What Finances R&D?
R&D, Cash Flow Sensitivities, and Financing Constraints

by

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January 2013

Job Market Paper

Abstract

Treating the potential endogeneity problems of the empirical specifications in prior studies, I employ a
dynamic multi-equation model in which firms make interdependent decisions in financing, investment, and
distribution, under the constraint that sources and uses of cash must be equal. I argue that the large R&D-
cash flow sensitivities found in prior studies are mostly due to the lack of controlling for the interdependence
and intertemporal nature of firm policies. My results show little support for prior arguments that high-
tech firms are financially constrained based solely on large cash flow effects on R&D. I argue that, instead
of focusing on R&D-cash flow sensitivities alone, it is more appropriate to study financing constraints by
investigating the asymmetry in firm responses to positive and negative cash flow shocks. Using this approach,
my findings indicate that young high-tech firms are constrained, based on their significantly lower capability
to absorb negative cash flow shocks than to accommodate positive ones. In addition, I find young and mature
firms rely on different financing sources for innovation: young firms finance innovation through internal and
external equity, while mature firms use cash flow and debt for R&D financing. R&D and physical capital
investment are likely to be complementary for mature, but not for young, firms.

Keywords: R&D, high-tech firms, cash flow sensitivities, financing constraints

JEL Codes: C33, D92, E22, G31, G32, O32

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and Banking. Email: zzhuang@wisc.edu. I am very grateful to my advisor, Mark Ready, and committee
members, Youchang Wu, Dean Corbae, and Oliver Levine, for their constant support and encouragement.
I am grateful for helpful comments from David Brown, Bjorn Eraker, Michael Gofman, Bruce Hansen,
Elizabeth Odders-White, and Hollis Skaife. I also thank the seminar participants at University of Wisconsin-
Madison, University of Waterloo, the 2012 Financial Management Association Annual Meeting, and the 2012
Midwest Finance Association Annual Meeting. All errors are my own.
1 Introduction

Research and development, a critical input in innovation and economic growth, is a primary type of firm investment, in addition to capital expenditures. The technological change induced by R&D significantly increases the productivity and boosts endogenous growth for firms (e.g., Arrow (1962), Hall (2002), Bond et al. (2003), McGrattan and Prescott (2009), McGrattan and Prescott (2010), Holmes et al. (2011), and Zhuang (2012)). Given the substantial role of innovation in productivity and growth, however, there is only a small amount of literature on the connection between firm access to the financial market, firm capital structure, and R&D. Compared to the vast literature on the financing and liquidity constraints of capital investment, little research has been conducted on the financing of R&D. Among the small number of empirical studies that test for financing constraints on R&D spending, most of them draw conclusions based on R&D-cash flow sensitivities (e.g., Hall (1992), Himmelberg and Petersen (1994), Harhoff (1998), Mulkay et al. (2001), Bougeas et al. (2001), Bond et al. (2003), and Brown et al. (2009)). The findings in prior studies universally demonstrate significant and substantial R&D-cash flow sensitivities for firms in many industrialized countries, which lead to the common conclusion that firms encounter liquidity constraints for R&D. While prior studies have important implications regarding the efficiency of capital allocation in the economy, the interpretation of their results faces at least two main challenges, as suggested by the literature of investment and finance.

First, it is a controversial practice to interpret investment-cash flow sensitivities as evidence for the presence of financing constraints. The supporting literature argues that, after controlling for investment opportunities with $q$ (often proxied by the market-to-book value), large and positive investment-cash flow sensitivities imply that firms respond to adverse cash flow shocks by a significant decrease in investment, a response consistent with costly access to external capital (e.g., Fazzari et al. (1988, 2000), Hoshi et al. (1991), Calomiris and Hubbard (1995), Gilchrist and Himmelberg (1995), Bond et al. (2003), Boyle and Guthrie (2003), and Brown et al. (2009)). On the contrary, critical papers point out that market-to-book is not a good proxy for investment opportunities. The resultant measurement error in $q$ creates potential endogeneity problems that make the investment-cash flow sensitivities a
multidimensional effect that describes firm investment and financing policies on various levels, which are difficult to disentangle (e.g., Kaplan and Zingales (1997, 2000), Cleary (1999), Erickson and Whited (2000), Moyen (2004), Hennessy et al. (2007), and Almeida et al. (2010)).

Second, all firm financing and investment decisions are likely to be interdependent and some of them may exhibit certain persistence. Without considering this interdependence and adjustment frictions in firm decisions, prior studies may produce inefficient estimates and a potentially misleading view of firm behavior. In fact, Gatchev et al. (2010) find a much smaller and insignificant investment-cash flow sensitivity, based on a dynamic multi-equation model in which firms make joint financing and investment decisions subject to the constraint that sources equal uses of funds. Intuitively, these issues with the interpretation of investment-cash flow sensitivities also apply to research that draws conclusions based on R&D-cash flow sensitivities.

This paper is primarily concerned with the second issue discussed above, the interrelation and persistence in firm decisions, and investigates its implication in the interpretation of R&D-cash flow sensitivities in the literature. I study R&D financing in a framework that incorporates the interdependence and intertemporal nature of investment and financial policies. Modifying the model in Gatchev et al. (2010) to allow for a fuller set of firm decision variables and applying it to R&D, I employ a ten-equation system consisting of firm investment (capital expenditures, R&D, acquisitions, and asset sales), financing (equity issues, short-term debt issues, long-term debt issues, and changes in cash balances), and distributions (dividends and share repurchases), subject to the identity constraint that sources must equal uses of cash at all given periods. This system of simultaneous regressions helps mitigate the problem that arises when the cash flow effect of R&D is confounded with other firm investment and financing decisions, because the cash flow effects on all decision variables are accounted for and linked together by simple accounting matter. Meanwhile, the comprehensive cash flow effects on all important dimensions of firm decisions may be more informative when examining capital market constraints for these firms. In addition, I use $q$ (proxied by market-to-book) and size to control for firm investment opportunities, which also

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1Interestingly, a number of simulation-based studies demonstrate that significant investment-cash flow sensitivities can be generated even for firms in models with no financial frictions (e.g., Gomes (2001), Altı (2003), and Abel and Eberly (2011)).
helps isolate the financing effect of cash flow on R&D. To account for the potential mismeasurement problem with $q$, I also use the standard instrumental variables approach extended by Biorn (2000) and the Arrellano and Bond (1991) instrumental variable estimator with GMM estimation in first differences as a robustness check of my results.

Using this model, I find a substantially reduced R&D-cash flow sensitivity compared to the findings in prior studies. Dividing the sample into two groups, young and mature, my results show small as well as economically and statistically similar R&D-cash flow sensitivities across the spectrum of all firms, suggesting that the large R&D-cash flow sensitivities found in prior research are mostly due to the lack of controlling for the interdependence and persistence among firm policy variables. Further dividing the sample into firms receiving positive and negative cash flow shocks, I find that, for young firms, the R&D-cash flow sensitivity is significantly larger when they face cash flow shortfalls than when they experience positive cash flow innovations. With additional cash flow, young firms only moderately expand their R&D spending but instead use a significantly greater amount of funds to change capital structure by cutting equity and debt finance and increasing cash holdings. This makes intuitive sense, since a constant concern for young firms may be the possibility of future distress caused by limited debt capacity and high costs for external equity financing. Therefore, when achieving favorable cash flow changes, they exhibit conservative increase in R&D activities and high motivation for precautionary savings. Facing cash flow shortfalls, young firms asymmetrically forgo more R&D investment and are only able to raise limited external financing to offset the consequences of negative cash flow shocks, providing more direct evidence that young firms encounter capital market constraints. On the contrary, mature firms have rather symmetric reactions in R&D and financing variables to cash flow movements in either direction, which offers little evidence that mature firms are constrained in innovative activities.

By taking into account the fact that firm investment, financing, and distribution deci-

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2 Using Monte Carlo simulations and real data, Almeida et al. (2010) demonstrate that, when dealing with the mismeasurment of $q$, the instrumental variables-type estimators generally perform better in efficiency and robustness than the high-order moments estimators developed by Erickson and Whited (2000).

3 The main reason for young firms’ inability to raise debt financing could be the limited collateral value of their knowledge assets and their limited track records in the credit market (e.g., Hall (2002), Brown et al. (2009), and Zhuang (2012)).
sions are likely to be interrelated, the dynamic multiequation model employed in this paper includes a number of variables that are omitted from prior studies on R&D financing. Among all these omitted variables, those regarding debt financing and fixed capital investment are likely to be most influential on R&D, and their absence from prior models may thus cause significant estimation bias. Brown et al. (2009) are the first to highlight the importance of public equity financing of R&D in high-tech industries, explaining the difficulties with obtaining debt financing for R&D. Their results also indicate that high-tech firms raise limited long-term debt. However, there is a potentially important alternative source of financing, short-term debt, that may be less costly and demand less collateral, which is omitted in their study. In fact, I find that mature firms issue more debt (long-term and short-term) than equity for external financing. High-tech firms, especially those that are mature, use comparable short-term and long-term debt. Intuitively, creditors may be more lenient about the collateral requirement when the borrowings are short-term and the debtors have established extensive and favorable track records, the typical characteristics of mature firms. Gertler (1988) and Oliner and Rudebusch (1992) make the similar point that firms with good credit records may find external financing easier to obtain. This is likely a result of the fact that strong and healthy prior lending-borrowing relationships alleviate the moral hazard in intangible assets and decrease lender’s monitoring costs (Petersen and Rajan (1994), Berger and Udell (1995), and Bharath et al. (2007)). R&D and fixed capital, as the two primary types of firm investment, are both crucial to the production and continuous growth of firms. Presumably, firms that are financially healthier with steadier growth tend to reach a balance of production capacities and prospective innovations. In contrast, constrained firms may be constantly in a process of sacrificing one type of investment for the other in some periods and catching up later in others. Indeed, residual correlations from the system of regressions indicate that, after controlling for the cash flow effect and variable persistence, there is a high, positive correlation between R&D and capital investment for mature firms that is less present in young firms. This heterogeneity in the relation between capital and

\footnote{Zhuang (2012) develops a dynamic model of investment and capital structure that incorporates the distinctive features of capital and R&D investment. His simulation results present the substitution and complementary effects between capital and R&D, as firm borrowing constraints are relaxed through the enhancement of the pledgeability of their knowledge assets. This validates the intuition discussed here.}
R&D investment is interesting and informative, implying that a model that accounts for both types of investment simultaneously is necessary to better understand the connection between firm investment strategies and finance. Surprisingly, few prior studies in either the capital investment or R&D literature consider the two interdependent and therefore do not study them jointly.

In addition to detecting financial constraints for young firms, my findings also reveal a picture of evolving channels of financing for R&D in high-tech industries, as firms mature. Beside internal cash, young firms primarily depend on the equity market for R&D finance. For mature firms, most R&D activities can be financed directly by cash flow, with debt serving as the next source of financing. This financial hierarchy is largely consistent with the pecking order theory. R&D projects are risky due to the problems they are associated with: The asymmetric information between firms and investors, moral hazard, and adverse selection (e.g., Leland and Pyle (1977), Bhattacharya and Ritter (1983), Kihlstrom and Matthews (1990), Hall (2002), and Brown et al. (2009)). Because creditors typically require collateral from risky borrowers and prefer physical assets for securitization (Berger and Udell (1990) and Hall (1992)), R&D projects themselves as well as the majority assets of young high-tech firms – intangibles like intellectual property – have limited collateral value and are thus difficult to finance through debt. Consequently, when facing cash flow deficiency, young firms have to obtain substantial equity finance. Mature firms hardly depend on equity issues, since internal cash and debt issues already supply sufficient funding to finance their R&D investments. This apparent increase in ability to utilize debt financing is likely to be the result of relatively higher asset tangibility and longer, more well-established track records.

The rest of the paper proceeds as follows. Section 2 reviews the literature on R&D-cash flow sensitivity and discusses the financing situation for R&D-intensive firms. Section 3 describes the dataset, which consists of annual data for Compustat firms in seven high-tech industries, and presents sample summary statistics. Section 4 explains the model specification and the estimation methodology. The main statistical results are presented in section 5. Section 6 reports results after accounting for the measurement error in q as well as results from alternative specifications and firm classifications for robustness check. Section 7 concludes.
2 The Financing of R&D

2.1 R&D in the United States

R&D expenditures in the U.S. have been on the upsurge for at least the past five decades. Figure 1 documents this trend for the period of 1953-2008, showing a continuous growth in U.S. R&D from 28.29 billion to 324.79 billion dollars (all are measured in year-2000 dollars). The progressing importance of knowledge input to the U.S. economy is thus self-evident. In fact, the national R&D share of the GDP has increased from 1.36% in 1953 to its historical high at 2.79% in 2008, as shown in Figure 2. Most of the R&D activities have been conducted by firms in the business world. While the business share of performed R&D has been steady at about 70%, the business sector has been playing an increasingly important role in funding R&D. From the 1950s through the 1980s, over 50% of innovation was consistently funded by government and other sectors such as universities and nonprofit organizations. However, the business sector started to take on the responsibility in the early 1990s. In fact, as shown in Figure 1B, U.S. firms have progressively become more and more active in funding their own innovation activities during this period. In the late 2000s, firms already find themselves in the position of funding over 92.64% of their performed R&D projects. This interesting trend has raised an increasingly significant issue, however, regarding the finance of firm R&D in the U.S.: How do firms manage to fund their innovation activities with less and less government support?

The advance in R&D investment is in fact a world-wide phenomenon. As documented in Figure 2B, the U.S. share of the worldwide total of R&D has actually decreased even as domestic R&D has seen substantial growth, which may potentially call for an even more radical increase in national R&D to keep up with the global competition. However, as suggested by the discussion in the following subsection, innovating firms, especially young ones that work in high-tech industries, are likely to undertake high costs for external finance, which may constrain business investment in innovation and thus suppress economic growth. Therefore, understanding the connection between R&D and finance should be essential and imperative for promoting innovation and growth.
2.2 The Literature of R&D Financing

The early works of Nelson (1959) and Arrow (1962) suggest that the biggest problems for firm R&D investment lie in knowledge protection and external financing. As to the former, if knowledge – the output of R&D – cannot be used exclusively by the firms that develop it, such firms will have less incentive to invest. In the time since Nelson and Arrow put forth these ideas, this topic has been thoroughly studied and there exist today, in the U.S. and many other developed countries, well-established legal protections for intellectual property, such as patents, copyrights, and trademarks. This greatly mitigates the problem with knowledge protection and thereby encourages R&D investment. Reassuringly, studies like Mansfield et al. (1981) and Levin et al. (1987) find that imitating a new invention typically costs 50% to 75% of the cost of the original invention, alleviating the concern of R&D under-investment due to poor intellectual property protections.

