Cash Holdings and R&D Smoothing*

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Abstract

The sharp increase in R&D investment in recent decades has important but unexplored implications for corporate liquidity management. Because R&D has high adjustment costs and is financed with volatile sources, it is very expensive for firms to adjust the flow of R&D in response to transitory finance shocks. The main contribution of this paper is to directly examine whether firms use cash reserves to smooth their R&D expenditures. We estimate dynamic R&D models and find that firms most likely to face financing frictions rely extensively on cash holdings to smooth R&D. In particular, our estimates suggest that young firms used cash holdings to dampen the volatility in R&D by approximately 75% during the 1998-2002 boom and bust in equity issues. Firms less likely to face financing frictions appear to smooth R&D without the use of costly cash holdings. Our findings provide new insights into the value of liquidity and the financing of intangible investment, and suggest that R&D smoothing with cash reserves is now important for understanding cash management for a substantial fraction of publicly traded firms.

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I. Introduction

In recent decades, R&D investment has risen sharply and is now the principal investment for a large fraction of publicly traded U.S. firms. The sharp increase in R&D has important implications for the management of corporate liquidity for at least three reasons. First, financing frictions should be particularly relevant for R&D due to limited collateral value and potentially severe information problems. Second, for a large fraction of firms, R&D is financed almost exclusively with volatile sources of finance (e.g., cash flow and stock issues). Finally, R&D faces large adjustment costs because most R&D is wage payments to highly skilled technology workers. In particular, firing R&D workers can result in large hiring and training costs as well as the unwanted dissemination of proprietary information on innovation efforts, making it very expensive for firms to adjust the flow of R&D investment in response to temporary changes in the availability of finance. Firms facing financing frictions should therefore have strong incentives to build and manage a buffer stock of liquidity in order to maintain a relatively smooth path of R&D spending.

In this study, we directly examine the role that corporate cash holdings play in buffering the flow of R&D from transitory finance shocks. To our knowledge, this is the first study to test for R&D smoothing with cash holdings and to emphasize its importance for corporate financial policy. Our findings indicate that R&D smoothing is now an important aspect of cash management for a significant fraction of publicly traded firms. In addition to offering new evidence on the impact that corporate liquidity has on real investment decisions, our study has a number of interesting implications. In particular, we offer a new insight into why liquidity can be so valuable for R&D-intensive firms: cash holdings buffer R&D from shocks to finance, thereby partially avoiding the high adjustment costs associated with altering the path of R&D investment. Our study also helps explain how individual firms facing potentially severe financing frictions manage to weather serious finance shocks, and, more broadly, why *aggregate* R&D investment is so smooth compared to the underlying volatility in key sources of finance.

We explore R&D smoothing with panel data for publicly traded firms in U.S. manufacturing over the time period 1970-2006. We focus on manufacturing because this sector is responsible for nearly two-thirds of U.S. private sector R&D. We divide the sample into three periods – 1970-1981, 1982-1993 and

1994-2006 – and we sort firms into various groups based on the *a priori* likelihood they face binding financing constraints. Our primary sample split divides firms into young and mature categories based on the number of years since the firm first appears in Compustat. Several recent studies use age as a proxy for the presence of quantitatively important financing frictions (e.g., Hadlock and Pierce (2009)), and we expect that cash holdings will be much more important for R&D smoothing among young firms, particularly those depending heavily on volatile sources of finance.

Figures 1A and 1B illustrate many of the main ideas in this paper. The figures report average values of key variables scaled by assets and Winsorized at the 1% level. For young firms (Figure 1A), both R&D and cash holdings rise dramatically over the period 1970 to 2006. Stock issues are a very important source of finance by the 1980s and appear to fund most of the sharp rise in R&D. Stock issues also display dramatic "equity cycles," with very sharp declines in periods such as 1988-1989 and 2001-2002, periods following precipitous declines in Nasdaq stock prices. While there is a substantial cycle in R&D spending in the late 1990s and early 2000s (e.g., Brown, Fazzari and Petersen (2009)), R&D is far smoother than new share issues, and neither debt finance nor cash flow appears to be the source of the funds for this smoothing. Rather, young firms appear to build cash reserves when cash flow and stock issues are plentiful and then draw them down in years when equity is less available (e.g., 2001-2002). In contrast, while mature-firm R&D is very smooth (Figure 1B), cash holdings do not appear to play a central role in this smoothing, as expected if mature firms face minimal financing frictions.

To formally examine R&D smoothing with cash holdings, we include changes in cash holdings (ΔCashHoldings) in a dynamic R&D regression that includes cash flow, debt issues, and stock issues (Table 2). We estimate the R&D regression with a "systems" GMM estimator that accounts for unobserved firm-specific effects and controls for the potential endogeneity of all financial variables, including ΔCashHoldings. Our main prediction is a *negative* coefficient on ΔCashHoldings in the R&D regression for firms who are likely to face financing frictions: all else equal, reductions in cash holdings free liquidity for R&D. A second prediction is that the coefficient for ΔCashHoldings should be near zero for firms not likely to face substantial frictions and thus able to smooth R&D without the use of costly cash holdings.

For young firms, we find limited evidence of R&D smoothing with cash reserves in the first period (1970-1981) when R&D investment is low. In the middle time period (1982-1993), the estimated coefficients on ΔCashHoldings are negative, significant, and substantial (in absolute value). We find the strongest evidence of R&D smoothing with cash holdings in the final period (1994-2006), when R&D intensity is greatest and stock issues are most volatile. The point estimates in the final two periods indicate a quantitatively important link between changes in cash reserves and young-firm R&D spending. In contrast, for mature firms, the estimated coefficients on ΔCashHoldings are quantitatively small and generally insignificant.

We also use the large change in the availability of equity finance during two narrow windows – 1998-2000 and 2000-2002 – to further explore the importance of cash holdings for R&D smoothing. The 1998-2000 period is often referred to as the "bubble period" (e.g., Bradley, Jordan and Ritter (2008)) because of the dramatic run-up in Nasdaq stock prices and stock issues. The 2000-2002 period contains the largest crash in share prices and stock issues in our data, suggesting a pronounced decline in the availability of finance. In addition, the 2000-2002 window also contains the largest decline in R&D in our data (and the largest single-year reduction in U.S. industrial R&D ever recorded by the NSF). When we estimate the R&D regressions for these windows, we find a strong, negative link between changes in cash holdings and young-firm R&D in both the boom and bust periods, but a small and statistically insignificant link for mature firms, consistent with our predictions. Based on the magnitude of the ΔCashHoldings coefficients, our estimates suggest that young firms used cash holdings to dampen the volatility in R&D by approximately 75% during the 1998-2002 boom and bust in equity issues.

We explore a wide variety of auxiliary regressions and tests of robustness. First, we re-estimate all regressions for alternative splits of the data. We find large negative coefficients for ΔCashHoldings for zero payout firms, small firms, and firms without bond ratings, all sample splits used in the literature to identify firms likely to face binding financing constraints; in contrast, the coefficients on ΔCashHoldings are near zero (and generally insignificant) for positive payout firms, large firms, and firms with bond ratings. We also use a variety of alternative estimation approaches and continue to find strong evidence that young firms rely extensively on cash holdings to smooth R&D. Finally, we estimate identical regressions for physical investment and find small, insignificant coefficients on ΔCashHoldings for both young and mature firms. This finding is consistent with firms having much less need to smooth physical investment with costly cash holdings, in part because physical capital adjustment costs are relatively “modest” (e.g., Cooper and Haltiwanger (2006)). Overall, our findings support an interpretation that firms facing financing constraints actively manage their liquid assets to buffer the flow of R&D from temporary changes in the availability of finance.

Our study is related to a number of different literatures. First, our findings are relevant for the empirical literature that considers how cash holdings impact firm performance and market value. Prior work by Harford (1999) and Harford, Mansi and Maxwell (2008) suggests that cash reserves can be value-decreasing because larger firms with weak governance mechanisms may “over spend” on acquisitions and capital investments. Alternatively, Mikkelson and Partch (2003) find that a sample of firms with large cash holdings have a higher median operating performance than a matched set of firms with lower cash balances. They also report that the sample of high-cash firms is considerably more R&D intensive than the comparison groups. Faulkender and Wang (2006) show that the marginal value of cash is higher for firms more likely to face financing frictions, particularly for those constrained firms that appear to have valuable investment opportunities but low levels of internal finance. Pinkowitz and Williamson (2007) find that the market value of the marginal dollar of cash is highest in R&D-intensive industries such as computer software, pharmaceuticals, computers, and electronic equipment. Denis and Sibilkov (in press) confirm that cash holdings are more valuable for constrained firms and they provide evidence showing that more cash permits constrained firms to increase investment and that the marginal value of added investment is greater for constrained firms than for unconstrained firms. We also provide direct evidence that cash holdings positively impact the real investment spending of constrained firms (but for R&D rather than physical investment) and we provide new insights into how cash holdings can be particularly valuable for R&D-intensive firms.

A number of studies provide theoretical models showing how cash holdings can benefit firms facing financing frictions. Kim, Mauer and Sherman (KMS, 1998) develop and find empirical support for a model where optimal cash holdings is determined by the tradeoff between the cost of holding liquid assets and the benefits of minimizing the need to fund future investment opportunities with costly external finance. Almeida, Campello and Weisbach (ACW, 2004) show that a benefit of holding cash is the ability to finance future projects that might arise, and that the greater the importance of future growth opportunities vis-à-vis current opportunities, the more cash firms hoard today. Han and Qiu (2007) assume that future cash flow can not be fully hedged and show that when returns are convex, the greater the volatility of cash flow, the greater the optimal precautionary cash stock. Acharya, Almeida and Campello (AAC, 2007) explore both cash holdings and debt policies and show that firms with "high hedging needs" will prefer to build cash stocks rather than debt capacity to hedge against cash flow shortfalls. One important way our work differs from these studies is that we directly examine the use of cash holdings for investment smoothing rather than the propensity with which firms invest their cash flows in precautionary cash stocks.

Our study also contributes to the relatively small literature on the financing of R&D with stock issues. Kim and Weisbach (2008) explore the motivations for public equity offerings across 38 countries and find that cash holdings and investment (R&D in particular) increase following equity offers. Brown, Fazzari, and Petersen (BFP, 2009) show that a significant portion of the U.S. aggregate R&D cycle of the late 1990s and early 2000s can be explained by the corresponding dramatic boom and bust in the availability of stock issues. But they do not consider cash holdings or explore how firms manage to *dampen* the impact of booms and busts in the availability of finance, thereby smoothing R&D relative to the dramatic fluctuations in equity finance (as suggested by Figure 1A). Our findings support the broad conclusions in BFP (2009) on the link between equity finance and R&D, but also show that the role of cash holdings is key to understanding both finance-driven fluctuations in R&D and the fact that aggregate R&D has historically been much smoother than key sources of finance. Our findings strongly suggest that the "boom" and "bust" in U.S. aggregate R&D in the 1998-2002 period would have been far greater had firms not smoothed R&D with cash holdings. More generally, these results are relevant for understanding how firms weather any serious decline in the availability of finance.

