
	(0.003)***	(0.003)***	(0.003)***	(0.002)***	(0.001)	(0.001)	(0.001)
Cash flow	-0.015	0.014	0.001	0.010	0.010	0.013	0.024
	(0.047)	(0.039)	(0.043)	(0.027)	(0.014)	(0.013)	(0.015)
Cash flow*EarlyCrisis			0.029				-0.023
			(0.032)				(0.013)*
Stock issues		0.115	0.114	0.114		0.006	0.016
		(0.036)***	(0.035)***	(0.034)***		(0.012)	(0.014)
Stock issues*EarlyCrisis			0.009			0.006	-0.028
			(0.049)			(0.012)	(0.019)
ΔCashHoldings	0.011	-0.032	-0.028	-0.027	-0.007	-0.008	-0.014
	(0.016)	(0.015)**	(0.016)*	(0.014)*	(0.007)	(0.007)	(0.008)*
ΔCashHoldings*	-0.056	-0.061	-0.073	-0.052	0.006	0.000	0.015
EarlyCrisis	(0.029)**	(0.024)**	(0.037)**	(0.022)**	(0.012)	(0.010)	(0.012)
ΔCashHoldings*				-0.080			
LateCrisis				(0.030)***			
m2	-.50	-0.76	-0.69	-2.09	-0.87	-0.92	-0.78
Hansen J-test	0.168	0.414	0.377	0.028	0.223	0.439	0.485
Diff-Hansen	0.009	0.006	0.001	0.003	0.104	0.650	0.569
Obs	5,767	5,766	5,766	8,681	5,817	5,817	5,817
Firms	752	752	752	752	752	752	752

Table 8: Fixed investment regressions: Alternative samples

The table reports dynamic investment regressions with fixed investment as the dependent variable. In columns (1)-(4) the regression sample is the *HighCap sample* described in Table 1. In columns (5)-(8) the regression sample includes all firms in the *Full sample* plus the firms that were excluded due to lack of R&D information. In columns (1)-(7) estimation is by systems GMM with lagged levels dated *t*-3 to *t*-4 used as instruments for the equation in differences and lagged differences dated *t*-2 used as instruments for the equation in levels. In column (8) estimation is by difference GMM with lagged levels dated *t*-3 to *t*-4 used as instruments for the differenced regression equation. Fixed firm and time effects are included in all regressions. Columns (1)-(2) and (5)-(6) report the sum of the coefficients on current and lagged financial variables. The models in columns (3)-(4) and (7)-(8) exclude lags of the financial variables and so the reported value is the coefficient estimate on the contemporaneous term only. The values in italics are *p*-values from Chi-squared tests of the null hypothesis that the coefficient estimates are equal to zero after adjusting standard errors for heteroskedasticity and within-firm serial correlation.

	HighCap Sample				*BroadCap Sample*			
	Baseline regression		Add debt issues, drop lags		Baseline regression		Add debt issues, drop lags	
	2004-2010	2007-2009	2004-2010	2007-2009	2004-2010	2007-2009	2007-2009	2007-2009
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cash flow	0.046	0.051	0.036	0.056	0.102	0.121	0.150	0.232
p-value	*0.019*	*0.099*	*0.031*	*0.065*	*0.000*	*0.001*	*0.000*	*0.000*
Stock issues	0.047	0.069	0.040	0.074	0.090	0.122	0.131	0.221
p-value	*0.017*	*0.030*	*0.026*	*0.013*	*0.003*	*0.019*	*0.008*	*0.013*
Debt issues			0.070	0.097			0.289	0.318
p-value			*0.027*	*0.032*			*0.000*	*0.003*
ΔCashHoldings	-0.033	-0.034	-0.013	-0.026	-0.132	-0.149	-0.104	-0.171
p-value	*0.248*	*0.490*	*0.643*	*0.509*	*0.003*	*0.017*	*0.018*	*0.013*
m2	-0.730	-2.450	-1.62	-2.64	2.39	0.13	0.16	0.62
Hansen J-test	0.327	0.803	0.361	0.797	0.000	0.000	0.000	0.364
Diff-Hansen	0.032	0.410	0.042	0.175	0.010	0.000	0.000	
Obs	3,922	1,698	3,922	1,698	14535	6274	6274	6274
Firms	566	566	566	566	2092	2092	2092	2092