The recent finance literature has been focusing on the difficulty of obtaining external financing for innovating firms, with most of the studies agreeing on a key conclusion: Due to the inherent riskiness of R&D investment, it is difficult and costly to finance R&D with external sources. The risk with R&D lies in several dimensions, including the asymmetric information between firms and investors, moral hazard, and adverse selection problems (Hall (2002), and Hall and Lerner (2010)). First, the innovating firm is expected to have better information about the quality and nature of its R&D projects than potential investors. Firms may be reluctant to disclose fully the information about their R&D projects in need of funding, because they worry about leaking information to potential competitors, as suggested by Bhattacharya and Ritter (1983). Second, theories presented in Leland and Pyle (1977), Bhattacharya and Ritter (1983), and Kihlstrom and Matthews (1990) also argue that there is possible moral hazard problem associated with the disclosure process, since managers can easily substitute high-risk for low-risk projects. Third, adverse selection problems are more likely in R&D-intensive industries because of the risky nature of R&D projects (Brown et al. (2009)).

Therefore, to compensate for the risk, R&D-intensive firms are likely to pay high costs for
external finance, and financial constraints may restrict R&D much more than other forms of investment (Brown et al. (2009)). Bates et al. (2009) find evidence that links R&D intensity to firm cash holdings, indicating that precautionary savings are motivated by costly access to the capital market. Pinkowitz et al. (2012) in fact identify the growing R&D intensity as, potentially, the central reason for the phenomenon of increasing cash holdings. If the firms do not have sufficient internal funds, as is generally the case for young and small firms, some innovations will not be accomplished, simply because the costs are prohibitive. In fact, a number of studies find evidence suggesting firms face financing constraints for R&D worldwide. For instance, Hall (1992), Himmelberg and Petersen (1994), and Brown et al. (2009) find some firms in the U.S. are constrained in the financing of R&D. The results in Harhoff (1998) and Bond et al. (2003) suggest similar constraints for firms in Germany and Britain while Mulkay et al. (2001) and Bougheas et al. (2001) make comparable conclusions about French and Irish firms.

Brown et al. (2009), who find that most of the finance for high-tech firms comes from internal sources, are also the first to highlight the importance of public equity financing to R&D in high-tech industries. Their results suggest that high-tech firms finance innovative activities mostly through cash flow, due to the high costs associated with and the difficulty in obtaining external financing. Equity issues are the main external source of finance for young high-tech firms, although stock issues incurs sizeable flotation costs to issue stocks and new share issues may also require a "lemons premium" to compensate for asymmetric information between firms and investors. Their results also suggest that high-tech firms use little long-term debt, which echoes the conclusion in Hall (2002) that "the capital structure of R&D-intensive firms customarily exhibits considerably less leverage than that of other firms."

Although more costly, as suggested by Brown et al. (2009), equity finance still has a number of noticeable advantages over debt for young high-tech firms: There are no collateral requirements for equity and additional equity does not magnify problems associated with financial distress. R&D-intensive firms tend to have limited debt capacity, especially if they are young and small. Since R&D projects are deemed risky, banks may be especially cautious in the lending process and require more collateral: Debt typically must be
secured by collateral when the borrowing firms are risky (Berger and Udell (1990)). Despite its necessity, collateral is exactly what R&D-intensive firms do not have. Tangible assets, like fixed capital, are the usual forms of collateral accepted by creditors, mainly banks (Hall (1992)), but the majority of assets owned by R&D-intensive firms are intangibles like intellectual property. Consequently, when facing cash flow deficiency, young firms have to obtain substantial equity finance. Mature firms hardly depend on equity issues, since internal cash and debt issues already suffice to finance their R&D investments. This apparent increase in ability to utilize debt financing is likely to be the result of relatively higher fixed capital intensity and enduring, well-established track records.

2.3 R&D-cash flow Sensitivities

Most prior studies in R&D financing employ static or dynamic reduced form regressions with a variety of specifications, including Hall (1992), Himmelberg and Petersen (1994), Mulkay et al. (2001), Bougheas et al. (2001), and Bond et al. (2003). Brown et al. (2009), one of the most recent studies in this field, modify a dynamic capital investment model by Bond and Meghir (1994) and apply it to R&D.

\[
RD_{i,t} = \beta_1 RD_{i,t-1} + \beta_2 RD_{i,t-1}^2 + \beta_3 C_{i,t-1} + \beta_4 C_{i,t} + \beta_5 Y_{i,t-1} + \beta_6 Y_{i,t} + \beta_7 STK_{i,t-1} + \beta_8 STK_{i,t} + d_t + \alpha_i + \nu_{i,t}
\]  

where \(RD_{i,t}\) is research and development spending for firm \(i\) in period \(t\); \(C_{i,t}\) represents gross cash flow; \(Y_{i,t}\) is firm sales; \(STK_{i,t}\) denotes new share issues. All of the level variables are scaled by beginning-of-period firm assets. Industry-year effects \(d_t\) control for the interactions between aggregate economic shocks and industry-specific changes in technological opportunities that affect R&D. Firm effects \(\alpha_i\) are also included in the model to control for all time-invariant determinants of R&D at the firm level. Variable definitions are presented in Appendix B.

The original model specification for fixed capital investment in Bond and Meghir (1994) is based on the Euler equation of capital accumulation subject to a quadratic adjustment.
cost function. The optimization of this Euler equation controls for expectations and the resulting equation can be estimated by evaluating the expectation at realized values. The difference between expectation and realization, namely, the expectation error, is assumed to be orthogonal to predetermined instruments. By considering profits as a function of the accumulated stock of R&D instead of fixed capital, Brown et al. (2009) transform the model and use it to study the financing of R&D.

They find significant financing effects from cash flow and net equity share issues to R&D investment by young firms only. For mature firms, on the other hand, the point estimates for the financial variables are not significant. This sharp difference indicates that young firms are more likely to face constraints than mature firms, because their R&D investments are significantly more sensitive to the availability of additional internal finance. In Table 1 and 2 I am able to closely replicate their results. Based on the whole sample of Compustat high-tech firms for the period of 1990-2004, the point estimate for R&D-cash flow sensitivity is 0.151 and significant at the 1% level, which is only slightly below the estimate of 0.158 in Brown et al. (2009). For young firms, the estimated contemporaneous cash flow effect on R&D (0.162 and significant at the 1% level) is in the range of estimates by Brown et al. (2009) (0.150-0.166). My replications also show strong effects from equity issues on R&D (0.131 and significant at the 1% level), mainly for young firms (0.145 and significant at the 1% level). Overall, my replications of the results match well with those of Brown et al. (2009) and demonstrate the findings that the innovative activities are highly sensitive to the availability of financing from cash flow and external equity for young, but not for mature, firms.

While prior studies have established the foundation for some interesting issues and results regarding R&D financing, the information and inferences conveyed may be incomplete, since some potentially important financing sources may have been omitted from the analysis, for instance, debt issues. Debt is largely ignored in the literature of R&D financing, because "[C]learly, debt finance is usually trivial" (Brown et al. (2009)). However, mature firms in my sample acquire more financing through debt than equity, if both long-term and short-
term debt are taken into account. Intuitively, short-term debt may be a good alternative financing source when firms find it difficult to borrow additional long-term debt. Creditors may be more lenient about the collateral requirement if the loans are short-term and the debtors have established positive track records. Gertler (1988) and Oliner and Rudebusch (1992) find that it is easier for firms with good credit records to obtain external finance, probably because the strong and healthy prior lending-borrowing relationships alleviate the moral hazard in intangible assets and decrease lender’s monitoring costs (Petersen and Rajan (1994), Berger and Udell (1995), and Bharath et al. (2007)). Therefore, it is expected that mature high-tech firms use more debt. In fact, my results presented in later sections indicate that the importance of short-term debt is comparable to that of long-term debt, for high-tech firms, especially mature ones. In addition, firms exhibit increasing utilization of debt as they grow older. Excluding such important heterogeneity in financing sources from the analysis could potentially produce misleading results. Therefore, a natural question to ask would be: Will taking into account these potentially omitted financing variables and other important firm investment and distribution decisions affect the estimation of R&D-cash flow sensitivities? Exploring answers to this question, the rest of the paper is devoted to extending prior research by linking all firm decisions regarding investment, financing, and distributions together to study R&D financing and examine the liquidity constraints for high-tech firms. Facing cash flow shocks, firms are expected to make interdependent adjustments in investment, financing, and distribution decisions. Consequently, to determine the total effect of a cash flow shock on R&D, both the direct effect of the shock and the indirect effect of adjustments in other firm policies must be considered.

3 Data Description

3.1 Sample Construction

My sample includes all publicly traded Compustat firms in seven high-tech industries in the U.S for the period of 1989-2010. Therefore, the sample period starts a year before the 1990s R&D boom, covers the recent financial crisis, and ends in the period of post-crisis recovery. The high-tech industries in my sample consist of drugs (SIC 283), office and computing
equipment (SIC 357), communications equipment (SIC 366), electronic components (SIC 367), scientific instruments (SIC 382), medical instruments (SIC 384), and software (SIC 737).

Firms not incorporated domestically and firms with no stock price data are excluded. I also require firms to have at least five R&D observations during the sample period. Due to the irregularity problems with the Compustat data, such as missing data and reporting errors (e.g., Gilchrist and Himmelberg (1995) and Abel and Eberly (2002)), I clean the data by the following procedure: I exclude firm-year observations for which capital expenditures, R&D, and total assets are negative. I also delete observations with capital investment exceeding the beginning of period capital. Firms with only one observation are also removed. In addition, I replace some missing data with their imputed values calculated by the "sources-equal-uses of cash" constraint; the rest are replaced with zeros to avoid dropping observations. Finally, outliers in all key variables are trimmed at the 1% level. My final sample includes 2,702 firms with 31,835 firm-year observations.

Similar to Brown et al. (2009), young and mature firms are classified based on the number of years since the firm’s first stock price appears in Compustat, which is also typically the year of the firm’s initial public offering. Firms are defined as young for the first 15 years following the year they first appear in Compustat with a stock price. Otherwise, they are treated as mature firms. Results based on different sample classifications are discussed in section 6. Since I treat all firm investment and financing decisions as potentially persistent, one-period lagged corresponding variables are included as explanatory variables, and all regressions are estimated over the post-1990 period.

3.2 Summary Statistics

Table 3 reports descriptive statistics for the key variables in my regressions and offers some informative statistics about the sources of finance for the sample firms. High-tech firms invest much more aggressively in R&D than in capital. This R&D intensity is especially noticeable for young firms: The mean and median ratios of R&D to capital investment are 11.622 and

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5Dropping observations with missing data does not create qualitatively different results. Estimation and statistical results with this alternative treatment of missing values are available upon request.
3.383 for young firms, as opposed to 6.586 and 1.745 for mature firms. The difference in such R&D intensities are statistically significant with p-values less than 1%. Mature firms have much higher ratios of cash flow to assets than young firms. For young firms, the mean of the cash flow ratio is considerably lower than the sum of the R&D and capital expenditure ratio means, suggesting that they must obtain substantial finance from external sources, which is likely to be equity issues. The mean new equity issue ratio for young firms is 0.219, as opposed to 0.083 for mature firms. Although the mean and median ratios of long-term and short-term debt all appear to be small and similar in number for young and mature firms, the test statistics for difference indicate otherwise: Only the difference in short-term debt mean ratios is statistically insignificant. Relative to their sizes, young and mature firms also differ substantially in investment and financial behavior like asset acquisitions and sales, dividend payouts, and cash holdings. Young firms also tend to be smaller in size and less tangible in assets but richer in investment opportunities.

Turning to statistics that describe the share of finance from each source (defined as the ratio of each source of financing to the sum of available internal cash (cash flow-change in cash balance), net long-term and short-term debt issues, and net equity issues), on average, over 88% of the financing is provided internally for mature firms, compared to less than 68% for young firms. For mature firms, the subsequent source of finance is debt, with the mean long-term debt share of total net finance being 3.9% and the mean short-term debt share being 3.4%. Young firms, on the other hand, resort to the equity market for additional finance and, on average, obtain over 21% of the net finance through stock issues. Equity financing, which only represents 3.6% of the total net finance, appears to be rather unimportant for mature firms. Young and mature firms differ significantly in debt utilization, with the difference in mean and median long-term and short-term debt share being significant at the 1% level. Compared to equity, debt is a less explored channel of finance for young firms: The mean (median) share of short-term debt finance is 1.6% (0.0%) and the mean (median) share of

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6It is noted, however, that Chan, Lakonishok, and Sougiannis (2001) and Chambers, Jennings, and Thompson (2002) find that firms have incentive to over-report R&D expense because the market views R&D activities to have future benefits for the firm. Skaife and Swenson (2011) show that R&D over-reporters tend to be younger, smaller, and less leveraged firms.
long-term debt issues is 2.4% (0.0%).

4 A Dynamic Multiequation Model

In the capital investment literature, Gatchev et al. (2010) demonstrate that models that do not account for the interdependence among financing and investment decision variables and the intertemporal nature of such decisions "produce inefficient estimates and provide an incomplete and potentially misleading view of financial behavior." Intuitively, this argument also applies to the research in R&D financing. To study the financing sources for R&D and investigate whether some subsets of high-tech firms are constrained in R&D, the accounting identities that link all firm decisions as well as the adjustment frictions in such decision variables must be taken into account. As suggested in Gatchev et al. (2010), this can be achieved by imposing the "sources-equal-uses of cash" constraint that controls for the fact that sources and uses of cash must match at any given period. Changes in any decision variable must thus be accompanied by adjustments in other firm policies.