Finally, our study complements the literature exploring the determinants of corporate cash holdings. Opler, Pinkowitz, Stulz and Williamson (OPSW, 1999) explore corporate cash holdings for publicly-traded U.S. firms from 1971-1994 and find that cash holdings increase with R&D intensity and are lower for firms with the greatest access to capital markets. Bates, Kahle and Stulz (BKS, 2009) explore the recent sharp rise in cash holdings for U.S. industrial firms and conclude that the main explanation for rising cash stocks is changes in four firm characteristics, one of which is rising R&D. Our findings also underscore the importance of R&D for understanding why firms hold cash: in our sample, cash holdings have risen in lock-step with R&D for young firms engaged in R&D, but there is essentially no rise in cash holdings for firms not reporting R&D.

The next section discusses R&D adjustment costs, the volatility of equity finance, and the testable predictions pertaining to R&D smoothing with cash holdings. Section three provides summary statistics and plots of the data. Section four contains the main econometric evidence directly linking changes in cash and R&D. Section five explores R&D smoothing during the boom and bust in the Nasdaq (1998-2002), while section six reports extensive tests of robustness. Section seven discusses some implications of our findings, including the value of liquidity and an explanation for why aggregate R&D is so much smoother than either physical investment or key sources of finance. Section eight summarizes the paper.

II. R&D Smoothing and Empirical Predictions

A. Key Features of R&D Investment

The most important feature of R&D for our analysis is the magnitude of adjustment costs (see Himmelberg and Petersen (1994) and Hall (2002)). Most R&D investment consists of wage payments to highly trained scientists, engineers, and other skilled technology workers who often require a great deal of firm-specific training. Thus, cutting R&D typically entails releasing workers. If the cut in R&D is temporary – as in a response to a transitory shock to finance – then new workers need to be hired in future periods, creating additional hiring and training costs. Studies suggest that these costs are often very large.[1] Perhaps even more costly, fired R&D workers know critical proprietary information that firms do not wish to share with competitors, and the dissemination of such information could undermine the value of innovation being undertaken by the firm. Finally, R&D is often conducted in teams, which is disrupted with repeated turnover of workers. All of these reasons suggest that the costs of adjusting R&D are

[1] Hamermesh and Pfann (1996) review the literature and state that studies indicate that the accounting costs of hiring and training amount to as much as one year of payroll costs for the average worker. In addition, firm-specific training costs rise rapidly with the skill of the worker, suggesting that training costs for R&D workers are likely to be very high.

quantitatively important and likely substantially larger than that for physical investment.[2] Thus, firms should be able to save substantial "adjustment costs" by maintaining a smooth path of R&D investment.

A second important feature of R&D is that equity finance appears to be the principal source of funds. Several studies conclude that R&D-intensive firms use comparatively little debt (see the review in Hall (2002)). One reason is that R&D has very limited collateral value and risky firms typically must pledge collateral to obtain debt finance (Berger and Udell (1990)). A second reason is that debt finance can lead to problems of financial distress that may be particularly severe for R&D-intensive firms (Cornell and Shapiro (1988), Opler and Titman (1994)). While equity has several advantages over debt for financing R&D, internal and external equity finance are likely not perfect substitutes. Public stock issues incur sizeable flotation costs, and new share issues may require a "lemons premium" due to asymmetric information (e.g., Myers and Majluf (1984)). Because nearly all young R&D-intensive firms exhaust internal equity finance, it is likely that a large fraction face financing frictions at the margin.

B. Volatility of Equity Finance

Both internal and external equity are volatile sources of finance (see the discussion in BFP (2009)). The variability of corporate income (and therefore internal equity finance) has long been documented (e.g., Mitchell (1951)). Stock issues – the key marginal external source of finance for many young publicly traded firms – appear to be even more volatile. Figure 1A shows multiple episodes of dramatic swings in stock issues by young manufacturing firms, typically following changes in equity prices. For example, average stock issues rose 188 percent between 1998 and 2000, only to fall 64 percent between 2000 and 2002. One explanation for such sharp equity financing cycles is market timing. Several studies show that stock-market mispricing can substantially impact the cost and use of external equity finance (e.g., Loughran and Ritter (1995) and Baker and Wurgler (2000)). Based on the market timing literature, the cost of public equity finance was likely relatively low during the extremely large run-up in stock prices on the Nasdaq between 1998-2000, and relatively high during the stock market

[2] The few studies that have estimated costs of adjustment for both R&D and physical investment typically report that the adjustment costs for R&D are substantially greater (e.g., Bernstein and Nadiri (1989)). Furthermore, Cooper and Haltiwanger (2006) provide a careful study of the nature of adjustment costs for physical investment and find that costs of adjustment for physical investment are "relatively modest." Substantial differences in the nature and size of adjustment costs for R&D and physical investment are consistent with the well-known fact that aggregate- and firm-level R&D investment is much less volatile (i.e., *smoother*) than physical capital investment.

collapse in 2001-2002. We focus specifically on this "bubble period" (e.g., Loughran and Ritter (2004)) in Section V.

C. Smoothing R&D with Cash Holdings: Testable Predictions

Because of high adjustment costs, firms who do a non-trivial amount of R&D should be concerned about maintaining a smooth path of R&D. For firms not facing financing frictions, R&D smoothing is straightforward, as shocks to one form of finance can be readily offset with other sources of finance. But for firms that face financing frictions and rely extensively on volatile sources of finance, R&D smoothing may be much more challenging. One approach for smoothing R&D is to build and utilize precautionary cash holdings. A negative shock to the availability of either cash flow or stock issues can then be partially (or completely) offset by drawing down cash holdings. During periods with positive shocks to cash flow, or during favorable times to issue stock, cash holdings can be rebuilt in anticipation of future negative shocks to finance.[3] Firms facing financing frictions may not, however, completely smooth R&D since holding large cash reserves is costly and depleting cash holdings today means less cash is available for future smoothing.[4]

This discussion leads to some basic predictions concerning R&D smoothing with cash holdings. First, for firms facing financing frictions and actively using cash holdings to smooth R&D, if the change in cash holdings (ΔCashHoldings) is included with other sources of finance in an R&D regression, it will attract a *negative* coefficient since (holding other sources of finance constant) reductions in cash holdings free liquidity for R&D and increases in cash holdings do the opposite. A related prediction is that for firms *not* facing financing frictions, there is no smoothing role for cash holdings: like other financial factors, the coefficient on ΔCashHoldings in the R&D regression should be approximately zero.

It has long been argued in the financing constraint literature that a regression of investment on financial variables (e.g., cash flow) should generate *positive* coefficients if there are financing frictions.

[3] McLean (2009) shows that firms save a larger fraction of new issue proceeds as cash during "good times" to issue new shares. He also documents an increasing propensity in recent decades for firms to save new issue proceeds as cash. This finding is consistent with our results on the sharp recent rise in R&D spending and corresponding need for cash reserves for R&D smoothing.

[4] As noted in the literature (e.g., KMS (1998) and ACW (2004)), cash stocks are costly for a financially constrained firm because higher cash holdings require a reduction in current period investment. Other costs of corporate liquidity are agency costs and the fact that interest earned on firm cash holdings is often taxed at a higher rate than interest earned by individuals (e.g., OPSW (1999) and Faulkender and Wang (2006)).

A potential weakness of this approach, however, is that the controls for investment demand are likely imperfect. As a consequence, because changes in financial variables correlate positively with changes in profits, the financial variables may simply reflect new information about the profitability of investment. We emphasize that ΔCashHoldings is *positively* correlated with R&D and the financial variables, and thus should be positively correlated with investment opportunities. By extension, problems measuring investment demand should also bias upward the estimated coefficients on ΔCashHoldings (i.e., lead to positive coefficients). It is therefore distinctly more challenging to dismiss a *negative* coefficient on ΔCashHoldings based on inadequate demand control.[5]

III. Data, Summary Statistics, and Plots

A. Data

We construct our sample from surviving and non-surviving U.S. incorporated manufacturing firms (two-digit SIC codes 20-39) with coverage in the Compustat database at any time over 1970-2006. We focus on manufacturing because most corporate R&D occurs in this sector. We divide these firms into "positive R&D" and "no R&D" samples based on whether the firm reports positive R&D in a given sample period. The vast majority of the "no R&D" firms are in industries which traditionally do little or no R&D (e.g., apparel, textiles, lumber, furniture, and printing and publishing), suggesting that these firms do not report R&D because it is approximately zero. We focus primarily on the "positive R&D" sample. While the "no R&D" sample is not useful for directly testing the importance of R&D smoothing with cash holdings, it is valuable for understanding how the level and variability of cash holdings differs across firms, so we also report plots and summary statistics for this sample. Finally, we require firms to both report a stock price and have total assets of at least $1 million before they enter the dataset, and we

[5] Fazzari and Petersen (1993) make a similar argument, but for smoothing physical investment with working capital rather than R&D investment with cash holdings. One possible alternative to the smoothing hypothesis that could also generate a negative coefficient on ΔCashHoldings is that firms run down cash reserves to expand R&D investment in response to positive productivity shocks. We note, however, that this explanation predicts a negative *correlation* between changes in cash holdings and R&D because cash holdings *fall* so that R&D can *increase*. For the smoothing hypothesis, on the other hand, cash holdings fall to *limit the fall* in R&D in the face of a negative finance shock (as suggested in Figure 1A). In this case, changes in cash holdings and R&D move in the same direction (i.e., the raw correlation is positive, as it is in our data), but the coefficient estimate on ΔCashHoldings is negative because the regression controls for fluctuations in other sources of finance.

exclude firms with fewer than four cash holdings observations in a given sample period since we use GMM estimators that rely on lagged values of regression variables as instruments.

We report summary statistics and regression results for three different sample periods: 1970-1981, 1982-1993 and 1994-2006. We also split firms based on the number of years since their first stock price appears in Compustat, typically the year of their IPO. Firm age is likely to be strongly correlated with asymmetric information problems and has been used as a proxy for the presence of financing frictions in a number of recent studies (e.g., BFP (2009); Fee, Hadlock and Pierce (2009) and Hadlock and Pierce (2009)).[6] We classify firms as "young" if their average age in a given sample period is less than or equal fifteen. We discuss the results for sample splits based on size, payout ratio, and presence of a bond rating in Section VI.