To fully incorporate the spirit of this argument and apply it to R&D, I modify the dynamic multiequation system proposed in Gatchev et al. (2010). In this paper, the "sources-equal-uses of cash" approach includes ten simultaneous regressions and three sets of constraints. The idea is to minimize a penalty function of the deviations of planned variables from their desired levels and the adjustment speed from past levels. Therefore, with the dependent variables being financial and investment measures that represent current sources and uses of cash, the lagged variables corresponding to these measures and contemporaneous cash flow are included as explanatory variables. In addition, since firms are assumed to seek desired levels of investment and financing to exploit available investment opportunities, variables like Tobin’s $q$ and firm size are used as controls. Specifically, Tobin’s $q$ (proxied by market-to-book ratio) is employed as a conventional measure of investment opportunities and firm size is also used as a control for the possibility that investment opportunities and the ability to obtain external financing depend on firm size.

Compared to the model in Gatchev et al. (2010), the dynamic multiequation system in this paper takes into account a richer set of important firm decisions. In particular, R&D is included jointly with capital investment, which is important to my model estimation and
statistical analysis. Since R&D and physical capital are the two main types of firm investment that are both critical to the production and continuous growth of firms, firms are likely to make the two investment decisions jointly. It is also likely that there exists heterogeneity in firm policies regarding the priority of a particular type of investment and the balance between these two types of investment. Presumably, financially healthier firms with steadier growth tend to keep a good balance between production capacities and prospective innovations. On the contrary, financially constrained firms are likely to sacrifice consistently the less productive type of investment for the other in any given period. In fact, in section 5.3, correlations of the residuals from the system of regressions indicate that, after controlling for the cash flow effect and variable persistence, there is a high, positive correlation between R&D and capital investment for mature firms that is less present for young firms. This heterogeneity in the interdependence between capital and R&D investment is interesting and informative, implying that a model that accounts for both types of investment simultaneously is necessary for understanding the connection between firm investment strategies and finance. Surprisingly, few prior studies in either the capital investment or R&D literature consider the two interdependent and therefore fail to study them jointly. Unlike prior studies, I include R&D as an additional firm decision variable, which is also a component of cash uses. Altering R&D investment under the "sources-equal-uses of cash" constraint implies that other investment and finance decisions must also adjust.

My dynamic system consists of ten simultaneous equations representing firm investment (capital expenditures, R&D, acquisitions, and asset sales), financing (equity issues, short-term debt issues, long-term debt issues, and changes in cash balances), and distribution (dividends and share repurchases). The details of the model structure are provided in Appendix A. In this model, managers make all investment and financing decisions simultaneously at the beginning of each period, based on their forecasts of cash flow realizations for that period. The managers’ decisions are constrained by the fact that the uses must be equal to the sources of funds during the year. By minimizing the penalty of deviating from desired levels and assuming perfect forecasts of cash flow realizations at the beginning of each period, I

\footnote{Forecast model using I/B/E/S analysts’ forecasts to construct estimates of cash flow provides similar results.}
obtain a convenient system of multiregressions as follows:

\[
\begin{bmatrix}
    CAPX_{i,t} \\
    RD_{i,t} \\
    AQC_{i,t} \\
    -ASALET_{i,t} \\
    -EQUIS_{i,t} \\
    RP_{i,t} \\
    DV_{i,t} \\
    -\Delta LD_{i,t} \\
    -\Delta SD_{i,t} \\
    \Delta CASHT_{i,t}
\end{bmatrix}
= A\begin{bmatrix}CF_{i,t}\end{bmatrix} + B\begin{bmatrix}
    CAPX_{i,t-1} \\
    RD_{i,t-1} \\
    AQC_{i,t-1} \\
    -ASALET_{i,t-1} \\
    -EQUIS_{i,t-1} \\
    RP_{i,t-1} \\
    DV_{i,t-1} \\
    -\Delta LD_{i,t-1} \\
    -\Delta SD_{i,t-1} \\
    \Delta CASHT_{i,t-1}
\end{bmatrix} + C\begin{bmatrix}Q_{i,t}, SIZE_{i,t}\end{bmatrix}
\]

\[
\begin{bmatrix}
    fCAPX_i \\
    fRD_i \\
    fAQC_i \\
    fASALET_i \\
    fEQUIS_i \\
    fRP_i \\
    fDV_i \\
    f\Delta LD_i \\
    f\Delta SD_i \\
    f\Delta CASHT_i
\end{bmatrix}
+ \begin{bmatrix}
    dCAPX_t \\
    dRD_t \\
    dAQC_t \\
    dASALET_t \\
    dEQUIS_t \\
    dRP_t \\
    dDV_t \\
    d\Delta LD_t \\
    d\Delta SD_t \\
    d\Delta CASHT_t
\end{bmatrix} + \begin{bmatrix}
    eCAPX_{i,t} \\
    eRD_{i,t} \\
    eAQC_{i,t} \\
    -eASALET_{i,t} \\
    -eEQUIS_{i,t} \\
    eRP_{i,t} \\
    eDV_{i,t} \\
    -e\Delta LD_{i,t} \\
    -e\Delta SD_{i,t} \\
    e\Delta CASHT_{i,t}
\end{bmatrix}
\]

\[
(2)
\]

where \(CAPX_{i,t}\) is capital expenditures for firm \(i\) in period \(t\); \(RD_{i,t}\) is research and development; \(AQC_{i,t}\) and \(ASALET_{i,t}\) denote acquisitions and sales of assets and investments, respectively; \(EQUIS_{i,t}\) and \(RP_{i,t}\) represent sales and repurchases of common and preferred stocks, respectively; \(DV_{i,t}\) is cash dividends; \(\Delta LD_{i,t}\) and \(\Delta SD_{i,t}\) stand for net long-term and short-term debt issues; \(\Delta CASHT_{i,t}\) denotes changes in cash and equivalents; \(CF_{i,t}\) represents cash flow; \(Q_{i,t}\) and \(SIZE_{i,t}\) stand for Tobin’s \(q\) (proxied by market-to-book ratio) and firm size; \(fX_i\) controls for all time-invariant determinants of investment/financing variable \(X\) for
firm \( i \). \( d_{X_t} \) is the dummy controlling for time effects in the equation for variable \( X \) at time \( t \). All variable definitions in Compustat terms are in Appendix \([\text{B}]\). \( A, B, \) and \( C \) are coefficient matrices of size \( 10 \times 1, 10 \times 10, \) and \( 10 \times 2 \), respectively.

The regression coefficients have to satisfy three sets of constraints, as follows, where \( i' \) is a \( 1 \times 10 \) unit vector and \( 0 \) is a vector of zeros with specified dimensions.

\[
i' A = 1 \quad i' B = 0 \quad i' C = 0
\]

The first set of constraints specify that sources of cash must equal uses of cash, i.e., when there is a one dollar shock in a source or use variable, the total response of other investment and financing variables is opposite in sign to the shock and adds up to one dollar. The second and third sets of constraints determine that the total cash flow responses from the nonsource and nonuse variables, i.e., lagged dependent variables and controls, across the system of equations, must sum to zero.

To account for time effects and firm fixed effects in the regressions, I subtract annual means from each variable and transform all variables to first differences. Dealing with the potential correlated error-regressor problem after first differencing, I use the corresponding lagged dependent variables dated \( t - 3 \) and \( t - 4 \) as instruments. These instruments are valid even if the error term follows a firm-specific MA(1) process (Bond et al. (2003)). First differences in cash flow are also essential for separating samples into firms that experience positive and negative cash shocks, which helps investigate firm financing constraints in the next section. Petersen (2009) shows that failure to cluster standard errors by firm may bias standard errors and, therefore, the test results. Therefore, I control for firm-level clustering in all significance tests. In addition, as in Gatchev et al. (2010), when comparing coefficients across the different models for young and mature firms, I use the robust jackknife method of Shao and Rao (1993) to estimate standard errors of differences to account for the heteroscedasticity in coefficient variances.

This approach controls for the accounting identities that are not treated in prior R&D-

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\[\text{Petersen (2009)}\] demonstrates that clustering standard errors by time appears unnecessary since the correlation of the residuals within a year is small. These standard errors are identical to those clustered by firm only. This is also the case in my estimation.
cash flow regressions. It helps disentangle the simple accounting matter from the pure boosting effect on R&D from cash flow and aids in a comprehensive understanding of how firms act by adjusting a variety of investment and financing decisions. In fact, with this approach, I find significantly reduced R&D-cash flow sensitivities for high-tech firms, as shown by the statistical results presented in the next section.

5 Empirical Results

5.1 Firm Decision Interdependence and Cash Flow Effects

My replications of results in section 2.3 are quantitatively and qualitatively similar to those in Brown et al. (2009). Contemporaneous cash flow and new stock issues both have statistically significant positive effects on R&D, which are particularly notable for young firms. The R&D response to cash flow is 0.162, suggesting that young high-tech firms increase their innovation investment by over 16 cents when they receive one additional dollar in cash flow. Mature firms’ R&D does not appear to be sensitive to contemporaneous cash flow shocks. These results lead to the conclusion in Brown et al. (2009) that young firms are constrained in R&D spending while mature firms are not, essentially based on the "cash flow sensitivity" argument. The idea is that a relatively small and insignificant cash flow coefficient implies that firms have the ability to maintain investments against adverse cash flow realization. On the contrary, a relatively large, positive, and significant coefficient indicates that firms decrease investments in response to adverse cash flow realizations. Since the significant financing effects - substantial and positive contemporaneous cash flow and stock coefficients - are found for young firms only, the results are consistent with young firms being financially constrained while mature firms are not.

Intuitive as it is, however, support for the argument decreases if the significant cash flow effects turn out to be largely caused by the lack of controlling for the interdependence and persistence among firm decisions. To investigate whether this is indeed the case, I impose the constraint that sources and uses of funds must match each other and run the system of simultaneous regressions in section 4. Corresponding results are presented in Table 4.

[Insert Table 4 here]
I use first difference to remove firm fixed effects and subtract annual means from each variable to account for year fixed effects. Intuitively, if cash flows are serially correlated, first difference captures the "surprise component" of cash flow, as discussed in [Alti (2003)]. How firms react to the surprise changes in cash flow is likely to be informative for inferring what optimal decisions firms make to absorb cash flow shocks at the margin. In addition to transforming variable levels to first differences, in unreported regressions, I also scale all decision variables by beginning-of-period firm assets to avoid potential spurious correlations caused by common trends in data, which reduces the cash flow coefficients for some financing variables in the regressions but does not qualitatively affect my results.

In Table 4, I report only the cash flow coefficients from the system of regressions, as the cash flow effects are the main focus of this paper. Column (1) of Table 4 displays point estimates of cash flow sensitivities obtained from full-sample regressions without the "sources-equal-uses of cash" constraint, i.e., the interdependence between firm decisions is not controlled for. But the "own-lagged" dependent variable is included in each regression to account for the intertemporal effects, i.e., in each firm policy regression, the lagged variable regarding that particular firm policy, but not other lagged variables, is included. In addition, market-to-book and size are used as standard controls for investment opportunities. The results indicate strong cash flow effects on R&D, which is in line with the estimates in Brown et al. (2009). Changes in cash flow also significantly affect firm decisions in capital expenditures, distributions, and debt financing, at the 1% level. The total effects from experiencing an additional dollar of cash flow, however, sum to only 0.6, leaving roughly 40 cents unaccounted for.

Results from the regressions with the accounting identity constraint that controls for the interrelation of firm decision variables are presented in Column (2) of Table 4 for comparison. Since these regressions account for both the interdependence and intertemporal effects of firm policies, all regressions are executed simultaneously and all lagged firm decisions are included as explanatory variables, in addition to market-to-book and size variables. The investment-cash flow sensitivities are substantially reduced in this setting. In particular, the cash flow effect on R&D diminishes by more than half, from 0.1451 to 0.0704. The capital expenditure-

\[9\] The complete regression results are available upon request.
cash flow sensitivity also significantly decreases from 0.0952 to 0.0453. Meanwhile, however, the financing-cash flow sensitivities (cash flow coefficients on equity issues and changes in long-term and short-term debt) become substantially larger, which echoes the findings in Gatchev et al. (2010).\footnote{Gatchev et al. (2010) employ a similar system of multi-regressions that controls for the interdependence and intertemporal nature of firm decisions to study capital investment, and find significantly increased firm responses in financing variables to cash flow than estimated by stand-alone regressions.} The results suggest that firms use a considerably higher amount of additional funds to change their capital structure than is estimated in stand-alone regressions. With a dollar increase in contemporaneous cash flow, high-tech firms decrease equity issues by 12 cents and add 10 cents to share repurchases; they also cut debt issues by approximately 30 cents (17 cents for long-term debt and 13 cents for short-term debt). With most results differing significantly from those in Column (1) at the 1% level, the dynamic system of simultaneous regressions produces a total firm response that fully accounts for the dollar increment in cash flow.

Conducting stand-alone regressions and the dynamic constrained system of multi-regressions separately on the young and mature firm samples, I find a pattern in results that is similar to that for the full sample. Table 5 reports these regression results and test statistics for difference in coefficients. Controlling for the interrelation and persistence in firm decision variables significantly moderates investment-cash flow sensitivities but enhances financing-cash flow sensitivities. In particular, for young firms, R&D/capital expenditure-cash flow sensitivity decreases from 0.1552/0.1013 to 0.0742/0.0455. Meanwhile, each additional dollar increase in cash flow leads to less potential use of equity finance, roughly 27 cents ($0.16 in equity issues and $0.11 in share repurchases). The debt-cash flow sensitivities advance to -0.1071 for long-term debt, and 0.0983 for short-term debt. For mature firms, the investment-cash flow sensitivities do not change as dramatically, but the cash flow effects on financing variables are substantially increased. In fact, for mature firms, over 77 cents of the dollar change in cash flow is accounted for by adjustment in financing decisions (the sum of the absolute values of cash flow coefficients on equity issues, share repurchases, change in long-term and short-term debt, and change in cash balances.) As an extra dollar of cash flow becomes available, equity issues decrease by approximately 11 cents and share repurchases increase by 9 cents, indicating a smaller cash flow-equity finance substitution for mature firms (27
cents for young firms versus 20 cents for mature firms.) However, the substitution effects between cash flow and debt financing appear to be bigger for mature firms (38 cents for mature firms versus 22 cents for young firms.) This is consistent with the pecking order theory in the sense that young firms have to rely more on costly equity finance for additional funds due to their inability to raise enough debt. Mature firms, on the other hand, are more likely to obtain finance through borrowings and thus avoid dependence on equity issues. Mature firms also retain less cash, 20 cents as opposed to 32 cents by young firms. Cash flow has a significant effect on dividends payout for mature, but not young, firms. Indeed, young firms in my sample rarely pay dividends.