B. Summary Statistics

Panel A in Table 1 contains summary statistics for the *positive* R&D sample. The statistics are based on annual firm observations, and all finance and investment values are scaled by beginning-of-period total assets. As expected, the median and average total assets (in 2000 dollars) of mature firms are many times larger than the assets of young firms. Median assets are smaller in the later periods because of the large number of IPOs in the 1980s and 1990s. Of greater interest, both average and median capital investment ratios (Capex) decline for both young and mature firms. For R&D, on the other hand, mean ratios increase from 0.025 to 0.067 for mature firms and 0.034 to 0.195 for young firms. The median R&D ratios have a similar pattern. Overall, these statistics illustrate a dramatic rise in the absolute and relative importance of R&D, particularly for young firms.

Turning to the financial variables, gross cash flow is stable over time for mature firms.[7] For young firms, median gross cash flow figures are similar to mature firms in the early period, but drop off somewhat over time. The means, however, decline substantially and are negative in the final period, due to the entry of a large number of unprofitable firms (e.g., Ritter and Welch (2002) and Fama and French

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[6] Hadlock and Pierce (2009) use qualitative information disclosed by firms to create an index of financing constraints for a large random sample of firms. They then examine a number of proxies used in the literature and conclude that firm age and size are the two variables most related to the qualitative information reported by firms concerning the presence of financing constraints.

[7] Because R&D is treated as a current expense for accounting purposes we add R&D expenses to the standard measure of net cash flow (after-tax earnings plus depreciation allowances) to obtain "gross" cash flow (see Hall (1992) and Himmelberg and Petersen (1994)).

(2004)). In sharp contrast, *average* net stock issues (StkIssues) by young firms rise from 0.011 in the first period to 0.252 in the final period. Values for median stock issues are small because the summary statistics in Table 1 are for *annual* observations and stock issues tend to be bunched in selected years (e.g., 1999 and 2000), as expected if firms engage in market timing. For mature firms, mean and median net stock issues are near zero in all periods. For young firms, median net new long-term debt issues (DbtIssues) are near zero in all periods, while average debt issues rise to 0.040 in the final period, a figure dwarfed by stock issues. Finally, of particular importance for our study, the stock of cash and cash equivalents (CashHoldings) by young firms rises from 0.088 in the first period to 0.395 in the last period, a more than fourfold increase. For mature firms, the rise in cash holdings is much smaller (0.077 to 0.152). The pattern for median cash holdings is similar to that for the means.

Panel B reports summary statistics for the "no R&D" firms. The "no R&D" sample is much smaller than the sample of firms reporting positive R&D (e.g., in the final period, young firms in Panel B have less than one-third as many firm-year observations as the young firms in Panel A). There are two noteworthy differences (besides absence of R&D) between the summary statistics reported in the two panels. The first is that "no R&D" firms issue very little stock. The second difference is that firms not reporting R&D have essentially no increase in cash holdings over time: average cash holdings for young firms is 0.089 in the first period and 0.102 in the final period. In the final period, the mean cash-to-assets ratio for young firms not reporting R&D is only 25 percent of the corresponding value for young firms that report positive R&D spending. Thus, across young firms in manufacturing, there is a strong connection between reporting R&D, issuing stock, and holding large (and rising) stocks of cash.

C. Plots of Yearly Averages

Yearly plots of average ratios for the *positive* R&D sample appear in Figures 1A and 1B. For young firms (Figure 1A), debt issues are small in all years while cash flow is the main source of finance in the 1970s but is negative in the late 1990s and early 2000s. Stock issues rise dramatically starting in the 1980s and are highly volatile, especially in the 1990s and 2000s. Cash holdings are also very volatile, and the sharp swings in average cash holdings in the 1990s and 2000s line up closely with the sharp swings in stock issues. Finally, the R&D ratio is low in the 1970s, rises somewhat in the 1980s, grows rapidly between 1993 and 2000, and falls substantially in 2001 before partially recovering by 2003.

It is important to emphasize that the swings in R&D in Figure 1A are much smaller than the booms and busts in finance in corresponding time periods. For example, while R&D does rise during the stock issue booms in 1994-1996 and 1999-2000, the rise in R&D is much attenuated compared to the rise in stock issues. Likewise, R&D does not decline in 1998 and the decline in 2001-2002 is much attenuated compared to the bust in stock issues. The source for this smoothing is almost surely not debt finance or cash flow. Debt finance is typically small in size and both debt finance and cash flow are positively correlated with stock issues. Rather, the evidence in Figure 1A points to cash holdings as the likely source of funds used for smoothing R&D. Cash holdings are considerably larger than annual R&D expenditures, indicating the capacity to buffer even fairly large temporary negative finance shocks. In addition, because cash holdings are a *stock* of finance, they need not decline simply because of a smaller *flow* of equity issues. Thus, it seems plausible that much of the sharp decline in cash holdings in years such as 1998 and 2001-2002 is due to the smoothing of R&D. We provide formal evidence of this linkage in Sections IV, V and VI.

The plot for mature firms engaged in R&D (Figure 1B) looks very different than the plot for young firms. For mature firms, cash flow is the main source of finance throughout the entire sample period. Compared to young firms, mature firms have much lower stock issues, cash holdings, and R&D ratios. Cash holdings do rise substantially in 1999-2004 (e.g., 0.124 to 0.217), and this rise appears to be financed in part by a period of relatively high stock issues. Most of this rise is coming from high-tech firms that switch (based on our classification) from young to mature in the late 1990s. Note that cash flow declines and stock issues increase during this period, suggesting that some of these new "mature" firms may still have relatively strong incentives to maintain sizeable reserves of cash for smoothing R&D. The R&D ratio for mature firms trends upward very smoothly over time, suggesting that mature firms are very successful at smoothing R&D investment. However, unlike Figure 1A, there is nothing in Figure 1B that suggests mature firms rely extensively on costly cash holdings to smooth R&D, consistent with most mature firms likely having ready access to lines of credit and other financial instruments for smoothing.

Finally, we comment briefly on the plots for young (Figure 2A) and mature firms (Figure 2B) who do not report R&D. These plots show (consistent with the summary statistics) that young firms not reporting R&D have far smaller average stock issues and cash holdings compared to young firms who do report R&D. Furthermore, the plots for young firms not reporting R&D display little of the volatility and trend in cash holdings that is evident in the plots for young firms who do report R&D. Mature firms also exhibit essentially no trend in cash holdings between 1970 to 2006. A comparison of Figures 1A and 2A (and Figures 1B and 2B) suggests that, among manufacturing firms, issuing stock and holding large (and rising) reserves of cash is confined almost exclusively to firms that invest in R&D.

IV. Formal Evidence of R&D Smoothing with Cash Holdings

A. Specification and Estimation

BFP (2009) discuss and estimate a dynamic R&D model with financial variables that is based on an Euler equation developed by Bond and Meghir (1994) to study fixed investment under the assumption of quadratic adjustment costs.[8] We estimate a similar a dynamic R&D specification, but we include changes in cash holdings to directly explore the use of cash reserves for R&D smoothing, an issue not considered in BFP (2009). The specification is:

$$\begin{aligned} RD_{j,t} &= \beta_1 RD_{j,t-1} + \beta_2 RD_{j,t-1}^2 + \beta_3 MarketBook_{j,t} + \beta_4 Sgwth_{j,t} + \beta_5 CashFlow_{j,t} \\ &+ \beta_6 CashFlow_{j,t-1} + \beta_7 StkIssues_{j,t} + \beta_8 StkIssues_{j,t-1} + \beta_9 DbtIssues_{j,t} + \beta_{10} DbtIssues_{j,t-1} \\ &+ \beta_{11} \Delta CashHoldings_{j,t} + \beta_{12} \Delta CashHoldings_{j,t-1} + d_t + \alpha_j + \nu_{j,t}, \end{aligned} \quad (1)$$

where $RD_{j,t}$ is R&D spending for firm *j* in period *t*. R&D is highly persistent and therefore the coefficient on lagged R&D should be close to one, while the expected coefficient on the quadratic term is negative. Sales growth (*Sgwth*) and the market-to-book ratio (*MarketBook*) are included as controls for investment demand. The financial variables include contemporaneous and lagged cash flow (*CashFlow*), net stock issues (*StkIssues*), net debt issues (*DbtIssues*), and changes in cash holdings (*ΔCashHoldings*).[9] Cash flow, stock issues, and debt issues should all share a positive relation with R&D in firms that face binding financing constraints, though debt issues are relatively unimportant as a source of funds for the typical R&D intensive firm (see Figure 1A). In contrast, as discussed above, the coefficients on ΔCashHoldings should be negative for firms that rely on cash reserves to smooth R&D. The R&D and financial variables are scaled by the beginning-of-period stock of firm assets. The model includes a firm-specific effect (α_j)

[8] Brown and Petersen (2010) also discuss and estimate a structural R&D model, with no controls for smoothing, to explore the role of the stock market for R&D and creative destruction among newly public high-tech firms.
[9] Detailed variable definitions with Compustat data codes are provided in the Appendix. Outliers in all regression variables are trimmed at the 1% level.

to control for all unobserved time-invariant determinants of R&D at the firm level, such as technology and industry characteristics. The model also includes a time-specific effect (d_t) to control for aggregate changes that could affect the demand for R&D.

We estimate equation (1) with the "system" GMM estimator developed for dynamic panel models by Arellano and Bover (1995) and Blundell and Bond (1998). This method jointly estimates a regression of equation (1) in differences with the regression in levels, using lagged levels as instruments for the regression in differences and lagged differences as instruments for the regression in levels. The systems estimator addresses the weak instrument problem that arises from using lagged levels of persistent explanatory variables as instruments for the regression in differences, but it does require an additional moment restriction to hold in the data: differences of the right-hand side variables in equation (1) must not be correlated with the firm-specific effect (Blundell and Bond (1998)).

We treat all financial variables (including ΔCashHoldings) as potentially endogenous and use 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.[10] To assess instrument validity we follow Arellano and Bond (1991) and report an *m2* test for second-order autocorrelation in the first-differenced residuals, which, if present, could render the GMM estimator inconsistent, and a Hansen *J*-test of over-identifying restrictions. We also report a difference-in-Hansen test that evaluates the validity of the additional instruments required for systems estimation and used in the levels equation. As we discuss below, a low p-value for either the *J*-test or difference-in-Hansen test indicates potential problems with instrument validity in just four of the eighteen regressions reported in the following three tables. We find no problems for young firms (the key group) outside of the first period, and no problems for either group in the final period, when R&D and cash holdings are the greatest and tests of R&D smoothing are the most compelling.

We report one-step GMM coefficient estimates and standard errors in the tables that follow. The standard errors are robust to heteroskedasticity and within-firm serial correlation. Arellano and Bond

[10] As we discuss in more detail below, our findings are robust to a number of alternative instrument sets, including starting the instrument set with lagged levels dated *t*-2 (and lagged differences dated *t*-1) and extending it to include lagged levels dated *t*-5 and *t*-6. Though lagged levels dated *t*-2 are potentially valid instruments if the error term in equation (1) is i.i.d. (Arellano and Bond (1991)), we found the validity of the *t*-2 instruments to be questionable in a number of the regressions.