[Insert Table 5 here]

Controlling for the interdependence and intertemporal effects in firm decisions provides some interesting implications in the results. First, the results imply that, for the most part, R&D-cash flow sensitivities found in prior studies can be explained by the lack of controlling for the accounting identities that connect all firm policies in investment, financing, and distribution. Second, both young and mature high-tech firms devote the majority of the extra cash flow to adjusting capital structure instead of investment in R&D. Compared to the cash flow sensitivities on financing variables, their R&D-cash flow sensitivities are both small and similar in magnitude, with the difference being economically and statistically negligible at just over 1 cent. Therefore, my findings suggest that prior arguments, arguments that innovating firms are constrained based on large R&D-cash flow sensitivities, lose their support (e.g., Hall (1992), Himmelberg and Petersen (1994), Harhoff (1998), Mulkay et al. (2001), Bougheas et al. (2001), Bond et al. (2003), and Brown et al. (2009)).

Ostensibly, my results are consistent with the notion that neither mature nor young firms are constrained in R&D, based on the argument that, otherwise, firms would aggressively expand innovation investment when additional internal funds become available, instead of using most of these funds to retire external financing. At the same time, however, these results are also consistent with the notion that high-tech firms are financially constrained. In the sense that first difference captures the surprise component of cash flow innovation, the regression results obtained in this paper are particularly informative to studying how firms optimally absorb cash flow shocks at the margin. It could be the case that firms constantly
worry about the possibility of future distress and thus only moderately increase R&D while instead allocating the majority of the extra funds to debt retirement for preserving the precious debt capacity; share repurchases for building a good image on the market; and cash holdings for precautionary purposes. Similar points are made in Whited and Wu (2006), Bates et al. (2009), Almeida et al. (2011) \(^{11}\) and DeAngelo et al. (2011).

Therefore, to further study whether high-tech firms are constrained in R&D financing, it could be beneficial to compare firm responses to positive and negative cash flow shocks. The asymmetry in such responses to cash flow innovations in opposite directions could provide more insights into the discussion of financial constraints for high-tech firms, which is the central purpose of the following subsection.

### 5.2 Positive and Negative Cash Flow Shocks

In the above analysis, the symmetry in firm reactions to positive and negative cash flow shocks is assumed. However, the presence of financing constraints on R&D is more likely to reflect itself when firms have to obtain external financing in response to sudden cash flow shortfalls. To examine the symmetry of investment-cash flow and financing-cash flow sensitivities, I conduct separate regressions on four subsets of the high-tech firm sample, young/mature firms with positive/negative cash flow innovation. My goal is to infer whether a subset of high-tech firms (young or mature) is financially constrained through an investigation of whether these firms have asymmetric abilities to absorb cash flow innovations in opposite directions.

Results displayed in Table 6 indicate that young firms have asymmetric reactions to positive and negative cash flow shocks, with most of the response differences in investment and financing variables being statistically significant at the 1% or the 5% level. Upon positive cash flow advancement, with each extra dollar of cash flow, young firms increase R&D by less than 7 cents and capital expenditures by just over 4 cents but reduce equity financing.

\(^{11}\) Almeida et al. (2011) also document anecdotal evidence that is consistent with this argument. For instance, in the Graham and Harvey (2001) survey, "financial flexibility," which was cited by 59% of CFOs as an important determinant of leverage levels, was the single most commonly cited determinant of leverage in the survey. In Passov (2003), Richard Passov, the treasurer of Pfizer, argues that, technology and life science companies carry little debt to preserve debt capacities, due to the high value they place on future R&D.
by 27 cents (-$0.17 in equity issues plus $0.10 in share repurchases) and debt use by 23 cents (-$0.12 in long-term and -$0.11 in short-term debt), while retaining over 30 cents in cash for future needs. However, when young firms face negative cash flow movement, they cut innovation and capital spending by 16 cents ($0.10 in R&D and $0.06 in capital expenditures), reduce share repurchases by 13 cents and cash holdings by 34 cents, while being able to raise only 12 cents through equity issues and 16 cents by debt financing (the sum of cash flow coefficients on changes in long-term and short-term debt.) These results show that young firms conservatively raise investment, but actively pay down debt and reduce outstanding shares, as the optimal allocation of additional cash flow at the margin; when negative shocks make young firms short on cash, they do not exhibit a commensurate capability to accommodate such unfavorable changes in cash flow, and thus have to cut more on investment.

[Insert Table 6 here]

Mature firms, however, have largely symmetric responses to cash flow changes in the two opposite directions. Their investment scale, debt retirement, reduction in equity financing, and retained cash when experiencing a one dollar increase in cash flow, are similar to the investment cut, debt acquirement, increase in equity financing, and cash holding reduction when facing a one dollar shortfall in cash flow. Difference tests based on these responses under positive and negative cash flow shocks all produce insignificant statistics. Among all the tests for reaction difference in the ten firm decision variables, only the one on dividend is statistically significant, suggesting that mature firms make more adjustment in dividend payout policy under negative cash flow shocks than under positive ones. Overall, the results are consistent with the notion that mature firms have commensurate ability to absorb positive and negative cash flow innovations, because they do not behave significantly differently in R&D and capital spending, and external financing acquirement.

Although young and mature firms both exhibit small as well as economically and statistically similar R&D-cash flow sensitivities, conducting separate regressions on firms that experience positive and negative cash flow shocks unveils the asymmetry in responses to cash flow changes for these two groups, which is particularly informative for the study of the financial constraints for high-tech firms. Young firms forgo more R&D when experiencing
a one dollar shortfall than they increase it under a one dollar advancement in cash flow, because they have less capability to obtain external financing under adverse cash flow shocks than they do to retire external financing in positive cash flow shocks. Mature firms, on the other hand, demonstrate largely symmetric reactions to positive and negative cash flow innovations. Since the presence of capital constraints on R&D is more likely to be detected by observing firm inability to raise external funds when facing negative cash flow changes than to retire capital in response to positive cash flow changes, my results suggest that young firms tend to be financially constrained in R&D. Young firms also appear to have much higher cash-cash flow sensitivities than mature firms, consistent with the findings in Almeida et al. (2004), that constrained firms exhibit larger cash flow effect on cash savings.

5.3 Residual Correlation Analysis

The statistical results and regression analyses in prior sections have already presented the evidence for the heterogeneity in sources of R&D financing between young and mature firms. To further discuss this topic, I resort to the residual correlation analysis from the constrained dynamic multiregression system. Assuming that the model is correctly specified, the potential comovements between residuals from the R&D and financial variable regressions may be interpreted as the financing effects on R&D from the corresponding financial variables. For example, the residual from the R&D regression captures the innovation in R&D that is unexplained by cash flow and the included control variables. Similarly, the residual from the equity issue regression represents the movement in equity issues that cannot be explained by cash flow and the control regressors. If the residuals from both regressions are significantly correlated, it could suggest that R&D is financed by equity issues, in addition to cash flow. Of course, this interpretation of results has to be based on the assumption that the model is appropriately specified and there are no significant missing variables that drive both R&D and equity issues.

[Insert Table 7.1 here]

Table 7.1 reports residual correlations across the ten equations for young firms. All residual correlations are significant at the 1% level. The highest two correlations are the one between the residuals from the R&D and equity issues equations (0.214), and the one
between the changes in short-term debt and long-term debt (0.168), suggesting that equity issues is the most important source of financing for young firms’ innovative activities after cash flow, and those with better utilization of long-term debt also raise more short-term debt. This makes intuitive sense, because young firms suffer more from the pledgeability difficulty with their knowledge assets, as discussed in section 2. However, young firms with good track records may have relatively better abilities to raise debt finance than their peers.

The results of residual correlations for mature firms are presented in Table 7.2. With all residual correlations again being significant at the 1% level, the highest three of them are the ones between R&D and changes in long-term debt (0.189), between capital expenditures and R&D (0.157), and between R&D and innovations in short-term debt (0.144). These results are consistent with the notion that mature high-tech firms seek further R&D financing in the credit market, as well as from cash flow. The residual correlation between capital and R&D spending for mature firms is considerably higher than that for young firms (0.016), suggesting that, for mature firms, there is certain complementary effect between fixed capital and R&D in production and profit generation, which is absent in the young firm sample. Intuitively, young high-tech firms tend to be highly R&D-intensive, before successfully launching a product line and developing the capacity to produce and deliver to the market. Conversely, mature firms are more likely to have an already established line of products and matching production scale, with a significant amount of their R&D investment spent on improving existing products. This intuition also has support from the summary statistics in Table 1. The median and mean ratios of R&D to capital expenditures are 3.38 and 10.62 for young firms, compared to the corresponding 1.75 and 6.86 for mature firms, indicating a much higher R&D intensity for young firms.

6 Alternative Tests and Robustness

6.1 The Measurement Error in Q

Since Fazzari et al. (1988) introduce the model in which a firm’s investment is regressed on a proxy for $q$ and cash flows, recent literature has emphasized concerns about measurement
errors in regressions involving $q$. Almeida et al. (2010) evaluate several popular methods that treat the measurement error in $q$ in the literature, including the high-order moment estimator by Erickson and Whited (2000) [EW], the standard instrumental variables approach extended by Biorn (2000) [OLS-IV], and the Arrellano and Bond (1991) instrumental variable estimator [AB-GMM]. Results in Almeida et al. (2010) suggest that the OLS-IV and AB-GMM generally perform better in efficiency and robustness when dealing with the mis-measurement of $q$ than the EW estimator. Given that numerous researchers have reported difficulties with the implementation of the EW estimator (e.g., Almeida and Campello (2007), Gan (2007), Lyandres (2007), and Agca and Mozumdar (2007)), I use the OLS-IV and AB-GMM approaches to treat the measurement error in $q$ in my regressions and test the robustness of my results to such potential mismeasurement problems.

[Insert Table 8 here]

Statistics in Table 8 indicate that my main results are not affected by the potential measurement error in $q$. Since the measurement errors in $q$ are likely to be serially correlated (e.g., Erickson and Whited (2000, 2002), Whited (2006), and Almeida et al. (2010)), the instruments must be lagged at least three periods if the error term follows a firm-specific MA(1) process (Bond et al. (2003)). Hence, I use the lagged level variables of market-to-book, cash flow, and size, all of which are dated $t-3$ and $t-4$, as instruments in both the OLS-IV and AB-GMM estimations to treat the potential endogeneity problems in the regressions caused by the mismeasurement of $q$. When accounting for the measurement error in $q$, the estimated R&D-cash flow sensitivities for both young and mature firms are similar to my results obtained in Section 5. It remains the case that young and mature high-tech firms devote the majority of the extra cash flow to adjusting capital structure instead of investment in R&D. While young firms make more adjustments in their reliance on equity financing when faced with cash flow shocks, mature firms carry out greater changes in debt financing. At the same time, young and mature firms also have significantly different behavior in cash holdings under these circumstances.
6.2 Alternative Classifications

To further investigate the connection between firm age and capital constraints in the high-tech industries, and to address the potential concern that my results are sample dependent, I separate firms with a finer classification based on age, specifically, a firm is defined as "infant" for the 10 years following the year it first appears in Compustat with a stock price, and "developing" thereafter, for 20 years, at which point a firm is categorized as "mature." The dynamic multiequation model is then estimated for the three groups of firms under positive and negative cash flow shocks. The obtained cash flow coefficients and corresponding difference test results are reported in Table 9.

[Insert Table 9 here]

Overall, the results are consistent with the notion that high-tech firms become less constrained as they grow older. Of course, part of this phenomenon could be caused by the potential selection bias in the sample: Many constrained infant firms that are constantly under financial distress have probably died out before reaching the next age stage. Nevertheless, my results suggest that constrained high-tech firms are more likely to be found in the younger subsets of the sample. Across the samples, infant firms have arguably the most significant difference in cash flow coefficients on various firm investment and financing policies, between receiving positive and negative cash flow shocks. Experiencing a negative one dollar advancement in cash flow, infant firms cut over 10 cents in R&D, which is 3 cents higher than the counterpart increase in R&D when obtaining an extra dollar of cash flow. Infant firms also have significantly weaker ability to compensate for cash flow shortfalls by raising external financing than to accommodate positive cash flow innovations. Six out of the ten firm decision variables examined in the system show sensitivity difference significant at the 1%, the 5%, or the 10% level under cash flow innovations in the two opposite directions. Mature firms exhibit the most symmetric reactions to either type of cash flow shocks, positive or negative, with the difference in cash flow coefficients being significant for only one variable-cash dividends.

Infant firms demonstrate the highest R&D-cash flow, equity issues-cash flow, and cash-cash flow sensitivities, while mature firms have the biggest cash flow effects on cash divi-
dends, long-term debt, and short-term debt. The developing firm sample exhibits moderate reactions to cash flow innovations in all investment, financing, and distribution variables, compared to the responses by infant and mature firms. Even the highest R&D-cash flow sensitivity for infant firms, however, is considerably smaller than those estimated in prior studies. In addition, the statistics in Table 9 suggest that, moving from the "oldest" mature sample to the "youngest" infant sample, the substitution effect between equity issues and cash flow grows stronger while the substitution effect between debt and cash flow diminishes. These results are consistent with the pattern found in section 5, and thus demonstrate the robustness of my findings.

6.3 Firm Age, the KZ Index, and the WW Index

My findings connect the tendency to face financing constraints in R&D to the age of high-tech firms, where age is calculated based on the number of years since the firm’s first stock price appears in Compustat, which is also typically the year of the firm’s initial public offering. To see how my identified constrained sample - young high-tech firms - line up with other popular measures of financing constraints in the literature, I sort my sample firms into quartiles based on the widely used KZ index (Kaplan and Zingales (1997)) and WW index (Whited and Wu (2006)) and report the percentages of young and mature firms that fall in each quartile. Details about the constructions of the KZ and WW indices are presented in Appendix C. A high value in either index indicates a high probability of being financially constrained.