(1991) recommend using one-step estimates for inference because the standard errors from two-step GMM are downward biased in small samples. Two-step estimates are more efficient, however, so we also estimate equation (1) using two-step GMM with the Windmeijer (2005) suggested correction to the standard errors. We discuss this and other tests of robustness in Section VI.

B. Regression Results

Table 2 provides estimates of the dynamic R&D regression (equation 1) for young and mature firms in the three sample periods. In all regressions, the coefficient on lagged R&D is near unity and the coefficient on lagged R&D squared is negative (or close to zero), as expected based on the model and the findings in BFP (2009). The coefficients for market-to-book are typically insignificant for young firms, which is not surprising given that stock issues is included in the regression. Low p-values from the instrument validity tests indicate potential problems in the young-firm regression in the first period and mature-firm regressions in the first two periods. In each case, the key findings are unchanged and we no longer reject instrument validity (i.e., the p-values increase above conventional levels) if we use deeper lags as instruments (e.g., *t*-4 to *t*-6). We also note that the first period is the least interesting period for considering R&D smoothing with cash holdings since R&D intensity is very low.

In the early period (columns one and two), contemporaneous cash flow coefficients are positive and statistically significant for both young and mature firms, and chi-squared tests (bottom of table) reject the null that the sum of the current and lagged coefficients is equal to zero. Other than relatively small positive coefficients on stock issues for young firms, the external finance variables are near zero for both young and mature firms, consistent with the paucity of both stock and debt issues during this period. For young firms, the sum of the coefficients on ΔCashHoldings is negative and statistically significant, but relatively small (-0.042), consistent with the low R&D intensity in this period.

For young firms in the middle time period, the sum of the coefficients on stock issues is substantial (0.103) and statistically significant, consistent with the rising importance of stock issues in this period. Of greater importance, the coefficients on contemporaneous and lagged ΔCashHoldings are both negative and statistically significant, and the sum of the coefficients is quantitatively substantial (-0.117). This suggests that young firms increasingly relied on cash holdings to smooth R&D in the 1982-1993 period, consistent with the greater importance of R&D in this period. In contrast, for mature firms, the estimated coefficients on all financial variables are quantitatively small and insignificant.

The final two columns contain the results for 1994-2006, the most important period in our study. For young firms, the coefficients on cash flow and stock issues are positive and statistically significant. The magnitude of the sum of coefficients for stock issues is particularly large (0.188), which, together with the size of stock issues indicated by the summary statistics, suggests a very strong link between R&D and stock issues during this period. Most importantly, the coefficients on current and lagged ΔCashHoldings are negative, large in absolute value (sum is -0.239), and highly significant. In sharp contrast, for mature firms, the sums of cash flow and stock issues are small and the chi-squared tests reject the null that the sums of the coefficients are statistically different from zero. The coefficient for current ΔCashHoldings is comparatively small (-0.039) and marginally significant, while the lagged coefficient is negative but insignificant (-0.026). The sum of the coefficients on ΔCashHoldings for mature firms is statistically different from zero, due almost entirely to a relatively small number of R&D-intensive firms that switch to "mature" in the final period.[11] We show in the robustness section that the coefficients on ΔCashHoldings are approximately zero and insignificant for other groups of firms (large, positive payout) which *a priori* are least likely to face binding financing frictions.

Overall, the results in Table 2 show a strong, negative relation between changes in cash holdings and R&D investment for the firms most likely to face financing frictions. The pattern of coefficients is as expected: as R&D intensity rises and firms become increasingly reliant on volatile stock issues, R&D smoothing with cash holdings becomes an important phenomena for young firms, as can be seen by the sharp rise in the absolute size of the coefficients on ΔCashHoldings in the R&D regressions. By the final period the coefficient estimates on ΔCashHoldings suggest a quantitatively important link between changes in cash reserves and young-firm R&D: on average, every one-half standard deviation change in cash holdings corresponds to a change in the R&D-to-assets ratio of 0.067, which is almost 35% of the young-firm R&D ratio in the final period. For comparison, the predicted impact (based on the estimates in Table 2) from a simultaneous half-standard deviation shock to *both* cash flow and stock issues is 0.068,

[11] If these firms are excluded, the coefficient estimates on ΔCashHoldings drop to approximately zero and are insignificant.

suggesting that young-firm R&D would remain essentially stable if cash flow, stock issues and cash holdings all fell by a half-standard deviation.

V. The 1998-2002 Boom and Bust and Quantitative Magnitudes

To further explore cash holdings and R&D smoothing, we examine the behavior of R&D in two narrow periods when the availability of equity finance changed dramatically: 1998-2000 and 2000-2002. The Nasdaq Index jumped from 1,574 at the start of 1998 to over 5,000 in 2000, but began a swift decent at the end of 2000, reaching approximately 1,100 in August, 2002. As shown in Figure 1A, stock issues by young firms soared in 1999 and 2000 and collapsed in 2001 and 2002. In addition, the 2000-2002 window contains the largest decline in R&D in our data (and the NSF reports that 2002 was the largest single-year absolute and percentage reduction in industrial R&D since the survey's inception in 1953). Thus, 1998-2000 was a boom period in terms of availability of finance, while 2000-2002 provides a key window to explore the buffering of R&D with cash holdings when access to equity finance collapsed. We use data prior to the narrow windows as instruments, which gives us sufficient observations to re-estimate the main regressions for these periods. The *J*-test and Diff-in-Hansen tests indicate no significant problems with instrument validity for young or mature firms in any of these periods. The findings are reported in Table 3.

The first two columns of Table 3 report both young and mature firm results for the period 1998-2002 (spanning the boom and bust in equity finance). For young firms, the sum of the coefficients on both stock issues and ΔCashHoldings are typically larger (in absolute value) than the corresponding numbers for young firms in the 1994-2006 period reported in Table 2. For example, the sum of the coefficients for ΔCashHoldings is -0.272 (and highly significant) in the 1998-2002 period compared to -0.239 in the 1994-2006 period. In sharp contrast, for mature firms, the sum of the coefficients for ΔCashHoldings is small (-0.023) and statistically insignificant. In the 1998-2000 boom period (columns three and four), there are strong and significant financial effects only for young firms; in particular, for young firms the sum of the coefficients on ΔCashHoldings is -0.312. The results for the 2000-2002 bust period (final columns) also indicate large and significant financial effects only for young firms; in particular, the sum of the coefficients on ΔCashHoldings is -0.306 for young firms compared to 0.030 for mature firms. The absolute size of the young-firm ΔCashHoldings coefficients is impressive given the enormous variation in cash holdings, particularly in the 2000-2002 period.

To evaluate the *quantitative* importance of the ΔCashHoldings coefficients, we use the point estimates in Table 3 to measure the extent to which changes in cash holdings smoothed young-firm R&D in the highly volatile 1998-2002 period. The mean changes in stock issues and cash flow during the 1998-2000 boom period generate a predicted increase in R&D intensity of approximately 0.067 (approximately 38% of the young firm average in 1998), due entirely to the sharp increase in stock issues during this period. Offsetting this large predicted increase, however, average cash holdings *increased* by 0.18, which has a negative predicted impact on R&D of 0.056. Thus, the combined effect of rising stock issues and cash holdings is a predicted increase in the R&D ratio of approximately 0.011, or over 80% less than the predicted increase without R&D smoothing. Similarly, the sharp fall in stock issues (and less severe decline in cash flow) between 2000 and 2002 has a predicted negative impact on the R&D ratio of 0.069 (32% of the young-firm average in 2000). But the predicted impact from the *decline* in average cash holdings during this period is an *increase* in the R&D ratio of 0.052, so the predicted change in R&D is attenuated by approximately 75% because of the change in cash holdings. Overall, these calculations suggest that changes in cash holdings have a quantitatively important impact on young-firm R&D. These coefficients also imply that, through the use of cash holdings, young firms managed to smooth R&D rather effectively during the turbulent 1998-2002 period, consistent with Figure 1A.

VI. Auxiliary Tests and Robustness

We now present a number of auxiliary tests of the role that cash holdings play in smoothing R&D. In this section we focus on 1994-2006, which is the most important period in our study, since R&D intensity is the highest and thus the benefits from smoothing should be the greatest.

A. Alternative Sample Splits

The finance literature has utilized a number of sample splits other than firm age to *a priori* classify firms into groups more or less likely to face financing frictions (e.g., Fazzari, Hubbard and Petersen (1988), Gilchrist and Himmelberg (1995), Almeida, Campello and Weisbach (2004)). In Table 5, we consider three of the most commonly used criteria: the payout ratio, firm size, and the absence/presence of a bond rating. As argued by Fazzari, Hubbard and Petersen (1988), firms with zero dividend payouts are more likely to face binding constraints than firms paying high dividends. We compute average payout ratios for each firm during the sample period and assign those with a positive average payout to the high payout group.[12] Gertler and Hubbard (1988), KMS (1998) and many others have used firm size as a proxy for access to external finance. We split firms into large and small size groups based on average sales during the sample period. We use a 70/30 split to assign firms because of the skewed size distribution (sales at the 70th percentile are only $248 million). Finally, we split firms based on whether or not a bond rating is reported in Compustat.