[Insert Table 10 here]

As indicated by the results in Table 10, my findings of financing constraints on R&D in the high-tech industries are more in line with the WW index. The majority (63%) of mature firms (identified as unconstrained) lie in the first and second quartiles of firms based on the WW index while the majority (59%) of young firms (identified as constrained) are included in the third and fourth quartiles. The KZ index, on the other hand, does not seem to agree with the connection between the financing constraint on R&D and firm age. Young firms are almost evenly distributed across the four quartiles based on the KZ index while a larger fraction (54%) of mature firms are actually associated with higher than average
KZ values in the sample. This is likely a result of the fact that firm size is an important component of the WW index but not the KZ index, while young firms in my sample tend to be significantly smaller in size than mature ones. For young firms, the lack of physical assets leads to limited debt capacity and thus heavy reliance on costly equity financing, which is a potentially important cause for firm underinvestment in R&D.

6.4 Alternative Empirical Specifications

My results in Section 5 demonstrate that young high-tech firms, which rely on equity issues for the financing of R&D, tend to face liquidity constraints. This finding has support from a number of studies that establish the connection between firm underinvestment and costly equity financing. For example, the structural model in Zhuang (2012) presents an optimal firm investment policy that demonstrates that equity issuers invest less in R&D, conditional on Tobin’s $q$. Similarly, Hennessy et al. (2007) develop a structural model with a testable implication that capital investment is lower for equity issuers after controlling for average $q$. I modify the dynamic investment regression model from Hennessy et al. (2007) and apply it to R&D to form an alternative test of the connection between the underinvestment of R&D and equity financing.

$$RD_{i,t} = \beta_1 Q_{i,t} + \beta_2 Q_{i,t} STK_{i,t} + \beta_3 OC_{i,t} + \beta_4 Index_{i,t} + \beta_5 CF_{i,t} + d_t + \alpha_t + v_{i,t} \quad (3)$$

where $RD_{i,t}$ is research and development spending for firm $i$ in period $t$; $Q_{i,t}$ stands for Tobin’s $q$ (proxied by the market-to-book ratio); $STK_{i,t}$ denotes new share issues; $OC_{i,t}$ represents a term of debt overhang correction; $Index_{i,t}$ is an index measuring finance constraints (the KZ or the WW index); $CF_{i,t}$ denotes cash flow. All of the level variables are scaled by beginning-of-period firm assets. Year effects $d_t$ control for the aggregate economic

$^{12}OC_{i,t} = Leverage_{i,t} \times Recovery Ratio_{i,t} \times \left[ \sum_{s=1}^{20} \rho_{t+s} [1 - 0.05(s - 1)](1 + r)^{-s} \right]$. The debt-overhang correction represents the current value of lenders’ rights to recoveries in default. Recovery ratios by SIC are based on Altman and Kishore (1996). Short-term debt is ignored and long-term debt is assumed to mature in a straight-line fashion, with 5% of the original debt maturing each year. $Leverage_{i,t}$ is measured by the ratio of long-term debt to total assets; $\rho_{t+s}$ denotes the probability of default in period $t+s$ based on the date $t$ debt rating. Moody’s reports of hazard rates by bond rating are used as the basis for default probabilities.
shocks that affect R&D. Firm effects $\alpha_i$ are also included in the model to control for all time-invariant determinants of R&D at the firm level.

[Insert Table 11 here]

Table 11 presents the results from the regression model (3). Regressions are conducted for both specifications with the KZ and WW indices, respectively. To account for time effects and firm fixed effects in the regressions, I subtract annual means from each variable and transform all variables to first differences. The potential measurement error in $q$ is treated by using lagged market-to-book dated $t-3$ and $t-4$ as instruments. I also control for firm-level clustering in all significance tests.

The coefficient on the interaction term $Q \ast STK$ is negative in both specifications with the KZ and WW indices, which indicates that, conditional on $q$, equity issuers invest less in R&D. This result is consistent with my finding in Section 5: Young firms that rely on the equities market for external financing tend to be constrained in R&D due to the high costs associated with equity issuance. In addition, the coefficient on the debt overhang correction $OC$ is negative, indicating that highly leveraged firms with high probabilities of default have lower R&D. Firms that are constrained, indicated by high KZ or WW indices, suffer from R&D underinvestment, although the coefficient on KZ index is not statistically significant.

7 Conclusion

R&D, the key factor for innovation, is critical to production and economic growth. U.S. R&D expenditures have been consistently increasing for the past five decades. The growth itself is dramatic: The national R&D in 2008 is almost 12 times as large as that in 1953. Firms in the U.S. account for over 70% of this growth in innovative activities. Firms have also been increasingly active in funding their performed R&D, as government financing declines. Since the late 1990s, over 90% of firm annual R&D has been consistently financed by firms themselves. It is thus important to understand the financing of R&D and study the liquidity constraints on firm innovative activities, the central interest of the finance literature that focuses on the capital market inefficiency regarding firm R&D investment. Typically, prior studies in this field employ stand-alone reduced form regressions to examine R&D-cash flow sensitivities, which are used to infer the degree of financial constraints on firm R&D. The
interpretations of results in prior studies are thus highly dependent on the magnitude of such cash flow effects on R&D.

As illustrated in this paper, regression models that do not account for the interdependence and intertemporal nature of firm investment and financing policies may produce potentially inefficient and misleading results, which are likely to have serious consequences on the inferences regarding the determinants of corporate decisions in prior research. To examine the significance of such a problem in the literature of R&D financing, I extend prior research by linking a fuller set of firm decision variables regarding investment, financing, and distribution via a dynamic multiequation system with the constraint that the sources and uses of cash must be equal in any given period. My results demonstrate that R&D-cash flow sensitivities are substantially reduced in this model specification, indicating that the large cash flow effects on R&D found in prior studies are mostly due to the lack of controlling for the interrelation and persistence among various firm policy variables.

Conducting separate regressions on firm samples with positive and negative cash flow shocks, my findings suggest that young high-tech firms exhibit a lower capacity to maintain R&D investment by raising external financing when experiencing cash flow shortfalls than to adjust innovative activities and retire external financing under positive cash flow innovations. Mature firms, however, show symmetric reactions to cash flow innovations in the two opposite directions. These results indicate that young firms are more likely to be constantly concerned with the possibility of future distress and thus only moderately increase R&D investment, instead actively retiring external financing and retaining cash, provided favorable cash flow advancements. On the other hand, their inferior ability to raise external financing forces them to curtail R&D investment more than they would if they had the capability of adjusting R&D commensurate to what they have under positive cash flow shocks. Therefore, my findings are consistent with the notion that young high-tech firms tend to be constrained in R&D.

Results in this paper also reveal a picture of evolving channels of finance for high-tech firm R&D spending. In addition to cash flow, young firms primarily depend on external equity finance. Mature firms, however, mainly explore the credit market for additional finance, other than cash flow. These findings are consistent with the pecking order theory, in the sense that young firms have to finance R&D through costly equity issues, which is likely to
be the result of poorer asset pledgeability and limited track records in the credit market. In addition to the heterogeneity in financing sources, my results also suggest that there is considerable difference in the relation between R&D and fixed capital investment between different subsets of high-tech firms: R&D and capital investment are more likely to be complementary for mature firms, who are, presumably, financially healthier and experiencing steadier growth and thus tend to match production capacities with prospective innovations.

While my results have implications for the literature on R&D financing and the liquidity constraints on innovative activities, the potentially more significant contribution of this paper is the demonstration of the necessity of accounting for the interdependence and intertemporal nature of firm policies in investment, financing, and distributions in empirical studies on the connection between R&D and finance. Studying any one of the firm policies in isolation from the others is likely to produce incomplete and misleading results. In addition, for empirical research that studies firm constraint in accessing the capital market, it is more informative to examine separate scenarios in which firms experience positive and negative cash flow shocks, without assuming symmetry in the results.
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Appendix A: Technical Notes

The ex post constraint that sources of cash must equal uses of cash constraint is

\[
\Delta CASH_t + RD_t + RP_t + DV_t + CAPX_t + AQC_t - \Delta LD_t - \Delta SD_t - EQUIS_t - ASALES_t = CF_t
\]

(4)

where \(CAPX_{i,t}\) is capital expenditures for firm \(i\) in period \(t\); \(RD_{i,t}\) is research and development; \(AQC_{i,t}\) and \(ASALE_{i,t}\) denote acquisitions and sales of assets and investments, respectively; \(EQUIS_{i,t}\) and \(RP_{i,t}\) represent sales and repurchases of common and preferred stocks, respectively; \(DV_{i,t}\) is cash dividends; \(\Delta LD_{i,t}\) and \(\Delta SD_{i,t}\) stand for net long-term and short-term debt issues; \(\Delta CASH_{i,t}\) denotes changes in cash and equivalents; \(CF_{i,t}\) represents cash flow.

The constraint for ex ante firm decisions is

\[
\Delta C\tilde{A}SH_t + \tilde{RD}_t + \tilde{RP}_t + \tilde{DV}_t + \tilde{CAPX}_t + \tilde{AQC}_t - \Delta \tilde{LD}_t - \Delta \tilde{SD}_t - \tilde{EQUIS}_t - \tilde{ASALES}_t = \tilde{CF}_t
\]

(5)

where \(\tilde{\cdot}\) represents ex ante planned values of firm decision variables and \(\tilde{CF}_t\) represents the exogenous cash flow variable to be forecasted.

Ex post quantities depart stochastically from ex ante planned values as

\[
\begin{bmatrix}
C\tilde{A}PX_t \\
RD_t \\
\vdots \\
\Delta SD_t \\
\Delta C\tilde{A}SH_t
\end{bmatrix}
= \begin{bmatrix}
C\tilde{A}PX_t \\
\tilde{RD}_t \\
\vdots \\
\Delta \tilde{SD}_t \\
\Delta C\tilde{A}SH_t
\end{bmatrix} + \begin{bmatrix}
e_{C\tilde{A}PX_t} \\
e_{RD_t} \\
\vdots \\
e_{\Delta SD_t} \\
e_{\Delta C\tilde{A}SH_t}
\end{bmatrix}
\]

(6)

Similarly, the forecasted \(\tilde{CF}_t\) departs stochastically from the realized value \(CF_t\) as:
\[
\tilde{CF}_t = CF_t + e_{CF,t}
\] (7)

Thus, the error terms satisfy

\[
e_{\Delta \text{CASH}_t} + e_{\text{RD}_t} + e_{\text{RP}_t} + e_{\text{CAPX}_t} + e_{\text{AQCI}_t} - e_{\Delta \text{LD}_t} - e_{\Delta \text{SD}_t} - e_{\text{EQUIS}_t} - e_{\text{ASALES}_t} = e_{CF_t}
\] (8)

Firms attempt to achieve desired levels of investment and financing variables subject to available investment opportunities controlled by Tobin’s \(q\) \((Q_t)\) and size \((\text{SIZE}_t)\)

\[
\begin{bmatrix}
\text{CAPX}_t^* \\
\text{RD}_t^* \\
\vdots \\
\Delta \text{SD}_t^* \\
\Delta \text{CASH}_t^*
\end{bmatrix} = A\begin{bmatrix}
\tilde{CF}_t \\
Q_t \\
\text{SIZE}_t
\end{bmatrix} + C 
\] (9)

Let the vector of ten planned endogenous variables be \(Y_t\). Assume that the penalty function of departing from desired levels is of the form \((Y_t - Y_t^*)'D(Y_t - Y_t^*) + (Y_t - Y_{t-1})'E(Y_t - Y_{t-1})\), where \(Y_t^*\) is a \(10 \times 1\) vector with the variables being desired levels, \(Y_{t-1}\) is a \(10 \times 1\) vector of the variables’ previous period realizations, and \(D\) and \(E\) are matrices that represent the penalties associated with deviations from desired levels and with the speed of adjustment, respectively.

Minimizing the penalty of deviating from desired levels and costs associated with adjustments, subject to the constraint (5), gives
Substituting (10) into (6) gives the system of equations to be estimated:

\[
\begin{bmatrix}
C\tilde{AP}X_t \\
\tilde{RD}_t \\
\vdots \\
\Delta\tilde{SD}_t \\
\Delta C\tilde{ASH}_t
\end{bmatrix} = A\begin{bmatrix}\tilde{CF}_t \end{bmatrix} + B\begin{bmatrix}
\tilde{AP}X_{t-1} \\
\tilde{RD}_{t-1} \\
\vdots \\
\Delta\tilde{SD}_{t-1} \\
\Delta C\tilde{ASH}_{t-1}
\end{bmatrix} + C\begin{bmatrix}
Q_t \\
SIZE_t
\end{bmatrix}
\]

(10)

where \(A, B, C\) are matrices of response coefficients of size \(10 \times 1, 10 \times 10, \) and \(10 \times 2, \) respectively.

Substituting (10) into (6) gives the system of equations to be estimated:

\[
\begin{bmatrix}
CAPX_t \\
RD_t \\
AQC_t \\
-ASALE_t \\
-EQUIS_t \\
RP_t \\
DV_t \\
-\Delta LD_t \\
-\Delta SD_t \\
\Delta CASH_t
\end{bmatrix} = A\begin{bmatrix}\tilde{CF}_t \end{bmatrix} + B\begin{bmatrix}
\tilde{AP}X_{t-1} \\
\tilde{RD}_{t-1} \\
A\tilde{Q}C_{t-1} \\
-A\tilde{S}ALE_{t-1} \\
-E\tilde{Q}UI\tilde{S}_{t-1} \\
\tilde{R}P_{t-1} \\
\tilde{D}V_{t-1} \\
-\Delta \tilde{L}D_{t-1} \\
-\Delta \tilde{S}D_{t-1} \\
\Delta \tilde{C}ASH_{t-1}
\end{bmatrix} + C\begin{bmatrix}
Q_t \\
SIZE_t
\end{bmatrix}
\]

(11)

where

\[
i' \cdot A = 1 \quad i' \cdot B = 0 \quad i' \cdot C = 0
\]

\(i'\) is a \(1 \times 10\) unit vector and 0 is a vector of zeros with specified dimensions. Thus, under the assumption of perfect cash flow forecast, equation (11) can be transformed into the regression model applicable to firm panel data, as specified by equation (2).
Appendix B: Variable Definitions

\[(Variable: Description (Compustat Item))\]

\[RD_t: \text{Research and development expense in period } t. \ (XRD)\]

\[C_t: \text{Gross cash flow in period } t. \text{ Gross cash flow is equal to (after-tax) income before extraordinary items plus depreciation and amortization plus research and development expense. (IB+DP+XRD)}\]

\[Y_t: \text{Net sales in period } t. \ (SALE)\]

\[STK_t: \text{New stock issues in period } t. \text{ New stock issues is defined as the sale of common and preferred stock minus the purchase of common and preferred stock. (SSTK-PRSTKC)}\]

\[CAPX_t: \text{Capital expenditures in period } t. \ (CAPX)\]

\[\Delta LD_t: \text{Net new long-term debt in period } t. \text{ Net new long-term debt is defined as long-term debt issuance minus long-term debt reduction or change in long-term debt if missing. (DLTIS-DLTR) or (DLTT-L.DLTT)}\]

\[\Delta SD_t: \text{New short-term debt in period } t, \text{ which is equal to the difference between debt in current liability and long-term debt due in one year in period } t \text{ minus the difference between debt in current liability and long-term debt due in one year in period } t-1 \text{ or change in short-term debt if missing. (DLC-L.DLC) or (DLCCH)}\]

\[CASH_t: \text{Cash and equivalents in period } t. \ (CHE)\]

\[EQUIS_t: \text{Sale of common and preferred stock in period } t. \ (SSTK)\]

\[ASALE_t: \text{Sale of assets and investments in period } t. \ (SPPE)\]

\[AQC_t: \text{Acquisitions in period } t. \ (AQC)\]

\[RP_t: \text{Purchase of common and preferred stock in period } t. \ (PRSTKC)\]

\[DV_t: \text{Cash dividends in period } t. \ (DV)\]

\[SIZE_t: \text{Log of total assets in period } t. \ (Log of AT)\]

\[Q_t (MB_t): \text{Market-to-book value of assets in period } t=(\text{Market value of equity-Book value of equity+Book value of total assets)/Book value of total assets}. \ (PRCC_F*CSHO-CEQ \text{ (or SEQ or AT-LT if missing)}+AT)/AT\]

\[CF_t: \text{Cash flow in period } t=\text{Operating income before depreciation-Net interest expense-Cash taxes-Change in net working capital+R\&D}. \ (OIBDP-(XINT-IDIT)-(TXT-TXDC)-Δ[(ACT-CHE)-(LCT-DLC)]+XRD)\]
Appendix C: Constructions of the KZ Index and the WW Index

This KZ index comes from Kaplan and Zingales (1997), who examine the annual reports of the 49 firms in the Fazzari et al. (1988) constrained sample, using this information to rate the firms on a financial constraints scale from one to four. They then run an ordered logit of this scale on observable firm characteristics. Several authors use these logit coefficients on data from a broad sample of firms to construct a synthetic KZ index to measure finance constraints. Specifically, the KZ index is constructed as

\[-1.001909CF + 3.139193TLTD - 39.36780TDIV - 1.314759CASH + 0.282639Q\]  \(\ (12)\)

in which \(CF\) is the ratio of cash flow to book assets, \(TLTD\) is the ratio of total long-term debt to book assets, \(TDIV\) is the ratio of total dividends to book assets, \(CASH\) is the ratio of the stock of cash to book assets, and \(Q\) is the market-to-book ratio.

The WW index is from Whited and Wu (2006). Their index is constructed from the Euler equation from a standard intertemporal investment model with convex adjustment costs. In this model, and in the absence of constraints, the marginal cost of investing today equals the opportunity cost of postponing investment until tomorrow. In the presence of constraints, a wedge appears between these two costs. The WW index is an estimated parameterization of this wedge. Specifically, the WW index is

\[-0.091CF - 0.062DIVPOS + 0.021TLTD - 0.044LNTA + 0.102ISG - 0.035SG\]  \(\ (13)\)

Here, \(DIVPOS\) is an indicator that is one if the firm pays dividends, and zero otherwise; \(SG\) is own-firm real sales growth; \(ISG\) is three-digit industry sales growth; and \(LNTA\) is the natural log of book assets.
Table 1: Replication of Results. This table presents the comparison between the results by Brown et al. (2009) and my replication of their results. The dynamic R&D regression is estimated over a sample of Compustat high-tech firms for the period of 1990-2004. The dependent variable is $R&D_{t-1}$. Variable definitions are provided in Appendix B. All variables are scaled by the beginning-of-period stock of firm assets. The Panel regression is estimated with one-step GMM in first differences to eliminate firm fixed effects, following Arrellano and Bond (1991) and Arrellano and Bover (1995). Level variables dated $t - 3$ and $t - 4$ are used as instruments. Industry-year dummies are included in the regressions. The statistics $m1$ and $m2$ test the null of no first- and second-order autocorrelation in the first-difference residuals. The $C \text{ Chi}(2)$ statistic represents a Chi-square test of the null that the sum of the current and lagged cash flow coefficients is zero, and $STK \text{ Chi}(2)$ is the corresponding test for net stock issues. Hansen is a test of the null that the overidentifying restrictions are valid.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Brown et al. (2009)</th>
<th>My Replication of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>$RD_{t-1}$</td>
<td>0.403 (0.130)</td>
<td>0.324 (0.136)</td>
</tr>
<tr>
<td>$RD_{t-1}^2$</td>
<td>-0.153 (0.075)</td>
<td>-0.174 (0.062)</td>
</tr>
<tr>
<td>$C_{t-1}$</td>
<td>0.006 (0.016)</td>
<td>0.009 (0.011)</td>
</tr>
<tr>
<td>$C_t$</td>
<td>0.158 (0.040)</td>
<td>0.151 (0.053)</td>
</tr>
<tr>
<td>$Y_{t-1}$</td>
<td>-0.022 (0.009)</td>
<td>-0.033 (0.031)</td>
</tr>
<tr>
<td>$Y_t$</td>
<td>-0.007 (0.018)</td>
<td>-0.006 (0.029)</td>
</tr>
<tr>
<td>$STK_{t-1}$</td>
<td>-0.017 (0.004)</td>
<td>-0.007 (0.011)</td>
</tr>
<tr>
<td>$STK_t$</td>
<td>0.149 (0.017)</td>
<td>0.131 (0.035)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Brown et al. (2009)</th>
<th>My Replication of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m1$ (p-value)</td>
<td>0.000</td>
<td>0.025</td>
</tr>
<tr>
<td>$m2$ (p-value)</td>
<td>0.345</td>
<td>0.278</td>
</tr>
<tr>
<td>$C \text{ Chi}(2)$ (p-value)</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>$STK \text{ Chi}(2)$ (p-value)</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>Hansen (p-value)</td>
<td>1.000</td>
<td>0.733</td>
</tr>
<tr>
<td>Observations</td>
<td>12,224</td>
<td>13,051</td>
</tr>
</tbody>
</table>
Table 2: Replication of Results: Dynamic R&D Regressions for Separate Young- and Mature-Firm Samples. This table presents the comparison between the results by Brown et al. (2009) and my replication of their results, for separate young and mature firm samples. Dynamic R&D regressions are estimated over a sample of Compustat high-tech firms for the period of 1990-2004. Firms are defined as young for the 15 years following the year they first appear in Compustat with a stock price, and mature thereafter. The dependent variable is $R\&D_{i,t}$. Variable definitions are provided in Appendix B. All variables are scaled by the beginning-of-period stock of firm assets. The Panel regression is estimated with one-step GMM in first differences to eliminate firm fixed effects, following Arrellano and Bond (1991) and Arrellano and Bover (1995). Level variables dated $t-3$ and $t-4$ are used as instruments. Industry-year dummies are included in all regressions. The statistics $m1$ and $m2$ test the null of no first- and second-order autocorrelation in the first-difference residuals. The $C \text{ Chi}^2(2)$ statistic represents a Chi-square test of the null that the sum of the current and lagged cash flow coefficients is zero, and $STK \text{ Chi}^2(2)$ is the corresponding test for net stock issues. Hansen is a test of the null that the overidentifying restrictions are valid.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Young Firms</th>
<th>Mature Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>$RD_{i,t-1}$</td>
<td>0.392 (0.130)</td>
<td>0.323 (0.122)</td>
</tr>
<tr>
<td>$RD^2_{i,t-1}$</td>
<td>$-0.144$ (0.074)</td>
<td>$-0.124$ (0.051)</td>
</tr>
<tr>
<td>$C_{i,t-1}$</td>
<td>0.012 (0.017)</td>
<td>0.031 (0.024)</td>
</tr>
<tr>
<td>$C_t$</td>
<td>0.150 (0.043)</td>
<td>0.162 (0.044)</td>
</tr>
<tr>
<td>$Y_{i,t-1}$</td>
<td>$-0.023$ (0.009)</td>
<td>$-0.044$ (0.026)</td>
</tr>
<tr>
<td>$Y_t$</td>
<td>$-0.006$ (0.019)</td>
<td>$-0.005$ (0.021)</td>
</tr>
<tr>
<td>$STK_{i,t-1}$</td>
<td>$-0.017$ (0.004)</td>
<td>$-0.014$ (0.009)</td>
</tr>
<tr>
<td>$STK_t$</td>
<td>0.148 (0.017)</td>
<td>0.145 (0.025)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Young Firms</th>
<th>Mature Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m1 \text{ (p-value)}$</td>
<td>0.000</td>
<td>0.036</td>
</tr>
<tr>
<td>$m2 \text{ (p-value)}$</td>
<td>0.432</td>
<td>0.397</td>
</tr>
<tr>
<td>$C \text{ Chi}^2(2) \text{ (p-value)}$</td>
<td>0.000</td>
<td>0.002</td>
</tr>
<tr>
<td>$STK \text{ Chi}^2(2) \text{ (p-value)}$</td>
<td>0.000</td>
<td>0.005</td>
</tr>
<tr>
<td>Hansen \text{ (p-value)}</td>
<td>1.000</td>
<td>0.865</td>
</tr>
<tr>
<td>Observations</td>
<td>8,831</td>
<td>9,492</td>
</tr>
</tbody>
</table>
Table 3: Sample Descriptive Statistics. This table presents summary Compustat data used in the empirical analyses. The sample covers publicly traded Compustat high-tech firms for the period of 1989-2010. Variable definitions with corresponding Compustat data codes are provided in Appendix B. All numbers, except for Market-to-Book and Firm Size, are scaled by beginning-of-period firm assets. Firm Size is measured as the natural logarithm of book assets. Firms are defined as young for the 15 years following the year they first appear in Compustat with a stock price, and mature thereafter. The \( p \)-value for tests that the mean and median values differ across young and mature firms are also reported.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Median</th>
<th>Standard Deviation</th>
<th>90th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital expenditures</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Sample</td>
<td>0.047</td>
<td>0.030</td>
<td>0.054</td>
<td>0.107</td>
</tr>
<tr>
<td>Young</td>
<td>0.048</td>
<td>0.029</td>
<td>0.057</td>
<td>0.112</td>
</tr>
<tr>
<td>Mature</td>
<td>0.043</td>
<td>0.030</td>
<td>0.045</td>
<td>0.096</td>
</tr>
<tr>
<td>Difference (( p )-value)</td>
<td>0.000</td>
<td>0.374</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R&amp;D</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Sample</td>
<td>0.186</td>
<td>0.121</td>
<td>0.213</td>
<td>0.418</td>
</tr>
<tr>
<td>Young</td>
<td>0.206</td>
<td>0.141</td>
<td>0.222</td>
<td>0.452</td>
</tr>
<tr>
<td>Mature</td>
<td>0.126</td>
<td>0.080</td>
<td>0.173</td>
<td>0.249</td>
</tr>
<tr>
<td>Difference (( p )-value)</td>
<td>0.000</td>
<td>0.000</td>
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<tr>
<td>Acquisitions</td>
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</tr>
<tr>
<td>Full Sample</td>
<td>0.018</td>
<td>0.000</td>
<td>0.058</td>
<td>0.048</td>
</tr>
<tr>
<td>Young</td>
<td>0.017</td>
<td>0.000</td>
<td>0.058</td>
<td>0.043</td>
</tr>
<tr>
<td>Mature</td>
<td>0.021</td>
<td>0.000</td>
<td>0.060</td>
<td>0.064</td>
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<tr>
<td>Difference (( p )-value)</td>
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<td>0.000</td>
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<tr>
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<tr>
<td>Full Sample</td>
<td>0.002</td>
<td>0.000</td>
<td>0.008</td>
<td>0.003</td>
</tr>
<tr>
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<td>0.002</td>
<td>0.000</td>
<td>0.007</td>
<td>0.002</td>
</tr>
<tr>
<td>Mature</td>
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<td>0.000</td>
<td>0.009</td>
<td>0.005</td>
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<tr>
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<tr>
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<td>0.185</td>
<td>0.013</td>
<td>0.487</td>
<td>0.568</td>
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<tr>
<td>Young</td>
<td>0.219</td>
<td>0.017</td>
<td>0.531</td>
<td>0.702</td>
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<tr>
<td>Mature</td>
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<td>0.007</td>
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<td>0.139</td>
</tr>
<tr>
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<td>0.000</td>
<td>0.000</td>
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</tr>
<tr>
<td>Share repurchases</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Sample</td>
<td>0.012</td>
<td>0.000</td>
<td>0.034</td>
<td>0.040</td>
</tr>
<tr>
<td>Young</td>
<td>0.011</td>
<td>0.000</td>
<td>0.032</td>
<td>0.032</td>
</tr>
<tr>
<td>Mature</td>
<td>0.017</td>
<td>0.000</td>
<td>0.038</td>
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<td>Mean</td>
<td>Median</td>
<td>Standard Deviation</td>
<td>90th Percentile</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------</td>
<td>--------</td>
<td>--------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td><strong>Cash flow</strong></td>
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<tr>
<td>Full Sample</td>
<td>0.059</td>
<td>0.128</td>
<td>0.394</td>
<td>0.371</td>
</tr>
<tr>
<td>Young</td>
<td>0.043</td>
<td>0.115</td>
<td>0.411</td>
<td>0.384</td>
</tr>
<tr>
<td>Mature</td>
<td>0.108</td>
<td>0.153</td>
<td>0.335</td>
<td>0.336</td>
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<tr>
<td><strong>Dividends</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td>0.000</td>
<td>0.009</td>
<td>0.007</td>
</tr>
<tr>
<td>Young</td>
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<td>0.000</td>
<td>0.007</td>
<td>0.000</td>
</tr>
<tr>
<td>Mature</td>
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<td>0.000</td>
<td>0.014</td>
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<tr>
<td><strong>Δ Long-term debt</strong></td>
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<td></td>
</tr>
<tr>
<td>Full Sample</td>
<td>0.013</td>
<td>0.000</td>
<td>0.124</td>
<td>0.086</td>
</tr>
<tr>
<td>Young</td>
<td>0.014</td>
<td>0.000</td>
<td>0.128</td>
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<td>0.000</td>
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<td></td>
</tr>
<tr>
<td><strong>Δ Short-term debt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Sample</td>
<td>0.006</td>
<td>0.000</td>
<td>0.094</td>
<td>0.063</td>
</tr>
<tr>
<td>Young</td>
<td>0.007</td>
<td>0.000</td>
<td>0.096</td>
<td>0.065</td>
</tr>
<tr>
<td>Mature</td>
<td>0.005</td>
<td>0.000</td>
<td>0.089</td>
<td>0.057</td>
</tr>
<tr>
<td>Difference (p-value)</td>
<td>0.123</td>
<td>0.000</td>
<td></td>
<td></td>
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<tr>
<td><strong>Δ Cash balances</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Sample</td>
<td>0.047</td>
<td>0.001</td>
<td>0.312</td>
<td>0.287</td>
</tr>
<tr>
<td>Young</td>
<td>0.054</td>
<td>0.000</td>
<td>0.340</td>
<td>0.347</td>
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<tr>
<td>Mature</td>
<td>0.030</td>
<td>0.005</td>
<td>0.213</td>
<td>0.167</td>
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<td>Difference (p-value)</td>
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<tr>
<td><strong>Market-to-book</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Full Sample</td>
<td>3.395</td>
<td>2.131</td>
<td>4.013</td>
<td>6.694</td>
</tr>
<tr>
<td>Young</td>
<td>3.615</td>
<td>2.303</td>
<td>4.154</td>
<td>7.226</td>
</tr>
<tr>
<td>Mature</td>
<td>2.700</td>
<td>1.734</td>
<td>3.438</td>
<td>4.891</td>
</tr>
<tr>
<td>Difference (p-value)</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Firm size</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Sample</td>
<td>3.894</td>
<td>3.837</td>
<td>2.057</td>
<td>6.682</td>
</tr>
<tr>
<td>Young</td>
<td>3.672</td>
<td>3.689</td>
<td>1.909</td>
<td>6.170</td>
</tr>
<tr>
<td>Mature</td>
<td>4.625</td>
<td>4.533</td>
<td>2.336</td>
<td>7.838</td>
</tr>
<tr>
<td>Difference (p-value)</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Asset tangibility</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Sample</td>
<td>0.149</td>
<td>0.106</td>
<td>0.140</td>
<td>0.336</td>
</tr>
<tr>
<td>Young</td>
<td>0.142</td>
<td>0.097</td>
<td>0.140</td>
<td>0.326</td>
</tr>
<tr>
<td>Mature</td>
<td>0.172</td>
<td>0.140</td>
<td>0.135</td>
<td>0.361</td>
</tr>
<tr>
<td>Difference (p-value)</td>
<td>0.000</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
This table presents key statistics that describe high-tech firm R&D intensities and the share of finance from each source relative to total finance raised. Net finance is the sum of available internal cash (cash flow-change in cash balance), net long-term and short-term debt issues, and net equity issues.
<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>CF\textsubscript{t} Full Sample (without constraint; with own-lagged dependent variable)</th>
<th>CF\textsubscript{t} Full Sample (with constraint; with all lagged dependent variables)</th>
<th>Diff in CF\textsubscript{t} ( (2) - (1) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital expenditures\textsubscript{t}</td>
<td>0.0952*** (0.0001)</td>
<td>0.0453*** (0.0015)</td>
<td>-0.0499*** (0.0021)</td>
</tr>
<tr>
<td>R&amp;D\textsubscript{t}</td>
<td>0.1451*** (0.0001)</td>
<td>0.0704*** (0.0011)</td>
<td>-0.0747*** (0.0018)</td>
</tr>
<tr>
<td>Acquisitions\textsubscript{t}</td>
<td>-0.0060 (0.5446)</td>
<td>0.0385* (0.0582)</td>
<td>0.0445** (0.0491)</td>
</tr>
<tr>
<td>Asset sales\textsubscript{t}</td>
<td>-0.0003 (0.5486)</td>
<td>-0.0228 (0.4749)</td>
<td>-0.0225 (0.7052)</td>
</tr>
<tr>
<td>Equity issues\textsubscript{t}</td>
<td>0.0094 (0.1175)</td>
<td>-0.1211*** (0.0001)</td>
<td>-0.1305*** (0.0001)</td>
</tr>
<tr>
<td>Share repurchases\textsubscript{t}</td>
<td>0.0388*** (0.0001)</td>
<td>0.0962*** (0.0001)</td>
<td>0.0574*** (0.0001)</td>
</tr>
<tr>
<td>Dividends\textsubscript{t}</td>
<td>0.0023*** (0.0001)</td>
<td>0.0363** (0.0452)</td>
<td>0.0340* (0.0508)</td>
</tr>
<tr>
<td>( \Delta ) Long-term debt\textsubscript{t}</td>
<td>-0.0487*** (0.0001)</td>
<td>-0.1722*** (0.0001)</td>
<td>-0.1235*** (0.0001)</td>
</tr>
<tr>
<td>( \Delta ) Short-term debt\textsubscript{t}</td>
<td>-0.0361*** (0.0001)</td>
<td>-0.1314*** (0.0001)</td>
<td>-0.0953*** (0.0001)</td>
</tr>
<tr>
<td>( \Delta ) Cash balances\textsubscript{t}</td>
<td>0.2496*** (0.0001)</td>
<td>0.2658*** (0.0001)</td>
<td>0.0162 (0.2524)</td>
</tr>
</tbody>
</table>