The results for the final period (1994-2006) using these alternative sample splits appear in Table 4. Other than a marginal Diff-in-Hansen test in the large sales regression, tests of instrument validity indicate no significant problems across the different sample splits. The coefficient estimates in Table 4 are very similar to the coefficient estimates in the corresponding regressions in Table 2. In particular, the sum of the coefficients for cash flow and stock issues is positive and statistically significant for zero payout, small, and non-bond rated firms, but quantitatively small and insignificant for positive payout, large, and bond-rated firms. More importantly, the estimated coefficients for contemporaneous and lagged ΔCashHoldings for zero payout, small, and non-bond rated firms in Table 4 are similar to the ΔCashHoldings coefficients for young firms in Table 2, consistent with substantial R&D smoothing with cash holdings. In contrast, for positive payout, large, and bond-rated firms the coefficients on ΔCashHoldings in Table 4 are quantitatively small. In particular, the ΔCashHoldings coefficients are statistically insignificant for positive payout firms and for large firms, suggesting no use of cash holdings to smooth R&D for the firms least likely to face financing frictions. We also use these sample splits to examine smoothing in the early and middle periods and again find financial and ΔCashHoldings coefficients consistent with those reported in Table 2.[13]

B. Alternative Estimation Strategies

The findings we present are robust to a number of alternative estimation procedures, instrument sets, and specifications. First, we re-estimate equation (1) using *two-step* GMM. Though the two-step

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[12] The payout ratio is computed by scaling dividends plus stock buybacks minus stock issues by beginning-of-period assets. We obtain similar results by splitting at the 50th and 70th percentiles of the average payout distribution.
[13] We did not have sufficient data on bond ratings to use that sample split in the earliest period.

estimator is more efficient relative to one-step GMM, the standard errors from two-step GMM are downward biased in small samples (e.g., Arellano and Bond (1991)). We address this downward bias by employing the finite-sample correction suggested by Windmeijer (2005). The two-step estimates are very similar in almost all respects to the results in Table 2. In particular, we continue to find strong evidence of smoothing with cash holdings for young firms (the sum of the current and lagged ΔCashHoldings is -0.246 with a p-value of 0.000 in the final period). Second, we adjust the instrument set to include levels dated *t*-2 to *t*-4 for the regression in differences, and differences dated *t*-1 for the regression in levels. Again, the results for young firms are quantitatively similar while the coefficients on ΔCashHoldings for mature firms are quantitatively small and only marginally significant.[14] Third, in place of first-differencing to remove the firm-specific effect, we use an "orthogonal deviations" transformation that eliminates the firm effect by subtracting the forward means of each regression variable (Arellano and Bover (1995)). With this transformation the financial effects are again similar in magnitude and statistical significance (the sum of ΔCashHoldings for young firms is -0.211 with a p-value of 0.000). Finally, it has long been noted that measurement error in Tobin's Q can bias inference in investment regressions, so we drop the market-to-book ratio as a demand control and continue to find large, negative coefficients on ΔCashHoldings for young firms (sum of ΔCashHoldings is -0.248 with a p-value of 0.000).

C. Physical Investment

We also considered whether changes in cash holdings were related to fixed capital investment with a specification that mirrors equation (1). In the final period, the sum of the coefficients on ΔCashHoldings are approximately zero and statistically insignificant for both young and mature firms, indicating no use of cash holdings for the smoothing of physical investment.[15] This finding likely arises for multiple reasons, including: i) physical investment has substantial collateral value, possibly permitting the use of debt finance for smoothing, and ii) physical investment has comparatively low adjustment costs, reducing the benefits to smoothing.

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[14] As previously discussed, however, instrument tests raise concerns about the validity of the *t*-2 instruments in a number of regressions, hence our use of deeper lags in Tables 2-4.

[15] This finding does not imply that cash holdings are always unimportant for physical investment. As emphasized in the literature, cash holdings may permit constrained firms to undertake valuable *future* investments that they would otherwise have to forego (e.g., see the evidence on the link between capital investment and the *level* of cash holdings in Denis and Sibilkov (in press)). This is a different idea than smoothing the current flow of investment with changes in the stock of cash.

VII. Implications

A. Value of Liquidity

Brealey, Myers and Allen (2006, p. 960-967) list ten important unsolved problems in finance, including: "What is the value of liquidity?" Almost all corporate finance textbooks have chapters on cash management, including a discussion of precautionary cash holdings. Explanations of the precautionary motive generally center on the fact that cash inflow and outflow are unpredictable and that the less predictable are cash flows, the greater the need for precautionary cash holdings (e.g., Brigham and Daves, 2002, p. 705). The common theme in textbook discussions is "protection against a rainy day." We can find no mention of the use of cash holdings for investment smoothing or reducing adjustment costs.

As noted in the introduction, recent studies develop models highlighting the benefits of precautionary cash holdings for financially constrained firms. KMS (1998) argue that building cash holdings minimizes the need to obtain costly external finance for future investment projects. Both ACW (2004) and Han and Qiu (2007) show that under plausible conditions it is optimal for constrained firms to hold cash reserves to enhance the firm's ability to undertake future investment, and AAC (2007) show that firms with "high hedging needs" will use cash holdings rather than debt capacity for protection against future cash flow shortfalls. Denis and Sibilkov (in press, p. 21) find that "higher cash holdings are associated with higher levels of investment for constrained firms with high hedging needs." While our work is broadly related to these studies, our insights into the value of liquidity are somewhat different because we focus on R&D, which differs from physical investment in several key ways, including the much higher adjustment costs. We emphasize that cash holdings can give firms better control over present and future *adjustment costs* of an *ongoing* R&D program, whose major expenses are the ongoing payroll costs of a team of R&D workers, which has not, to our knowledge, been discussed in the literature.

Our focus on R&D ties in well with the literature addressing when cash reserves are likely to be good or bad for shareholders (e.g, OPSW, 1999; Harford, Mansi and Maxwell, 2008). While large firms with relatively weak governance may over spend cash reserves on fixed capital and acquisitions (e.g., Harford, 1999), young R&D-intensive firms are much less likely to suffer from these agency problems. Instead, substantial cash reserves that allow R&D-intensive firms to buffer R&D against temporary negative finance shocks should be associated with higher performance and greater market valuation. Indeed, recent studies provide strong evidence that the marginal dollar of cash is highest in R&D intensive industries (Pinkowitz and Williamson, 2007) and that firms with large cash balances are more R&D intensive and have higher operating performance than firms with lower balances (Mikkelson and Partch, 2003).

B. Why is Aggregate R&D so Smooth?

It is well known that aggregate R&D has historically been quite smooth compared to fixed capital investment. Yet, BFP (2009) show that there was a "boom" and "bust" cycle in aggregate R&D in the late 1990s and early 2000s. For our study, what is particularly noteworthy about the findings in BFP is that the R&D cycle was not in fact *far larger*, given the dramatic swing in cash flow and stock issues for young, constrained firms (see, e.g., Figure 2b in BFP (2009)). Consistent with BFP (2009), our Figure 1A shows a clear R&D cycle in the late 1990s and early 2000s that is much attenuated compared to the corresponding volatility in finance. Figure 1A also suggests that changes in cash holdings (a source of finance not considered by BFP (2009)) could have at least partially offset the volatility in stock issues and cash flow during this period. (Figure 1A also suggests that young firms likely used cash holdings to smooth R&D during other financial cycles as well.) Further, our regression results indicate a strong negative relation between young-firm R&D and changes in cash holdings, particularly during the volatile 1998-2002 period, where our estimates indicate that young firms used cash holdings to sharply limit the volatility in R&D. This evidence suggests that part of the reason *aggregate* R&D is so smooth is that the *typical* R&D-intensive firm is rather successful at building and utilizing cash holdings to avoid substantial alterations to R&D. Such a conclusion has implications not only for corporate finance but also for understanding economic growth and productivity at the economy-wide level.

C. R&D and the Rise in Cash Holdings

BKS (2009) report that the average cash-to-assets ratio (cash ratio) of U.S. industrial firms increased from 10.5% to 23.2% between 1980 to 2006. As discussed above, BKS conclude that the rise in the cash ratio is due primarily to changes in four firm characteristics, one of which is the rise in R&D. Our findings strongly support the conclusion that rising R&D is a key factor behind the rise in cash holdings.[16] First, we show a dramatic rise in R&D intensity among young R&D-reporting firms (e.g., Figure 1A), which, based on our arguments, should have led to a very large increase in the demand for cash holdings to smooth R&D. Second, our regression results strongly confirm the importance of R&D smoothing with cash holdings in recent decades, but only for firms likely to face financing frictions. Finally, we find that cash holdings have increased lock-step with R&D for firms likely to face financing frictions (e.g., Figure 1A) and we find essentially no increase in cash holdings for firms not reporting R&D (Figures 2A and 2B).

VIII. Conclusion

To our knowledge, this is the first study to test for R&D smoothing with cash holdings and to emphasize its importance for corporate financial policy. Figure 1A shows that for young manufacturing firms, the path of R&D investment is far less volatile than key sources of finance and that firms appear to accomplish this smoothing by drawing down cash holdings when the availability of finance is low (e.g., 2001-2002) and building up cash reserves when finance is readily available. To formally explore the use of cash holdings for R&D smoothing we use GMM to estimate dynamic investment regressions that include the *change* in cash holdings with other sources of finance (cash flow, new stock issues, and new debt issues) as explanatory variables. For firms relying on cash holdings to smooth R&D, the coefficient on the change in cash holdings should be negative, because reductions in cash free liquidity for R&D. We find strong evidence of R&D smoothing for firms most likely to face financing frictions, but little evidence that changes in cash holdings impact R&D for firms less likely to be financially constrained. Furthermore, the link between R&D and the change in cash holdings is particularly strong in both the 1998-2000 boom, and the 2000-2002 bust, in stock prices and equity availability.

Our findings show a direct link between corporate liquidity and real investment decisions and provide a number of related insights. As we have emphasized, R&D has high adjustment costs and is often financed by volatile sources of finance. Based on these facts and our findings, we conclude that one way that liquidity can create value is by allowing constrained firms to maintain a relatively smooth *flow* of R&D spending in the face of shocks to finance, which reduces the adjustment costs. The potential

[16] Our findings also support the related conclusion in McLean (2009) that increases precautionary motives (including rising R&D) caused firms in recent decades to increasingly save funds from stock issues in cash reserves.

gains from smoothing R&D have likely increased a great deal in recent decades, given the dramatic increase in R&D intensity in portions of the U.S. economy. This in turn can explain much of the sharp rise in cash holdings in recent years. Our paper also provides new insights concerning why aggregate R&D investment is so smooth compared to fixed capital investment and the underlying volatility in key sources of finance: firms facing financing frictions appear to be able to offset a substantial fraction of the shocks to finance through their management of liquidity. In particular, our estimates suggest that young firms used cash holdings to dramatically dampen the aggregate R&D cycle in the 1998-2002 boom and bust in equity finance.

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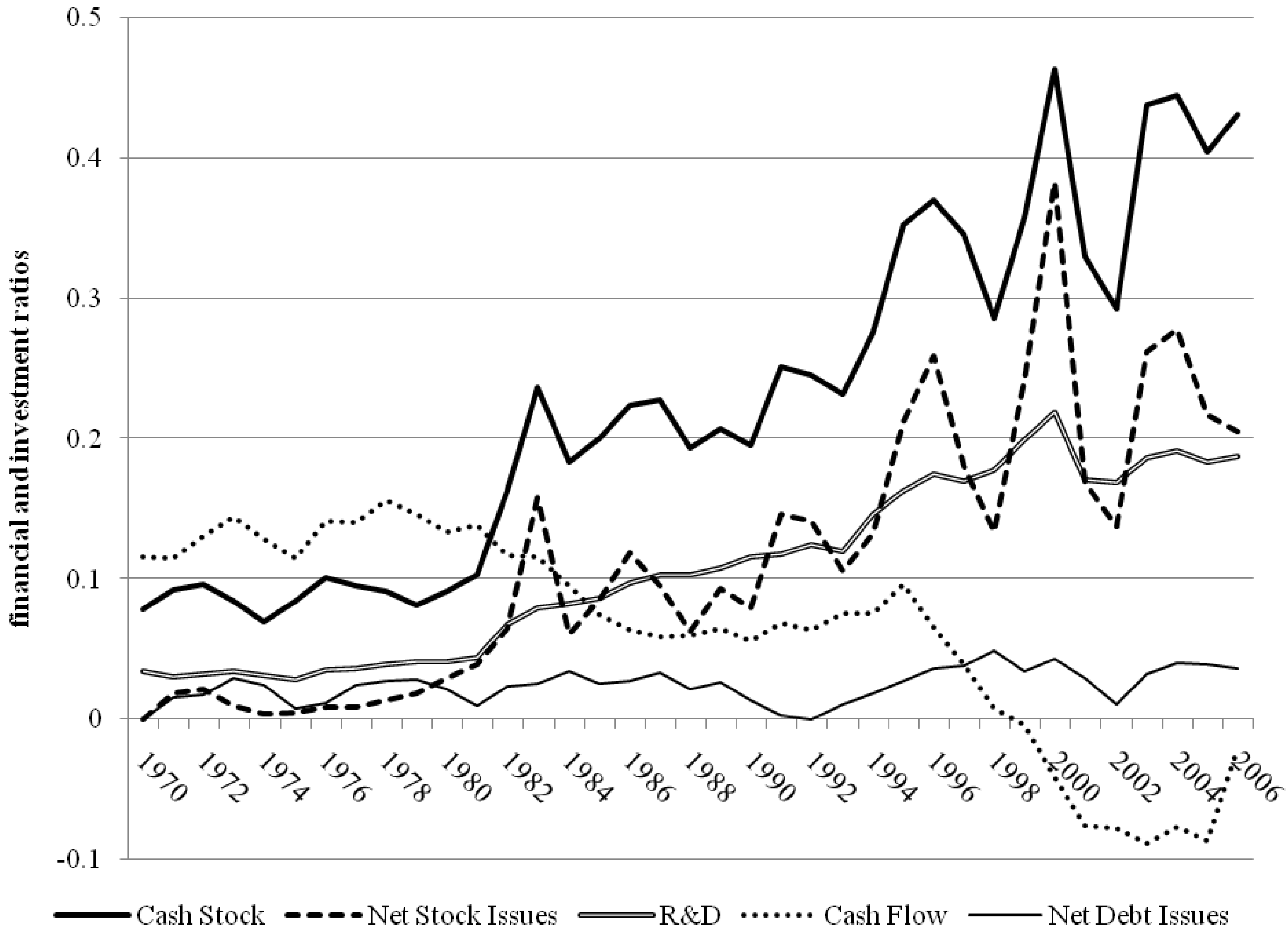

Figure 1A. Young-firm R&D, cash holdings and sources of finance. The figure plots average ratios across young firms in U.S. manufacturing that report positive R&D expenditures. All variables are scaled by beginning of period total assets and all ratios are Winsorized at the 1% level. A firm is classified as young for the first 15 years following the year it first appears in Compustat with a stock price.

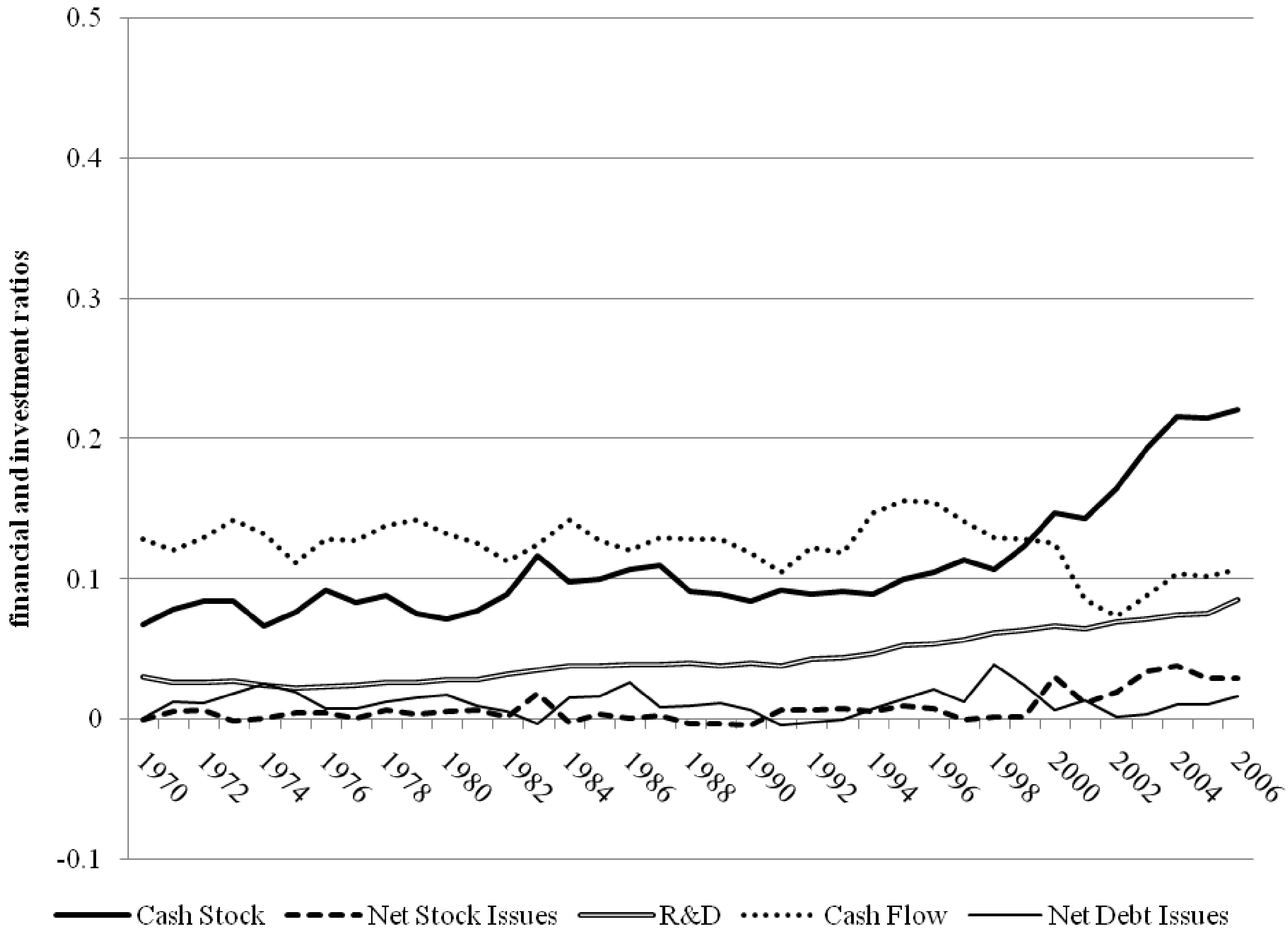

Figure 1B. Mature-firm R&D, cash holdings and sources of finance. The figure plots average ratios across mature firms in U.S. manufacturing that report positive R&D expenditures. All variables are scaled by beginning of period total assets and all ratios are Winsorized at the 1% level. A firm is classified as mature if it is more than 15 years after the year it first appears in Compustat with a stock price.

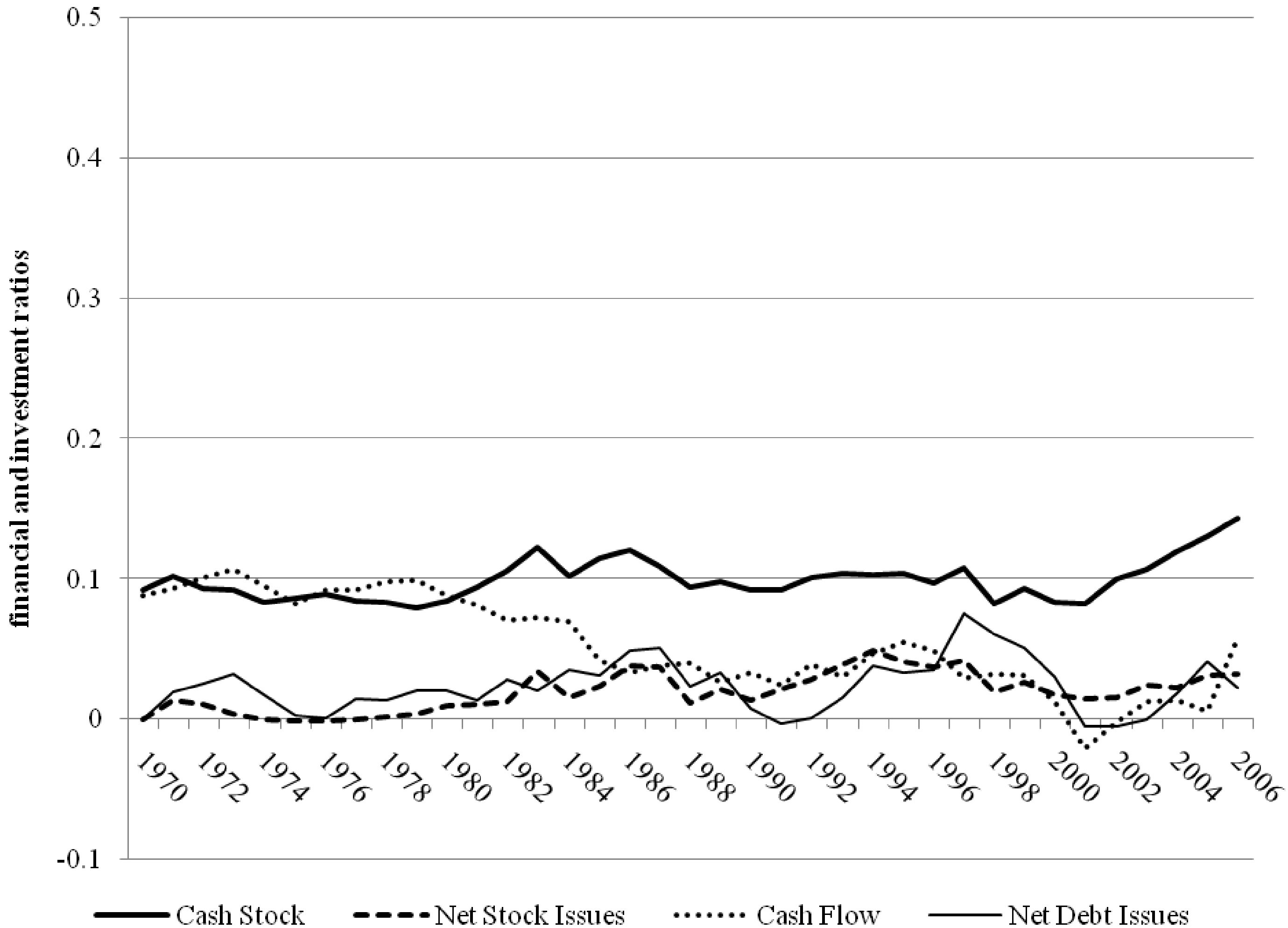

Figure 2A. Young-firm cash holdings and sources of finance, no R&D sample. The figure plots average ratios across young firms in U.S. manufacturing that do not report positive R&D expenditures. All variables are scaled by beginning of period total assets and all ratios are Winsorized at the 1% level. A firm is classified as young for the first 15 years following the year it first appears in Compustat with a stock price.