| \( \Delta \) Uses\textsubscript{t}+\( \Delta \) sources\textsubscript{t} | 0.6004 | 1.000 |

**Table 4: Cash Flow Sensitivities: Constrained Multiequation Regressions.** This table presents coefficient estimates and differences in such estimates of firm cash flow from different models. Models are estimated over a sample of Compustat high-tech firms for the period of 1989-2010, which consists of 31,835 firm-year observations. Regressors in model (1) consist of cash flow, own-lagged dependent variable, market-to-book (as a proxy for \( q \)), and firm size. Imposing the constraint that sources and uses of cash must be equal, model (2) use regressors including cash flow, all lagged dependent variables, market-to-book (as a proxy for \( q \)), and firm size. Variables are defined in Appendix B. Regressions use first differences to remove firm fixed effects and subtract annual means from each variable to account for year fixed effects. In each regression, corresponding dependent variables dated \( t-3 \) and \( t-4 \) are used as instruments to account for the potential correlated error-regressor problem after first differencing. Firm-level residual clustering is controlled for in all regressions. The \( p \)-values of the estimated coefficients are reported in parentheses. The \( p \)-values of the differences are computed using a jackknife method proposed by Shao and Rao (1993). *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.
Table 5: Cash Flow Sensitivities: Constrained Multiequation Regressions (Young and Mature Firms). This table presents separate coefficient estimates and differences in such estimates of firm cash flow from different models, for the young and mature firm samples. Models are estimated over a sample of Compustat high-tech firms for the period of 1989-2010, which consists of 31,835 firm-year observations. Regressors in model (1) and (3) consist of cash flow, own-lagged dependent variable, market-to-book (as a proxy for $q$), and firm size. Imposing the constraint that sources and uses of cash must be equal, model (2) and (4) use regressors including cash flow, all lagged dependent variables, market-to-book (as a proxy for $q$), and firm size. Variables are defined in Appendix B. Regressions use first differences to remove firm fixed effects and subtract annual means from each variable to account for year fixed effects. In each regression, corresponding dependent variables dated $t - 3$ and $t - 4$ are used as instruments to account for the potential correlated error-regressor problem after first differencing. Firm-level residual clustering is controlled for in all regressions. The $p$-values of the estimated coefficients are reported in parentheses. The $p$-values of the differences are computed using a jackknife method proposed by Shao and Rao (1993). *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.
<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Positive Cash Flow Shocks</th>
<th>Negative Cash Flow Shocks</th>
<th>Diff in CF$_t$</th>
<th>CF$_t$ Young Firms</th>
<th>CF$_t$ Mature Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(2) – (1)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Capital expenditures$_t$</td>
<td>0.0421*** (0.0002)</td>
<td>0.0553*** (0.0001)</td>
<td>0.0132 (0.2736)</td>
<td>0.0438*** (0.0088)</td>
<td>0.0387** (0.0122)</td>
</tr>
<tr>
<td>R&amp;D$_t$</td>
<td>0.0655*** (0.0002)</td>
<td>0.0992*** (0.0001)</td>
<td>0.0337*** (0.0097)</td>
<td>0.0611** (0.0135)</td>
<td>0.0669** (0.0174)</td>
</tr>
<tr>
<td>Acquisitions$_t$</td>
<td>0.0393 (0.0837)</td>
<td>0.0441 (0.1226)</td>
<td>0.0048 (0.8899)</td>
<td>0.0311 (0.1112)</td>
<td>0.0413* (0.0869)</td>
</tr>
<tr>
<td>Asset sales$_t$</td>
<td>-0.0322 (0.2850)</td>
<td>-0.0398 (0.2434)</td>
<td>-0.0076 (0.8673)</td>
<td>-0.0189 (0.4534)</td>
<td>-0.0213 (0.4421)</td>
</tr>
<tr>
<td>Equity issues$_t$</td>
<td>-0.1705*** (0.0001)</td>
<td>-0.1196*** (0.0001)</td>
<td>0.0509*** (0.0064)</td>
<td>-0.0928*** (0.0006)</td>
<td>-0.1222*** (0.0002)</td>
</tr>
<tr>
<td>Share repurchases$_t$</td>
<td>0.0981*** (0.0001)</td>
<td>0.1297*** (0.0001)</td>
<td>0.0316* (0.0180)</td>
<td>0.0888*** (0.0002)</td>
<td>0.0797*** (0.0001)</td>
</tr>
<tr>
<td>Dividends$_t$</td>
<td>0.0177 (0.3310)</td>
<td>0.0186 (0.3453)</td>
<td>0.0009 (0.9732)</td>
<td>0.0577*** (0.0001)</td>
<td>0.0398*** (0.0001)</td>
</tr>
<tr>
<td>Δ Long-term debt$_t$</td>
<td>-0.1225*** (0.0001)</td>
<td>-0.0874*** (0.0001)</td>
<td>0.0351** (0.0256)</td>
<td>-0.1997*** (0.0001)</td>
<td>-0.2294*** (0.0001)</td>
</tr>
<tr>
<td>Δ Short-term debt$_t$</td>
<td>-0.1110*** (0.0001)</td>
<td>-0.0704*** (0.0001)</td>
<td>0.0406*** (0.0080)</td>
<td>-0.1698*** (0.0001)</td>
<td>-0.1605*** (0.0001)</td>
</tr>
<tr>
<td>Δ Cash balances$_t$</td>
<td>0.3011*** (0.0001)</td>
<td>0.3359*** (0.0001)</td>
<td>0.0348* (0.0460)</td>
<td>0.2063*** (0.0001)</td>
<td>0.2002*** (0.0001)</td>
</tr>
<tr>
<td>Δ Uses$_t$ + Δ sources$_t$</td>
<td>1.000</td>
<td>1.000</td>
<td></td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Observations</td>
<td>16,972</td>
<td>7,179</td>
<td></td>
<td>5,320</td>
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</tr>
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</table>

Table 6: Cash Flow Sensitivities: Young/Mature Firms with Positive/Negative Cash Flow Shocks. This table presents coefficient estimates and differences in such estimates of firm cash flow, based on four different subsamples of young/mature firms that experience positive/negative cash flow shocks. Models are estimated over a sample of Compustat high-tech firms for the period of 1989-2010, which consists of 31,835 firm-year observations. All dynamic multiequation regressions impose the constraint that sources and uses of cash must be equal. Dependent variables are a variety of firm decisions specified in equation (2). Explanatory variables consist of cash flow, all lagged dependent variables, market-to-book (as a proxy for q), and firm size. Variables are defined in Appendix B. Regressions use first differences to remove firm fixed effects and subtract annual means from each variable to account for year fixed effects. In each regression, corresponding dependent variables dated $t − 3$ and $t − 4$ are used as instruments to account for the potential correlated error-regressor problem after first differencing. Firm-level residual clustering is controlled for in all regressions. The p-values of the estimated coefficients are reported in parentheses. The p-values of the differences are computed using a jackknife method proposed by Shao and Rao (1993). *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.
Table 7.1: Residual Correlations across the System of Multiequation Regressions (Young Firms). This table presents the residual correlations across the system of multiequations estimated for young firms (column (2) of Table 5.) Models are estimated over a sample of Compustat high-tech firms for the period of 1989-2010, which consists of 31,835 firm-year observations. All dynamic multiequation regressions impose the constraint that sources and uses of cash must be equal. Dependent variables are a variety of firm decisions specified in equation (2). Explanatory variables consist of cash flow, all lagged dependent variables, market-to-book (as a proxy for $q$), and firm size. Variables are defined in Appendix B.
Correlation of Residuals across Equations for Mature Firms

<table>
<thead>
<tr>
<th>Residual</th>
<th>Capital Expenditures$_t$</th>
<th>R&amp;D$_t$</th>
<th>Acquisitions$_t$</th>
<th>Sales$_t$</th>
<th>Issues$_t$</th>
<th>Repurchases$_t$</th>
<th>Dividends$_t$</th>
<th>Δ Long-term debt$_t$</th>
<th>Δ Short-term debt$_t$</th>
<th>Δ Cash balances$_t$</th>
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</thead>
<tbody>
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</tr>
<tr>
<td>R&amp;D$_t$</td>
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<td></td>
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</tr>
<tr>
<td>Acquisitions$_t$</td>
<td>0.058***</td>
<td>0.038***</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Asset sales$_t$</td>
<td>0.091***</td>
<td>0.055***</td>
<td>0.023***</td>
<td>1.000</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Equity issues$_t$</td>
<td>0.051***</td>
<td>0.088***</td>
<td>0.075***</td>
<td>0.016***</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Share repurchases$_t$</td>
<td>0.048***</td>
<td>0.051***</td>
<td>0.044***</td>
<td>-0.023***</td>
<td>-0.077***</td>
<td>1.000</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Dividends$_t$</td>
<td>0.029***</td>
<td>0.037***</td>
<td>0.035***</td>
<td>-0.017***</td>
<td>0.034***</td>
<td>0.068***</td>
<td>1.000</td>
<td></td>
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</tr>
<tr>
<td>Δ Long-term debt$_t$</td>
<td>0.123***</td>
<td>0.189***</td>
<td>0.099***</td>
<td>0.048***</td>
<td>0.062***</td>
<td>0.105***</td>
<td>0.022***</td>
<td>1.000</td>
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</tr>
<tr>
<td>Δ Short-term debt$_t$</td>
<td>0.102***</td>
<td>0.144***</td>
<td>0.076***</td>
<td>0.039***</td>
<td>0.024***</td>
<td>0.093***</td>
<td>0.014***</td>
<td>0.111***</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Δ Cash balances$_t$</td>
<td>-0.049***</td>
<td>-0.042***</td>
<td>-0.093***</td>
<td>0.059***</td>
<td>0.057***</td>
<td>-0.046***</td>
<td>0.008***</td>
<td>0.072***</td>
<td>0.089***</td>
<td>1.000</td>
</tr>
</tbody>
</table>