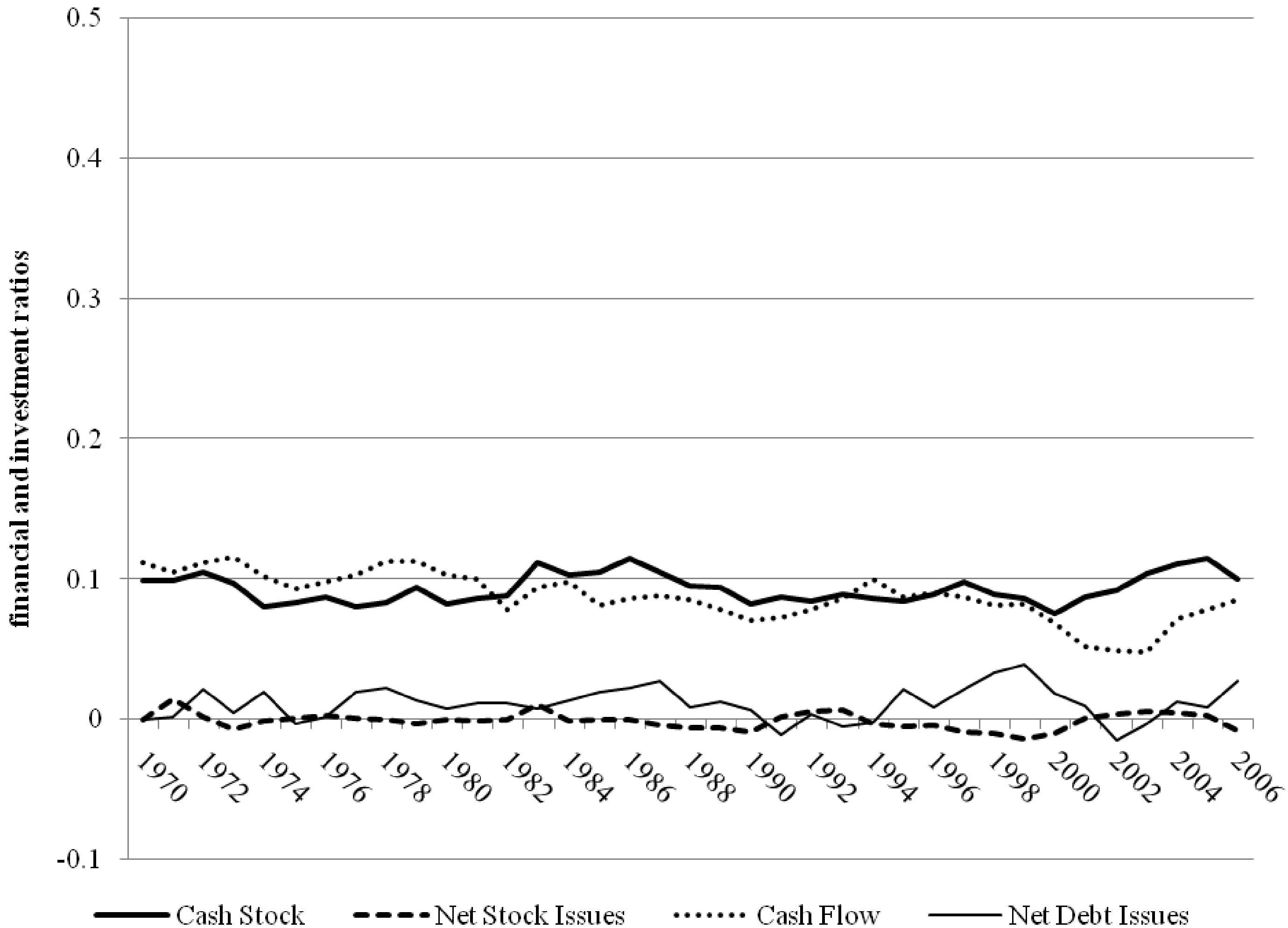

Figure 2B. Mature-firm cash holdings and sources of finance, no R&D sample. The figure plots average ratios across mature firms in U.S. manufacturing that do not report positive R&D expenditures. All variables are scaled by beginning of period total assets and all ratios are Winsorized at the 1% level. A firm is classified as mature if it is more than 15 years after the year it first appears in Compustat with a stock price.

Table 1: Sample Descriptive Statistics

The sample is constructed from manufacturing firms (SIC codes 20-39) with coverage in the Compustat database during 1970-2006. We exclude firms incorporated outside of the U.S. and firms without at least four non-missing cash holdings observations in a given sample period. Firms must have a non-missing stock price and total assets of at least $1 million before they enter the sample. Firm-years involving a significant merger or acquisition are excluded. All variables are scaled by beginning-of-period total assets. Firms are classified as young if their average age (measured from the first year a stock price appears in Compustat) in a sample period is 15 or less. Any dollar values are in millions of 2000 dollars. All variables are Winsorized at the 1% level.

Sample Period		***1970-1981***		***1982-1993***		***1994-2006***	
Firm Type:		Young	Mature	Young	Mature	Young	Mature
Panel A: Positive R&D Firms							
Assets	Mean	378.480	2899.267	96.253	2535.021	326.896	2835.294
	Median	99.889	755.094	22.308	386.089	50.613	231.486
Capex	Mean	0.075	0.070	0.069	0.065	0.053	0.051
	Median	0.056	0.060	0.044	0.056	0.031	0.040
R&D	Mean	0.034	0.025	0.102	0.039	0.195	0.067
	Median	0.020	0.019	0.063	0.026	0.103	0.036
SalesGwth	Mean	0.051	0.027	0.080	0.001	0.097	0.037
	Median	0.054	0.038	0.062	0.015	0.083	0.041
CashFlow	Mean	0.137	0.128	0.074	0.127	-0.056	0.125
	Median	0.129	0.124	0.114	0.130	0.084	0.135
StkIssues (net)	Mean	0.011	0.003	0.101	0.003	0.252	0.023
	Median	0.000	0.000	0.001	0.000	0.008	0.000
DbtIssues (net)	Mean	0.018	0.011	0.019	0.008	0.040	0.014
	Median	0.000	0.000	-0.001	-0.002	0.000	0.000
MarketBook	Mean	1.357	1.205	2.532	1.376	3.911	1.996
	Median	1.037	0.987	1.554	1.201	2.160	1.499
CashHoldings	Mean	0.088	0.077	0.215	0.098	0.395	0.152
	Median	0.052	0.053	0.105	0.056	0.224	0.075
Cash Holdings Observations		10446	4819	10758	7491	15038	9293

Panel B: No R&D Firms							
Assets	Mean	209.644	904.511	160.421	860.569	341.736	1206.686
	Median	89.988	346.073	32.199	209.076	100.976	240.426
Capex	Mean	0.072	0.076	0.069	0.060	0.062	0.054
	Median	0.051	0.058	0.041	0.047	0.038	0.040
SalesGwth	Mean	0.029	0.023	0.025	0.004	0.063	0.025
	Median	0.036	0.028	0.036	0.015	0.053	0.030
CashFlow	Mean	0.095	0.100	0.041	0.084	0.006	0.070
	Median	0.096	0.099	0.068	0.090	0.072	0.087
StkIssues (net)	Mean	0.003	0.001	0.026	0.001	0.038	-0.002
	Median	0.000	0.000	0.000	0.000	0.000	0.000
DbtIssues (net)	Mean	0.014	0.013	0.024	0.012	0.037	0.017
	Median	0.000	0.000	-0.001	-0.003	0.000	0.000
MarketBook	Mean	1.120	1.176	1.502	1.271	1.918	1.507
	Median	0.929	0.961	1.182	1.106	1.323	1.235
CashHoldings	Mean	0.089	0.084	0.105	0.099	0.102	0.095
	Median	0.052	0.056	0.040	0.044	0.032	0.034
Cash Holdings Observations		4649	1271	3909	3402	3945	3119

Table 2: Dynamic R&D Regressions with Change in Cash Holdings

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 sample is described in Table 1. Outliers in all regression variables are trimmed at the 1% level. Standard errors are robust to heteroskedasticity and with-in firm serial correlation.

Dependent Variable: $(R\&D)_t$

Sample Period	*1970-1981*		*1982-1993*		*1994-2006*	
	Young	**Mature**	**Young**	**Mature**	**Young**	**Mature**
$(R\&D)_{t-1}$	0.936	0.910	1.060	0.947	0.965	1.020
	(0.064)	*(0.034)*	*(0.099)*	*(0.039)*	*(0.099)*	*(0.063)*
$(R\&D)_{t-1}^2$	-0.336	0.106	-0.794	0.004	-0.331	-0.489
	(0.419)	*(0.402)*	*(0.244)*	*(0.235)*	*(0.097)*	*(0.160)*
$(MarketBook)_{t-1}$	-0.001	-0.001	0.001	0.001	0.002	0.001
	(0.001)	*(0.000)*	*(0.001)*	*(0.001)*	*(0.001)*	*(0.001)*
$(SalesGwth)_{t, t-1}$	-0.022	-0.006	0.003	0.007	-0.012	0.018
	(0.005)	*(0.003)*	*(0.013)*	*(0.003)*	*(0.014)*	*(0.011)*
$(CashFlow)_t$	0.147	0.087	0.058	0.034	0.082	0.054
	(0.022)	*(0.015)*	*(0.030)*	*(0.011)*	*(0.039)*	*(0.029)*
$(CashFlow)_{t-1}$	-0.091	-0.052	-0.026	-0.031	-0.000	-0.051
	(0.018)	*(0.014)*	*(0.023)*	*(0.010)*	*(0.027)*	*(0.018)*
$(StkIssues)_t$	0.039	-0.004	0.110	0.018	0.207	0.103
	(0.024)	*(0.028)*	*(0.026)*	*(0.013)*	*(0.040)*	*(0.024)*
$(StkIssues)_{t-1}$	0.030	0.021	-0.007	0.005	-0.019	-0.051
	(0.022)	*(0.025)*	*(0.020)*	*(0.012)*	*(0.032)*	*(0.021)*
$(DbtIssues)_t$	0.011	0.001	0.013	0.003	0.118	0.032
	(0.012)	*(0.009)*	*(0.027)*	*(0.009)*	*(0.053)*	*(0.019)*
$(DbtIssues)_{t-1}$	-0.029	-0.013	-0.038	-0.018	-0.145	-0.088
	(0.014)	*(0.007)*	*(0.025)*	*(0.007)*	*(0.051)*	*(0.021)*
$(\Delta CashHoldings)_t$	-0.049	0.007	-0.053	-0.008	-0.112	-0.039
	(0.014)	*(0.008)*	*(0.028)*	*(0.010)*	*(0.045)*	*(0.020)*
$(\Delta CashHoldings)_{t-1}$	0.007	0.003	-0.064	-0.005	-0.127	-0.026
	(0.011)	*(0.008)*	*(0.023)*	*(0.007)*	*(0.041)*	*(0.016)*
Sum CashFlow (p-value)	0.000	0.000	0.146	0.673	0.034	0.896
Sum StkIssues (p-value)	0.042	0.701	0.004	0.189	0.000	0.112
Sum DbtIssues (p-value)	0.359	0.264	0.559	0.135	0.731	0.046
Sum ΔCashHoldings (p-value)	0.014	0.353	0.002	0.253	0.000	0.017
m2	1.35	0.16	2.39	-1.70	1.80	0.99
J-test (p-value)	0.020	0.058	0.499	0.016	0.548	0.745
Diff-Hansen (p-value)	0.005	0.029	0.218	0.096	0.866	0.458
Observations	6858	3288	7485	5796	10808	7496
Firms	1052	427	1233	696	1650	854

Table 3: Dynamic R&D Regressions During the Equity Finance Boom and Bust

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 sample is described in Table 1. Outliers in all regression variables are trimmed at the 1% level. Standard errors are robust to heteroskedasticity and with-in firm serial correlation.

Dependent Variable: $(R\&D)_t$

Sample Period	*1998-2002*		*1998-2000*		*2000-2002*	
	Young	**Mature**	**Young**	**Mature**	**Young**	**Mature**
$(R\&D)_{t-1}$	0.689	1.087	0.549	1.039	0.910	1.155
	(0.145)	*(0.078)*	*(0.199)*	*(0.091)*	*(0.144)*	*(0.126)*
$(R\&D)_{t-1}^2$	-0.208	-0.635	-0.136	-0.474	-0.302	-0.723
	(0.123)	*(0.183)*	*(0.156)*	*(0.223)*	*(0.134)*	*(0.581)*
$(MarketBook)_{t-1}$	0.001	-0.000	0.004	0.000	0.000	-0.002
	(0.002)	*(0.001)*	*(0.004)*	*(0.001)*	*(0.003)*	*(0.001)*
$(SalesGwth)_{t,\ t-1}$	-0.023	0.013	0.009	0.024	-0.028	0.023
	(0.025)	*(0.014)*	*(0.048)*	*(0.022)*	*(0.023)*	*(0.015)*
$(CashFlow)_t$	0.133	0.083	0.157	0.099	0.113	0.045
	(0.062)	*(0.029)*	*(0.083)*	*(0.042)*	*(0.076)*	*(0.030)*
$(CashFlow)_{t-1}$	0.003	-0.078	0.054	-0.088	-0.008	-0.049
	(0.038)	*(0.025)*	*(0.054)*	*(0.031)*	*(0.045)*	*(0.022)*
$(StkIssues)_t$	0.247	0.111	0.213	0.134	0.248	0.083
	(0.058)	*(0.038)*	*(0.096)*	*(0.048)*	*(0.062)*	*(0.031)*
$(StkIssues)_{t-1}$	0.054	-0.041	0.093	-0.088	0.018	-0.017
	(0.046)	*(0.033)*	*(0.073)*	*(0.054)*	*(0.052)*	*(0.034)*
$(DbtIssues)_t$	0.240	0.098	0.234	0.109	0.237	0.034
	(0.080)	*(0.025)*	*(0.149)*	*(0.033)*	*(0.084)*	*(0.032)*
$(DbtIssues)_{t-1}$	-0.128	-0.070	-0.100	-0.090	-0.128	-0.071
	(0.073)	*(0.026)*	*(0.143)*	*(0.035)*	*(0.069)*	*(0.028)*
$(\Delta CashHoldings)_t$	-0.111	0.000	-0.163	-0.039	-0.138	-0.003
	(0.073)	*(0.031)*	*(0.112)*	*(0.045)*	*(0.079)*	*(0.032)*
$(\Delta CashHoldings)_{t-1}$	-0.161	-0.023	-0.149	-0.053	-0.168	0.033
	(0.070)	*(0.029)*	*(0.132)*	*(0.036)*	*(0.070)*	*(0.037)*
Sum CashFlow (p-value)	0.031	0.775	0.006	0.622	0.119	0.817
Sum StkIssues (p-value)	0.000	0.103	0.004	0.468	0.005	0.074
Sum DbtIssues (p-value)	0.281	0.415	0.415	0.717	0.310	0.349
Sum ΔCashHoldings (p-value)	0.006	0.583	0.057	0.108	0.005	0.502
m2	-0.77	1.86	-1.17	0.56	1.40	0.80
J-test (p-value)	0.169	0.860	0.579	0.710	0.274	0.743
Diff-Hansen (p-value)	0.174	0.169	0.690	0.165	0.131	0.316
Observations	4705	2820	2821	1806	2794	1550
Firms	1408	729	1162	705	1191	587

Table 4: Dynamic R&D Regressions: Alternative Sample Splits

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 sample is described in Table 1. Outliers in all regression variables are trimmed at the 1% level. Standard errors are robust to heteroskedasticity and with-in firm serial correlation.

Dependent Variable: $(R\&D)_t$

Sample Period	***1994-2006***		***1994-2006***		***1994-2006***	
Sample Split	**No Payout**	**Positive Payout**	**Small Sales**	**Large Sales**	**No Bond Rating**	**Bond Rating**
$(R\&D)_{t-1}$	0.924	1.037	0.894	1.156	0.934	1.140
	(0.098)	*(0.055)*	*(0.093)*	*(0.048)*	*(0.079)*	*(0.061)*
$(R\&D)_{t-1}^2$	-0.314	-0.295	-0.280	-0.833	-0.291	-0.752
	(0.099)	*(0.261)*	*(0.088)*	*(0.207)*	*(0.094)*	*(0.190)*
$(MarketBook)_{t-1}$	0.002	0.000	0.003	-0.000	0.003	0.001
	(0.001)	*(0.001)*	*(0.001)*	*(0.001)*	*(0.001)*	*(0.001)*
$(SalesGwth)_{t,\,t-1}$	-0.016	-0.003	-0.012	0.016	-0.020	0.025
	(0.014)	*(0.006)*	*(0.014)*	*(0.008)*	*(0.013)*	*(0.010)*
$(CashFlow)_t$	0.081	0.067	0.086	0.057	0.063	-0.026
	(0.035)	*(0.018)*	*(0.036)*	*(0.021)*	*(0.033)*	*(0.034)*
$(CashFlow)_{t-1}$	0.007	-0.069	0.005	-0.068	0.007	-0.006
	(0.026)	*(0.017)*	*(0.026)*	*(0.019)*	*(0.024)*	*(0.023)*
$(StkIssues)_t$	0.195	0.056	0.195	0.020	0.169	0.069
	(0.034)	*(0.021)*	*(0.035)*	*(0.026)*	*(0.033)*	*(0.025)*
$(StkIssues)_{t-1}$	-0.001	-0.075	-0.016	-0.076	-0.017	-0.080
	(0.030)	*(0.020)*	*(0.030)*	*(0.021)*	*(0.028)*	*(0.022)*
$(DbtIssues)_t$	0.124	0.007	0.130	0.002	0.045	0.028
	(0.050)	*(0.014)*	*(0.050)*	*(0.017)*	*(0.062)*	*(0.017)*
$(DbtIssues)_{t-1}$	-0.079	-0.014	-0.035	-0.033	-0.007	-0.053
	(0.048)	*(0.012)*	*(0.050)*	*(0.016)*	*(0.054)*	*(0.013)*
$(\Delta CashHoldings)_t$	-0.109	0.002	-0.108	-0.037	-0.083	-0.039
	(0.040)	*(0.015)*	*(0.041)*	*(0.019)*	*(0.039)*	*(0.018)*
$(\Delta CashHoldings)_{t-1}$	-0.141	-0.007	-0.131	0.005	-0.142	-0.013
	(0.040)	*(0.014)*	*(0.040)*	*(0.016)*	*(0.038)*	*(0.016)*
Sum CashFlow (p-value)	0.006	0.917	0.004	0.530	0.016	0.127
Sum StkIssues (p-value)	0.000	0.374	0.000	0.009	0.000	0.708
Sum DbtIssues (p-value)	0.503	0.705	0.151	0.059	0.588	0.208
Sum ΔCashHoldings (p-value)	0.000	0.834	0.000	0.174	0.000	0.028
m2	2.19	1.98	2.07	2.81	2.94	2.20
J-test (p-value)	0.596	0.359	0.304	0.377	0.607	0.221
Diff-Hansen (p-value)	0.816	0.437	0.145	0.067	0.483	0.110
Observations	11660	6330	11996	6101	13551	4658
Firms	1707	800	1771	736	1950	555

Appendix: *Variable Definitions with Compustat Data Codes*

$(R\&D)_t$: Research and development expense (data46) in period t divided by the book value of total assets (data6) at the beginning of period t.

$(Capex)_t$: Capital expenditures (data128) in period t divided by the book value of total assets (data6) at the beginning of period t.

$(CashHoldings)_t$: Cash and short-term investments (data1) in period t divided by the book value of total assets (data6) at the beginning of period t.

$(\Delta CashHoldings)_t$: The change in cash and short-term investments (data1) between the beginning and end of period t, divided by the book value of total assets (data6) at the beginning of period t.

$(CashFlow)_t$: Gross cash flow in period t divided by the book value of total assets (data6) at the beginning of period t, where gross cash flow is defined as (after-tax) income before extraordinary items (data18) plus depreciation and amortization (data14) plus research and development expense (data46).

$(StkIssues)_t$: Net cash raised from stock issues in period t divided by the book value of total assets (data6) at the beginning of period t, where net cash from stock issues is equal to the sale of common and preferred stock (data108) minus the purchase of common and preferred stock (data115).

$(DbtIssues)_t$: Net new long-term debt issued in period t divided by the book value of total assets (data6) at the beginning of period t, where net new long-term debt is equal to long-term debt issued (data 111) minus long-term debt reduction (data114).

$(MarketBook)_{t-1}$: Market value of assets in period t-1 divided by the book value of total assets (data6) in period t-1, where market value of assets is equal to the market value of equity (data25*data199) plus the book value of assets (data6) minus the book value of equity (data60).

$(SalesGwth)_{t,\, t-1}$: Log change in net sales (data12) between period t and t-1.