Table 7.2: Residual Correlations across the System of Multiequation Regressions (Mature Firms). This table presents the residual correlations across the system of multiequations estimated for mature firms (column (4) of Table 5.) Models are estimated over a sample of Compustat high-tech firms for the period of 1989-2010, which consists of 31,835 firm-year observations. All dynamic multiequation regressions impose the constraint that sources and uses of cash must be equal. Dependent variables are a variety of firm decisions specified in equation (2). Explanatory variables consist of cash flow, all lagged dependent variables, market-to-book (as a proxy for $q$), and firm size. Variables are defined in Appendix B.
Table 8: Cash Flow Sensitivities: Constrained Multiequation Regressions Accounting for the Measurement Error in Q. This table presents coefficient estimates and differences in such estimates of firm cash flow from the constrained multiequation regressions, accounting for the measurement error in q. This is done by using the standard instrumental variables approach extended by Biorn (2000) (OLS-IV) and the Arrellano and Bond (1991) instrumental variables approach with GMM estimation in first differences (AB-GMM). For the AB-GMM approach, the p values of the Hansen test with the null that the overidentifying restrictions are valid are also reported. Models are estimated over a sample of Compustat high-tech firms for the period of 1989-2010, which consists of 31,835 firm-year observations. All dynamic multiequation regressions impose the constraint that sources and uses of cash must be equal. Dependent variables are a variety of firm decisions specified in equation (2). Explanatory variables consist of cash flow, all lagged dependent variables, market-to-book (as a proxy for q), and firm size. Variables are defined in Appendix B. Lagged level variables market-to-book, cash flow, and size, all of which are dated $t-3$ and $t-4$, are used as instruments in both the OLS-IV estimation and the AB-GMM estimation. Regressions use first differences to remove firm fixed effects and subtract annual means from each variable to account for year fixed effects. Firm-level residual clustering is controlled for in all regressions. The p-values of the estimated coefficients are reported in parentheses. The p-values of the differences are computed using a jackknife method proposed by Shao and Rao (1993). *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.
<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Positive Cash Flow Shocks</th>
<th>Negative Cash Flow Shocks</th>
<th>Diff in CF&lt;sub&gt;o&lt;/sub&gt;</th>
<th>Positive Cash Flow Shocks</th>
<th>Negative Cash Flow Shocks</th>
<th>Diff in CF&lt;sub&gt;o&lt;/sub&gt;</th>
<th>Positive Cash Flow Shocks</th>
<th>Negative Cash Flow Shocks</th>
<th>Diff in CF&lt;sub&gt;o&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>CF&lt;sub&gt;o&lt;/sub&gt; Infant Firms</td>
<td>CF&lt;sub&gt;o&lt;/sub&gt; Developing Firms</td>
<td>CF&lt;sub&gt;o&lt;/sub&gt; Mature Firms</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
<td>(7)</td>
<td>(8)</td>
<td>(9)</td>
<td>(10)</td>
</tr>
<tr>
<td>Capital expenditures&lt;sub&gt;o&lt;/sub&gt;</td>
<td>0.0572*** (0.0001)</td>
<td>0.0693*** (0.0001)</td>
<td>0.0121 (0.2799)</td>
<td>0.0541*** (0.0044)</td>
<td>0.0553*** (0.0008)</td>
<td>0.0012 (0.9566)</td>
<td>0.0441** (0.0051)</td>
<td>0.0392*** (0.0162)</td>
<td>-0.0049 (0.6729)</td>
</tr>
<tr>
<td>R&amp;D&lt;sub&gt;o&lt;/sub&gt;</td>
<td>0.0622*** (0.0001)</td>
<td>0.1029*** (0.0001)</td>
<td>0.0407** (0.0008)</td>
<td>0.0658*** (0.0005)</td>
<td>0.0891*** (0.00063)</td>
<td>0.0236*** (0.0056)</td>
<td>0.0585** (0.0251)</td>
<td>0.0617** (0.0268)</td>
<td>0.0032 (0.8018)</td>
</tr>
<tr>
<td>Acquisitions&lt;sub&gt;o&lt;/sub&gt;</td>
<td>0.0423 (0.0051)</td>
<td>0.0482 (0.2273)</td>
<td>0.0069 (0.8907)</td>
<td>0.0387 (0.2151)</td>
<td>0.0436 (0.2145)</td>
<td>0.0049 (0.9869)</td>
<td>0.0342 (0.0798)</td>
<td>0.0421 (0.0571)</td>
<td>0.0059 (0.7887)</td>
</tr>
<tr>
<td>Asset sales&lt;sub&gt;o&lt;/sub&gt;</td>
<td>-0.0372 (0.0038)</td>
<td>-0.0401 (0.1034)</td>
<td>-0.0029 (0.9255)</td>
<td>-0.0242 (0.5755)</td>
<td>-0.0335 (0.0517)</td>
<td>-0.0099 (0.8415)</td>
<td>-0.0248 (0.4179)</td>
<td>-0.0224 (0.3240)</td>
<td>-0.0036 (0.9234)</td>
</tr>
<tr>
<td>Equity issuance&lt;sub&gt;o&lt;/sub&gt;</td>
<td>-0.1937*** (0.0001)</td>
<td>-0.1263*** (0.0001)</td>
<td>0.0734*** (0.0089)</td>
<td>-0.1235*** (0.0002)</td>
<td>-0.1109*** (0.0001)</td>
<td>0.0126 (0.4735)</td>
<td>-0.0869*** (0.00005)</td>
<td>-0.1135*** (0.0002)</td>
<td>-0.0265 (0.1664)</td>
</tr>
<tr>
<td>Share repurchase&lt;sub&gt;o&lt;/sub&gt;</td>
<td>0.0903*** (0.0001)</td>
<td>0.1179*** (0.0001)</td>
<td>0.0276** (0.0077)</td>
<td>0.0810*** (0.0001)</td>
<td>0.0889*** (0.0001)</td>
<td>0.0079 (0.0227)</td>
<td>0.0745*** (0.0002)</td>
<td>0.0789*** (0.0002)</td>
<td>-0.0044 (0.6788)</td>
</tr>
<tr>
<td>Dividend&lt;sub&gt;o&lt;/sub&gt;</td>
<td>0.0157 (0.1650)</td>
<td>0.0174 (0.1642)</td>
<td>0.0017 (0.9197)</td>
<td>0.0437 (0.0570)</td>
<td>0.0412 (0.0414)</td>
<td>-0.0005 (0.6607)</td>
<td>0.0488*** (0.00001)</td>
<td>0.0433*** (0.00000)</td>
<td>-0.0455*** (0.00074)</td>
</tr>
<tr>
<td>Δ Long-term debt&lt;sub&gt;o&lt;/sub&gt;</td>
<td>-0.1021*** (0.0001)</td>
<td>-0.0793*** (0.0000)</td>
<td>0.0228 (0.0088)</td>
<td>-0.1546*** (0.0004)</td>
<td>-0.1338*** (0.0001)</td>
<td>-0.0206 (0.2068)</td>
<td>-0.2022*** (0.0001)</td>
<td>-0.2189*** (0.0001)</td>
<td>-0.0367 (0.5702)</td>
</tr>
<tr>
<td>Δ Short-term debt&lt;sub&gt;o&lt;/sub&gt;</td>
<td>-0.0985*** (0.0001)</td>
<td>-0.0684*** (0.0000)</td>
<td>0.0301*** (0.0031)</td>
<td>-0.1270*** (0.0001)</td>
<td>-0.1231*** (0.0006)</td>
<td>0.0039 (0.0089)</td>
<td>-0.1889*** (0.0001)</td>
<td>-0.1758*** (0.0001)</td>
<td>0.0131 (0.0584)</td>
</tr>
<tr>
<td>Δ Cash balance&lt;sub&gt;o&lt;/sub&gt;</td>
<td>0.0308*** (0.0001)</td>
<td>0.3362*** (0.0000)</td>
<td>0.3054*** (0.0031)</td>
<td>0.2874*** (0.0001)</td>
<td>0.3113*** (0.0000)</td>
<td>0.0229** (0.0088)</td>
<td>0.2031*** (0.00001)</td>
<td>0.2042*** (0.00000)</td>
<td>0.0031 (0.9740)</td>
</tr>
<tr>
<td>Δ Uses&lt;sub&gt;o&lt;/sub&gt; + Δ sources&lt;sub&gt;o&lt;/sub&gt;</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Observations</td>
<td>11.233</td>
<td>4.884</td>
<td>6.911</td>
<td>3.005</td>
<td>4.017</td>
<td>1.786</td>
<td></td>
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</tr>
</tbody>
</table>

Table 9: Cash Flow Sensitivities: Infant/Developing/Mature Firms with Positive/Negative Cash Flow Shocks. This table presents coefficient estimates and differences in such estimates of firm cash flow, based on six different subsamples of infant/developing/mature firms that experience positive/negative cash flow shocks. A firm is defined as "infant" for the 10 years following the year it first appears in Compustat with a stock price, and "developing" thereafter, for 20 years, at which point a firm is categorized as "mature." Models are estimated over a sample of Compustat high-tech firms for the period of 1989-2010, which consists of 31,835 firm-year observations. All dynamic multi-equation regressions impose the constraint that sources and uses of cash must be equal. Dependent variables are a variety of firm decisions specified in equation (2). Explanatory variables consist of cash flow, all lagged dependent variables, market-to-book (as a proxy for q), and firm size. Variables are defined in Appendix B. Regressions use first differences to remove firm fixed effects and subtract annual means from each variable to account for year fixed effects. In each regression, corresponding dependent variables dated t – 3 and t – 4 are used as instruments to account for the potential correlated error-regressor problem after first differencing. Firm-level residual clustering is controlled for in all regressions. The p-values of the estimated coefficients are reported in parentheses. The p-values of the differences are computed using a jackknife method proposed by Shao and Rao (1993). *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.
Table 10: Percent of Young and Mature Firms in Index Quartiles. This table presents the percent of young and mature firms in each index quartile based on the WW index and the KZ index. Statistics are calculated for a sample of Compustat high-tech firms for the period of 1989-2010, which consists of 31,835 firm-year observations. The WW index is an index of financial constraints from Whited and Wu (2006), and the KZ index is an index of financial constraints from Kaplan and Zingales (1997). Constructions of KZ and WW indices are presented in Appendix C. For both indices, higher values indicate a greater likelihood both of needing external finance and facing costly external finance.

<table>
<thead>
<tr>
<th>Index Quartile</th>
<th>Percent (Young/Mature) WW</th>
<th>Percent (Young/Mature) KZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.17%/41.03%</td>
<td>26.07%/21.35%</td>
</tr>
<tr>
<td>2</td>
<td>22.98%/21.76%</td>
<td>25.01%/24.98%</td>
</tr>
<tr>
<td>3</td>
<td>28.59%/19.72%</td>
<td>24.89%/25.36%</td>
</tr>
<tr>
<td>4</td>
<td>30.27%/17.49%</td>
<td>24.02%/28.31%</td>
</tr>
</tbody>
</table>

Table 11: Regressions with Alternative Empirical Specifications. This table presents the regression results from alternative empirical specifications, which are obtained by modifying an investment regression model in Hennessy et al. (2007). Models are estimated over a sample of Compustat high-tech firms for the period of 1989-2010, which consists of 31,835 firm-year observations. Regressions use first differences to remove firm fixed effects. Annual means are subtracted from each variable to account for year fixed effects. Firm-level residual clustering is controlled for in all regressions. Standard errors are reported in parentheses. The dependent variable is $R&D_{i,t}$. Tobin’s $q$ is proxied by the market-to-book ratio. The potential measurement error in $q$ is treated by using lagged market-to-book ratios dated $t-3$ and $t-4$ as instruments. Definitions of financial variables are provided in Appendix B. Constructions of KZ and WW indices are presented in Appendix C. The debt overhang correction $OC$ is the imputed market value of lenders’ recovery claim in default normalized by the capital stock. The WW index is an index of financial constraints from Whited and Wu (2006), and the KZ index is an index of financial constraints from Kaplan and Zingales (1997). For both indices, higher values indicate a greater likelihood both of needing external finance and facing costly external finance. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.
**Figure 1: U.S. R&D for 1953-2008.** This figure presents various statistical facts about R&D investment in the U.S. Figure A documents the total annual U.S. R&D expenditures in constant year-2000 dollars for the period of 1953-2008. Figure B presents the shares of R&D performed and funded by business and non-business sectors in the U.S. for the period of 1953-2008. Non-business sectors consist of the federal government, universities and colleges, and nonprofit organizations. Raw data are collected from the National Science Foundation, Division of Science Resources Statistics (NSF/SRS), Research and Development in Industry 2007; Academic Research and Development Expenditures: FY 2008; Federal Funds for Research and Development: FY 2007–09; and Research and Development Funding and Performance by Nonprofit Organizations: FY 1996–97.
Figure 2: U.S. R&D Share of GDP for 1953-2008, and U.S. R&D and the Worldwide Total of R&D for 1996-2007. This figure documents statistics of R&D investment in the U.S. and in the world. Figure A presents the annual U.S. R&D as a fraction of GDP for the period of 1953-2008. Figure B presents the annual R&D expenditures in the U.S. and the worldwide total of R&D for the period of 1996-2007. Raw data are provided by the National Science Foundation, Division of Science Resources Statistics, National Patterns of R&D Resources (annual series), and United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics.