Financing Innovation and Growth: Cash Flow, External Equity and the 1990s R&D Boom

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Abstract
Recent endogenous growth models link finance and innovation, but there is no micro empirical
evidence that financing matters for aggregate R&D. U.S. high-tech firms finance R&D from
volatile sources: cash flow and stock issues. We estimate dynamic R&D models for high-tech
firms that collectively account for two thirds of aggregate R&D. We find significant effects of
cash flow and external equity for young, but not mature, firms. The financial coefficients for
young firms are large enough that finance supply shifts can explain most of the dramatic 1990s
R&D boom. These results highlight a key connection between finance and economic growth.

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I. Introduction

The rate of technological change has long been considered a key determinant of economic growth. In recent years, an explosion of literature on endogenous growth focuses on technological change created by the R&D activities of profit-maximizing firms. Among the pioneering contributions are Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992). A compelling feature of R&D is that knowledge created by one firm may spill over to many firms, possibly overcoming diminishing returns to produced factors. An additional feature of R&D is that it may be difficult to finance with external sources (e.g., Arrow 1962). Recent efforts have been made to incorporate financing into models of endogenous growth and technological change, such as King and Levine (1993), De la Fuente and Marin (1996), Morales (2003), Aghion, Howitt, and Mayer-Foulkes (2005), and Aghion, Angeletos, Banerjee, and Manova (2005). While a small number of empirical studies suggest that some firms face financing constraints for R&D (see Hall 2002), no studies have examined whether financing matters for enough firms to impact aggregate R&D and therefore to affect economic growth.

In the U.S., R&D investment is financed largely by cash flow and public share issues. This reliance on internal and external equity finance is not surprising since, for R&D-intensive firms, information problems, high variance of returns, and lack of collateral value make debt a poor substitute for equity finance. One implication is that shifts in the supply of internal or external equity finance will lead to changes in R&D investment for financially constrained firms. If firms that face financing constraints undertake a large fraction of aggregate R&D, economy-wide changes in the availability of finance will have macroeconomic significance. In particular, booms and busts in the availability of finance may lead to booms and busts in aggregate R&D.

We argue that the U.S. has recently experienced a finance-driven cycle in R&D. From 1994 to 2004, there was a major boom and bust in both cash flow and the market for new share issues. During the same period, there was also a dramatic boom, and subsequent decline, in R&D: the ratio of privately financed, industrial R&D to GDP rose from 1.40 percent in 1994 to an all-time high of 1.89 percent in 2000 before declining to an average of 1.70 percent from 2002 to 2004. The NSF reports that the 2002 decline in the R&D-GDP ratio was the largest reduction since it began its survey in 1953. To our
knowledge, this is the first paper to study this significant R&D cycle. In particular, previous research has not examined the role of finance in the recent boom and decline of aggregate R&D investment.

As we will show, just seven high-tech industries (drugs, office equipment and computers, electronic components, communication equipment, scientific and medical instruments, and software) accounted for virtually all of the 1990s U.S. R&D boom. Figures 1a-1c present aggregated R&D investment and financing information for publicly traded firms in these industries (all figures in millions of 2000 dollars). Figure 1a shows R&D (heavy line) for all firms while figures 1b and 1c provide separate data for young firms (publicly traded for 15 years or less) and mature firms (publicly traded for more than 15 years). For all firms, R&D spending rose smoothly between 1980 and 1993, accelerated between 1994 and 2000, and then slowly declined between 2001 and 2004. Figure 1b shows young-firm R&D rising sharply above trend starting in 1994 and then declining substantially beginning in 2001. As discussed in the next section, for the six years at the top of the boom (1996-2001) young-firm R&D averaged 65 percent above a geometric trend fit to data from 1980 to 1993, but it fell below the trend by 2003. Figure 1c shows little or no break in trend for mature-firm R&D between 1994 and 2004. The evidence we present shows that young high-tech firms accounted for the entire 1990s boom and subsequent decline in economy-wide R&D.

The recent boom and bust in both cash flow and external equity finance for these seven high-tech industries are also striking in figures 1a-1c. As figure 1a shows aggregate internal finance (cash flow) for publicly traded firms (dashed line) increased from $89 billion to $231 billion between 1993 and 2000, and then collapsed in 2001 and 2002. The volatility of cash flow is a well-documented feature of business cycles and is due, in part, to the fact that a large share of costs in modern firms are quasi-fixed, so relatively small changes in sales can lead to large changes in the supply of internal finance. There was also a dramatic rise, and fall, in external public equity finance in the late 1990s and early 2000s (solid line). Between 1998 and 2000, public equity finance for the seven high-tech industries increased from $24 billion to $86 billion, but then plummeted by 62 percent in 2001. One possible explanation for the recent external equity cycle, explored in a rapidly growing literature, is that stock market “mispricing” on the NASDAQ sharply reduced the cost of public equity finance in the late 1990s for high-tech firms, leading to a shift in the supply of external equity finance.
The central question in this paper is whether supply shifts in both internal and external equity finance can explain a significant part of the 1990s boom and subsequent decline in aggregate R&D. To meet this objective, we use a Generalized Method of Moments procedure, similar to Bond and Meghir (1994) and Bond, et al. (2003), to estimate dynamic R&D investment models. We examine a panel of 1,347 publicly traded firms in the seven high-tech industries from 1990 to 2004. In pooled regressions, both internal and external equity finance appear to play an important role in explaining R&D investment. We find, however, very sharp differences when we disaggregate the data into young and mature firms. For mature firms, the point estimates for the equity finance variables are statistically insignificant and quantitatively unimportant. For young firms, the point estimates for both cash flow and external equity finance are quantitatively large, similar in size, and highly statistically significant. Furthermore, the financial coefficients are large enough that the financial cycles for young, high-tech firms alone, evident in figure 1b, can explain about 75 percent of the aggregate R&D boom and subsequent decline.

Our interpretation of the results is that shifts in the supply of internal and external equity finance in the 1990s relaxed financing constraints that restricted R&D for young firms. Of course, new technological opportunities during this period also could have led to a demand shift for R&D. To identify the supply effect, our approach accounts for demand in a variety of ways. First, we employ a structural specification that controls for expectations that might affect investment demand. Second, the results do not change in any significant way when we include industry-level time dummies that control for all time-varying demand shocks at the industry level. Third, although demand shocks presumably affected all firms in these industries, we find significant financial effects for young firms only, which is inconsistent with the view that the financial effects proxy for some kind of unobserved demand shift. Finally, the R&D boom and bust was confined entirely to young firms, consistent with the supply interpretation.

Our findings have implications for several important economic issues. First, the results suggest a chain of events that may have played an important causal role in the recent U.S. productivity boom. We propose that shifts in cash flow and external equity supply led to an unprecedented R&D boom, which likely contributed to the surge in labor productivity associated with the “new economy” of the late 1990s. Second, because the corporate tax system affects after-tax cash flow, our findings highlight a potentially important channel through which business tax policies affect R&D investment. The impact of corporate
tax reform will be greater than predicted by standard models that consider only the traditional cost of capi
tal effects of tax policy if, as our results imply, changes in cash flow affect aggregate R&D. Third,
our findings have implications for the large literature on finance and economic growth (see the survey by
Levine, 2005), particularly the portion of this literature exploring the role of financial intermediation and
credit constraints. While there are good reasons to focus on debt and credit constraints, our results
suggest that more attention should be placed on the role of internal and external equity finance,
particularly for growth models that emphasize innovation. Fourth, although empirical studies on finance
and growth have examined the potential impact of stock markets, they do not emphasize (or test for) the
stock market as a source of finance. Our evidence suggests that stock markets can be an important source
of funds. Finally, our findings have implications for assessing the debate about the relative merits of
bank-lending versus market-based financial systems.

The next section of the paper discusses background material on R&D and equity finance. Section
three motivates the empirical tests and section four describes the dynamic econometric model and
estimation procedure. Section five discusses the panel data and provides summary statistics on
investment and sources of finance. Section six presents our empirical findings. Section seven discusses
several implications of our findings and section eight summarizes the paper.

II. R&D and Equity Finance

A. R&D and Growth: Testing for Financial Linkages

R&D is central to much of the modern literature on endogenous growth.¹ For example, Romer
(1990, pp. 74-75) stresses that new technology is a non-rivalrous input with incomplete excludability.
The resulting spillovers could be strong enough to overcome decreasing returns to capital that limit the
economic factors affecting long-run growth in the traditional Solow model. Similarly, in “Schumpeterian
competition” models (e.g., Aghion and Howitt, 1992), the knowledge created by a successful innovator
becomes common knowledge for the next wave of challengers. A large body of supporting empirical
evidence indicates that R&D spillovers can be substantial (see the reviews in Griliches, 1992 and Jaffe,
1996). Jones and Williams (1998) link the theoretical models of new growth theory to the empirical
findings in the productivity literature and find that previous estimates of social returns to R&D of 30

¹ See Barro and Sala-i-Martin (1995) and Aghion of Howitt (1998 and 2005) for excellent reviews of the literature.
percent or more should be viewed as lower bounds. They report (p. 1121) that the “optimal R&D spending as a share of GDP is more than two to four times larger than actual spending.”

As noted above, a number of recent studies have sought to incorporate financing into models of innovation and endogenous growth. The most obvious channel for exploring the role of finance for technological change is the financing of R&D, which is likely the most important determinant of innovation. While there are a handful of empirical studies (see below) that have found a link between R&D investment and access to finance, these studies provide no information concerning whether access to finance matters for aggregate R&D. As we document below, high-tech R&D in the U.S. is financed almost entirely by both internal and external equity finance. Whether access to finance is a binding constraint on enough of these firms to have an aggregate effect on R&D is completely unknown. We explore this question by examining the role of equity finance in the recent R&D cycle. Did supply shifts relax financing constraints for enough firms to bring about an R&D boom? If so, our findings suggest that access to finance should play an important role in models of innovation and endogenous growth.

B. The 1990s R&D Boom and Subsequent Decline

The 1990s boom and decline after 2000 in private R&D spending is likely without precedent. According to the National Science Foundation survey, aggregate privately financed R&D rose smoothly from 1953 through 1969 until a sluggish period in the early 1970s. There were then three distinct waves of R&D growth. The annualized trough-to-peak real growth rate in the final wave, 1994-2000, was 9.2 percent, greatly exceeding the growth rates of the first two waves.\(^2\) Between 1994 to 2000, the R&D-GDP ratio rose extremely rapidly, reaching an all-time peak of 1.89 percent in 2000, 35 percent greater than the 1994 figure. The R&D-GDP ratio declined modestly (to 1.86) in 2001 and then fell sharply (to 1.72) in 2002. The 2002 decline, as noted in the NSF report, was the largest single-year absolute and percentage reduction in the R&D-GDP ratio since the survey began in 1953. The R&D-GDP ratio was largely unchanged in 2003 (1.69) and 2004 (1.70), numbers that are high by historical standards but still considerably below the levels of 2000 and 2001.

Unlike other types of investment, R&D is highly concentrated in just a few high-tech industries: drugs, office equipment and computers, electronic components, communication equipment, scientific and

\(^2\) The respective growth rates of the first two waves were 6.8 percent (1975-1986) and 5.4 percent (1987-1992). See National Patterns of R&D Resources, National Science Foundation (annual series).
medical instruments and software. Furthermore, within these industries, virtually all of the R&D is undertaken by publicly traded firms. Figure 2 plots R&D investment in billions of 2000 dollars (solid line) for all publicly traded firms listed in Compustat from 1980 to 2004. The dotted line is the level of R&D for all firms excluding those in the seven high-tech industries. Three facts stand out. First, the high-tech share of R&D is very large, particularly in the last fifteen years. For example, between 2001 and 2003, the seven high-tech industries accounted for approximately 68 percent of all corporate R&D in the U.S. Second, there is a sharp acceleration in economy-wide R&D investment starting in 1994 and ending in 2000. Third, the seven high-tech industries account for virtually all of the cycle in aggregate R&D between 1994 and 2004.

As discussed in the introduction, figures 1b and 1c suggest that young high-tech firms accounted for nearly all of the 1990s R&D boom and subsequent decline. This fact is central to our paper. To estimate the boom quantitatively, we fit a geometric trend from 1980 to 1993 to real R&D for both young and mature firms. The trend annual growth rates over this 14-year period are a robust 7.5 percent for mature firms (figure 1c) and a remarkably high 11.8 percent for young firms (figure 1b). The trends fit quite well (R² of 0.99 for young firms, 0.96 for mature firms). We then project what post-1993 R&D investment would have been if it had continued to grow along the estimated trend. In 1994 young high-tech firms’ R&D began to pull away from the estimated trend. For the six years from 1996 through 2001, the level of young firm R&D plotted in figure 1b averaged 65 percent above the value predicted by a trend that already incorporated almost 12 percent annual growth. These numbers provide clear evidence of a very large R&D boom for young firms. In 2002, however, the boom came to an abrupt end. R&D dropped so rapidly that it fell below the trend by 2003 and 2004. In contrast to this dramatic cycle, mature-firm R&D continued to grow at very close to the pre-1994 trend rate. From 1994 through 2004 R&D for mature firms deviated from the pre-1994 trend by an average of just -4.2 percent per year. For these reasons, we argue that the high-tech R&D boom was confined entirely to young firms, and, as figure 2 shows, high-tech R&D explains virtually all of the aggregate R&D cycle.

The existing literature has little to say about the potential causes of an aggregate boom in R&D. In particular, an R&D boom is more difficult to explain than a boom in fixed investment because R&D

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3 The sum of R&D for the publicly traded firms tracked by Compustat was equal to 90.1 percent of industrial R&D reported by the NSF for 2003.
likely has a substantial gestation period before it becomes productive. This is obviously true of industries such as pharmaceuticals, but there is also evidence of long gestation periods for the typical high-tech industry. With sufficiently long gestation lags, periods of high cyclical demand will have little or no impact on the firm’s demand for R&D. We argue below, however, that shifts in the supply of R&D finance can explain the emergence (and end) of an R&D boom. The financing hypothesis also makes sharp predictions about why the boom and bust will be concentrated in young firms.

C. Financing R&D: The Role of Internal and External Finance

Financing constraints, if they exist, may restrict R&D more than other forms of investment. Reasons for this include the lack of collateral value for the R&D “capital” and firms’ need to maintain secrecy (even from potential investors) because of appropriability problems. Compared to the vast literature testing for the presence of financing constraints on physical investment, relatively few studies consider financing constraints on R&D. An excellent review of the existing literature appears in Hall (2002). Some studies find evidence suggesting that firms in the U.S. face financing constraints for R&D, including Hall (1992) and Himmelberg and Petersen (1994). Previous studies have not, however, explored the implications of financing constraints for aggregate R&D. Nor have previous studies typically examined the role of public equity as a source of finance.

Financial economists have long argued that it is difficult to finance R&D investments with debt. Hall (2002, p. 12) concludes that “the capital structure of R&D-intensive firms customarily exhibits considerably less leverage than that of other firms,” an observation strongly confirmed in our data. There are several reasons why young, high-tech firms obtain little or no debt finance. First, the structure of a debt contract is not well suited for R&D-intensive firms with uncertain and volatile returns. Creditors do not share in firms’ returns in the very good states, and thus “lenders are only concerned with the bottom part of the tail of the distributions of returns” (Stiglitz, 1985, p. 146). Second, adverse selection problems

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4 Ravenscraft and Scherer (1982) report mean gestation lags of four to six years. Also see Griliches (1979, p. 101).
5 Hall (2002) also surveys studies that examine R&D and financing constraints for other countries. Bond, Harhoff and Van Reenen (2003) compare U.S. and German firms and find that cash flow affects R&D and investment for large U.S. firms but not for German firms. Mulkay, Hall and Mairese (2001) compare French and U.S. firms and find that cash flow effects are much larger in the U.S.
(as discussed, for example, in Stiglitz and Weiss, 1981) are more likely in high-tech industries due to the inherent riskiness of investment. Third, debt financing can lead to *ex post* changes in behavior (moral hazard) that are likely more severe for high-tech firms because of their greater ability to substitute high-risk for low-risk projects. Fourth, the expected marginal cost of financial distress rises rapidly with greater leverage for young high-tech firms because their market value depends heavily on future growth options that rapidly depreciate if they face financial distress (see Cornell and Shapiro, 1988). Finally, the limited collateral value of intangible assets should greatly restrict the use of debt: risky firms typically must pledge collateral to obtain debt finance (Berger and Udell, 1990).

Equity finance has several advantages over debt for young high-tech firms. For both internal and external equity finance, shareholders share in upside returns, there are no collateral requirements, and additional equity does not magnify problems associated with financial distress. In addition, internal equity finance does not create adverse selection problems. Internal and external equity finance are not, however, perfect substitutes. Public stock issues incur sizeable flotation costs. In addition, as developed in Myers and Majluf (1984), new share issues may require a “lemons premium” due to asymmetric information, and evidence suggests that this premium can be substantial. Brealey and Myers (2000, p. 423) write that “[m]ost financial economists now interpret the stock price drop on equity issue announcements as an information effect.” Nevertheless, because of the other advantages of equity finance over debt, together with the nearly total absence of debt financing, external equity finance is the more relevant substitute for internal cash flow for young, high-tech firms. In spite of its potential advantages, public equity finance has been largely ignored in the literature.  

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7 One reason is the limited role of public equity, particularly for small firms, throughout much of the 20th century (see the discussion in Jovanovic and Rousseau, 2002). Furthermore, aggregate statistics show that, in recent decades, net external equity issues have been small in the U.S. economy. Large firms, however, often use stock buybacks to distribute earnings to shareholders which reduces aggregate net new equity figures (see Brealey and Myers, 2000, table 14.1). The aggregate net equity figures obscure the fact that some firms make extensive use of follow-up stock issues to raise finance in the early stage of their life cycle (e.g., Rajan and Zingales, 1998). Over the last three decades, there has been a sharp upward trend in public equity issues. Jay Ritter (http://bear.cba.ufl.edu/ritter/seoall.html) identifies 1,082 seasoned offerings in the 1970s, 2,468 offerings in the 1980s, and 4,867 offerings in the 1990s. A large fraction of offerings occur in the high-tech sectors (Loughran and Ritter, 1995). Brown (2006), Fama and French (2005) and Frank and Goyal (2003) also present facts on the use of public equity finance.
D. The Financing Hierarchy for R&D

The supply of funds schedules in figure 3 depict a simple financing hierarchy based on the ideas presented in the previous subsection. The quantity of finance is measured on the horizontal axis, and the marginal cost of funds is measured on the vertical axis. The quantity of available internal finance is \( CF \) (cash flow). The marginal opportunity cost of internal finance is \( MCCF \). The firm exhausts internal equity financing first, and then, if demand for funds is high enough, turns to external equity.\(^8\) The vertical jump of the marginal cost of finance at the point where the firm exhausts internal funds reflects both issue costs as well as any lemons premium incurred by the initial issue of new shares. The schedule is upward sloping beyond \( CF \) because information asymmetries become more severe as the amount of funds raised increases. One reason is that quasi-insiders will likely have better information about the firm’s true prospects and therefore demand smaller lemons premia than the typical supplier of finance. In addition, in recent years, there are usually just a few analysts that specialize in tracking any given small, high-tech firm.\(^9\) Evidence from Asquith and Mullins (1986, table 7) is consistent with an upward sloping supply curve for external equity. They find that the announcement-day excess return for new share issues is inversely related to the size of the planned issue: the greater the amount of funds raised, the larger the percentage loss in firm market value.

We expect differences in the cost premium for external equity between young and mature firms. As a firm matures, it establishes relationships that likely lower the transaction costs of external finance. Also, mature firms have a longer track record, allowing outsiders to more easily assess true market values. These factors suggest a smaller premium for initial equity issues, and a more elastic supply of external equity if mature firms seek external funds. In addition, the slope of the supply schedule for external equity is irrelevant for mature firms if their cash flow from established operations is large enough to finance their entire investment demand.

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\(^8\) The emphasis on external equity finance, rather than debt, as the form of external finance is the primary departure here from the standard financing hierarchy (see Hubbard, 1998, for example).

\(^9\) The paucity of analysis means that a small number of potential buyers may have information advantages over the rest of the market. The extent of these information advantages determines the supply elasticity of external equity finance for a particular firm. Alternatively, potential purchasers of new share issues may have different views about the firms’ prospects. But the investors with the most favorable perceptions will not provide unlimited funds to any single firm because they want to maintain diversification. Therefore, the more funds a firm chooses to raise, the more it will need to entice investors with less favorable views, pushing the marginal cost of equity issues higher as the quantity rises.
E. Fluctuations in the Supply of Internal and External Equity Finance

In the mid and late 1990s, there was a strong boom in corporate income, the largest component of internal finance. Economy-wide profits, however, stagnated in 2000 and collapsed in 2001 (falling 87 percent) but did recover by 2004.\(^\text{10}\) This economy-wide experience mirrors the behavior of the aggregated cash flow data for the seven high-tech industries in our study. For young high-tech firms it is apparent from figure 1b that there was a dramatic boom in cash flow beginning in 1994. For the six years from 1995 through 2000, the level of cash flow averaged 90 percent above the value predicted by the 1980-1993 exponential trend, peaking at 122 percent above trend in 1999. After 2000, young-firm cash flow collapses, although it recovers at the very end of our sample. Mature firms also experience a significant cash flow boom beginning in 1994.

It has been widely documented that corporate income (and therefore internal finance) is highly volatile.\(^\text{11}\) One explanation is the presence of quasi-fixed costs combined with the fact that corporate income is a small fraction of corporate revenues and costs. The 1990s internal finance boom was likely the result of a number of favorable, but temporary, shocks to revenues combined with quasi-fixed costs.\(^\text{12}\) For the modern corporation, most of labor costs are likely quasi-fixed. One reason is that hiring and training costs can be very large. Goldin (2000, p. 585) argues that while labor markets in the early part of the 20th century can be categorized as spot markets, labor markets at the end of the 20th century have substantial investment in human capital, labor hoarding, and job security. This is particularly true for highly skilled workers, the preponderance of employees at high-tech firms. The consequence is that relatively modest percentage changes in revenue can lead to very large percentage changes in income and therefore large changes in the supply of internal equity finance.

In addition to the major shifts in cash flow, fluctuations in the supply of external equity for the seven high-tech industries were also dramatic during the period that we study. Figures 1a-1c provide information for net public equity issues where negative issues (buybacks) are set equal to zero. Figure 1b shows that 1999 and 2000 were boom years for share issues by young firms, followed by a bust starting in

\(^{10}\) Data from the Census Bureau Quarterly Financial Reports, various issues. Nominal profits data are deflated by the GDP chain-weighted price index.

\(^{11}\) Wesley Mitchell (1951, p. 286) reports that the percentage change in business income over the business cycle was several times greater than any other macroeconomic series in his study.

\(^{12}\) Nominal and real interest rates were low together with low commodity prices, particularly oil. Real wages were stagnant or falling for most of the 1990s with only modest growth at the end of the decade.
2001. Between 1994 and 1996, young firms collectively increased their net stock issues by nearly 200 percent. Starting from this high base, young firms again increased their stock issues by nearly 265 percent between 1998 and 2000. In 2000, net stock issues by young firms in the seven high-tech industries were so large that they accounted for nearly half of net issues in the entire economy. Young-firm stock issues then fell by more than 83% between 2000 and 2002. Almost all of the young high-tech firms trade on the NASDAQ. The large swings in stock issues line up well with the dramatic swing in NASDAQ stock prices: the NASDAQ Index stood at 743 at the start of 1995, 1,574 at the start of 1998, and was above 4,000 for much of 2000 (breaking 5,000 briefly), only to bottom out at approximately 1,100 in August, 2002.

This correspondence between dramatic cycles in share issues and stock prices was probably not a coincidence. Many financial economists have argued that there was a bubble in the NASDAQ in the late 1990s. An extensive literature shows that stock-market mispricing can lower the cost of external equity finance and increase the availability and use of public equity. For example, Morck, Shleifer, and Vishney (1990, p. 160) note that overpriced equity lowers the cost of capital and may allow financially constrained firms the opportunity to issue shares and increase investment. Baker and Wurgler (2000) find that firms are more likely to issue equity when stock prices are high, and Loughran and Ritter (1995, p 46) state that their “evidence is consistent with a market where firms take advantage of transitory windows of opportunity by issuing equity, when, on average, they are substantially overvalued.” A natural question is whether deviations of stock prices from fundamentals impact firm investment. Baker, Stein and Wurgler (2003, p. 970), based on a model in Stein (1996), argue “that those firms that are in need of external equity finance will have investment that is especially sensitive to the non-fundamental component of stock prices.” They present empirical findings that mispricing affects investment most for equity-dependent firms. Polk and Sapienza (2004) find that firm physical investment is positively related to a

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13 A large body of evidence has emerged consistent with the view that stock prices can be influenced by changes in investor sentiment that are independent of market fundamentals. For example, Bond and Cummins (2000, p. 100) study stock prices and intangible investment in the U.S. in the 1980s and 1990s and conclude that there are “serious anomalies in the behavior of share prices.” A number of theoretical models explain bubbles in stock prices. In one class of models, investors face constraints on their ability to sell short, causing prices to disproportionately reflect the views of the most optimistic sellers (e.g., Chen, Hong and Stein, 2002). In these models, increases in the dispersion of beliefs about fundamental values can lead to bubbles. Sadka and Scherbina (2007) point to trading costs among stocks with high analyst disagreement about future earnings as one explanation for persistent mispricing. Wurgler and Zhuravskaya (2002) and Kumar and Lee (2006) also study the potential link between costly arbitrage and mispricing.
number of proxies for mispricing and that investment is most sensitive to mispricing for firms with higher R&D intensities. Gilchrist, Himmelberg, and Huberman (2005) examine the impact of an increase in dispersion in beliefs about stock market valuation on both the cost of capital and corporate investment. They show that an increase in dispersion leads to a lower cost of capital for firms that exploit the mispricing by issuing shares.\textsuperscript{14}

A key implication of this research for our work is that mispricing changes the cost of equity capital and shifts the supply curve for external equity. Many public firms in the late 1990s likely enjoyed overpriced (or less underpriced) stock.\textsuperscript{15} Thus, in the mid and late 1990s, there were arguably major rightward shifts in the supply of both internal and external equity finance, and these shifts reversed sharply (at least temporarily) after 2000.

\textbf{III. Theoretical Predictions and Empirical Implications}

This section uses a simple graphical model to motivate the hypotheses that we test in our empirical work. The demand curves for R&D in figures 3a and 3b are based on the firm’s ranking of potential projects. The equilibrium level of R&D for the representative firm equates this demand with the supply of finance discussed previously. In figure 3a, a rise in cash flow slides the supply of low-cost internal equity out from CF\textsubscript{0} to CF\textsubscript{1}. Consider three different cases for how this shift affects equilibrium financing and R&D. First, for firms that use external equity as their marginal source of funds, like the one depicted in figure 3a, the shift increases R&D.\textsuperscript{16} Second, if a firm’s R&D demand curve intersects the vertical segment of the supply curve it will increase R&D when cash flow rises. Third, if a firm has adequate internal funds to finance all of its desired R&D, its demand curve intersects the horizontal segment of supply (to the left of CF\textsubscript{0}), and it will not change R&D in response to a rise in cash flow. We define firms as financially constrained in the first two cases.

\textsuperscript{14} Chirinko and Schaller (2001) present evidence that a stock price bubble in Japan in the late 1980s and early 1990s affected Japanese fixed investment.

\textsuperscript{15} Bond and Cummins (2000, p. 100) found a growing (upward) departure of stock prices from fundamentals in the late 1990s, noting that “even when we account for the role of intangible investment, there is a wide, and growing, gap between the market valuation of firms and valuation based on expected future profits.”

\textsuperscript{16} External equity may be the marginal source of funds for a firm even if it does not issue new shares every year. Because of the high fixed transaction costs of new equity issues, firms will likely bunch their share issues, but will still face the cost of new share issues as the marginal cost of finance.
Figure 3b shows a rightward shift in the supply of external equity finance. Such a shift could be caused by a reduction in the lemons premium or, as discussed in section II.E, a period of stock mispricing. Again, for a firm that uses external equity as the marginal source of funds for R&D, the change in the external equity supply curve raises R&D spending. It is also possible that a firm that was initially on the vertical segment of supply (i.e., not issuing shares) would decide to sell new shares and increase R&D after the rightward supply shift. Firms that did not exhaust internal cash flow before the supply shift would not change R&D.

This model suggests heterogeneity across firms in how R&D responds to changes in the supply of internal and external finance. As the summary statistics in table 1 below show, the firms we classify as mature have, on average, adequate internal finance to cover their investment and make virtually no use of external finance. The model predicts that the R&D for these firms will not respond to changes in the supply of cash flow or external equity. In contrast, young firms in our sample use external finance extensively. For these firms, binding financing constraints will make R&D sensitive to changes in both internal and external equity finance.

This kind of heterogeneity has been widely used to test for the existence of financing constraints. Kaplan and Zingales (1997), however, have criticized these tests. The Kaplan-Zingales approach assumes that all firms face binding financial constraints, and they provide a theoretical example in which firms that face a steeper supply schedule for external funds could have a lower sensitivity of investment to internal finance. Bond, et al. (2003, p. 154) argue, however, that it “remains the case in [the Kaplan-Zingales] model that a firm facing no financial constraint (no cost premium for external finance) would display no excess sensitivity to cash flow,” in which case the Kaplan-Zingales criticism of heterogeneity tests does not apply.17 The summary statistics and regression results we present below are consistent with an absence of binding financing constraints for the firms that we classify as mature.

According to the model depicted in figures 3a and 3b, R&D should rise less than dollar for dollar in response to a change in finance for firms that use external equity as their marginal source of funds. The magnitude of the response depends on the slope of both the supply and demand curves. There are, however, other reasons why the magnitude will be much less than dollar for dollar. First, firms have

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17 Also see the discussion in Fazzari, Hubbard, and Petersen (2000).
other uses of funds besides R&D, including physical investment and working capital. Second, R&D likely has high adjustment costs, as documented in several empirical studies.\(^{18}\) Most R&D investment is payment to highly skilled technology workers. Skilled R&D workers often require a great deal of firm-specific knowledge and training. Fired R&D workers may also be able to transmit critical knowledge to competitors who hire them. When confronted with high adjustment costs, a firm that is unsure about the permanence of a positive supply shift in finance is likely to conserve some of its new equity finance so that it will have future resources to maintain its initial increase in R&D. Symmetrically, a firm faced with declining financial resources will likely cut back slowly on R&D. This point implies that firms should smooth R&D to some degree relative to temporary finance shocks.

IV. Empirical Specification and Estimation

To test the impact of internal and external equity finance on R&D we modify an investment model from Bond and Meghir (1994) and Bond, et al. (2003). This specification is based on the dynamic optimization “Euler condition” for imperfectly competitive firms that accumulate productive assets. The advantage of a structural approach is that it controls for expectations. A major challenge facing empirical work on financing constraints has been to separate the influence of variables that measure access to finance from their possible role as proxies for expected future profitability. The Euler equation estimation approach eliminates terms in the solution to the optimization problem that depend on unobservable expectations, such as the shadow value of capital, and it replaces expected values of observable variables with actual values plus an expectation error orthogonal to pre-determined instruments, under the assumption of rational expectations. If firms do not face financing constraints, Bond, et al. (2003, p. 153) write that, “under the maintained structure, the model captures the influence of current expectations of future profitability on current investment decisions; and it can therefore be argued that current or lagged financial variables should not enter this specification merely as proxies for expected future profitability.”

In the model from Bond and Meghir (1994) designed to study fixed investment, firm profits are a function of the physical capital stock and capital adjustment costs are a quadratic function of the ratio of physical investment to capital. To extend the model to R&D, it is natural to consider profits as a function

\(^{18}\) See, for example, Hall, Griliches, and Hausman (1986) and Bernstein and Nadiri (1989), who find that adjustment costs for R&D are considerably higher than for physical investment.
of the accumulated stock of R&D. Measurement of the R&D stock, however, is fraught with difficulties. In many situations, including the study of young firms we pursue in this paper, the absence of a long time-series of R&D expenditures makes perpetual inventory methods for stock computations infeasible. Furthermore, the relevant depreciation rate for an intangible asset like R&D is hard to determine. We therefore use firms’ stock of total assets as a scale factor in the regressions and assume that adjustment costs of R&D investment are quadratic in the ratio of R&D to total assets. This approach has precedents in the literature. Baker, Stein, and Wurgler (2003), for example, also use total assets as a scale variable in firm-level regressions for both physical capital and R&D.

The Euler equation leads to this empirical specification in the absence of financing constraints:

$$
\left( \frac{RD_{j,t}}{TA_{j,t}} \right)_{j,t} = \beta_1 \left( \frac{RD_{j,t-1}}{TA_{j,t-1}} \right)^2 - \beta_2 \left( \frac{GCF_{j,t}}{TA_{j,t-1}} \right) + \beta_3 \left( \frac{SALES_{j,t}}{TA_{j,t-1}} \right) + d_t + \alpha_j + \nu_{j,t}
$$

where $RD$ is research and development spending for firm $j$ in period $t$, $TA$ is the beginning-of-period stock of firm assets, and $SALES$ is firm revenue. The variable $GCF$ denotes gross cash flow, the flow of internal funds defined consistently with previous literature on finance and R&D.\(^{19}\)

The model includes firm and time effects. The firm effects control for all time-invariant determinants of R&D at the firm level. Bond and Meghir (1994) include aggregate time dummies to control for, among other things, movements in the aggregate cost of capital and tax rates. We take this approach a step further and also report regressions with time dummies at the three-digit industry level. This broader set of dummies controls for industry-specific changes in technological opportunities that could affect the demand for R&D.

The parameters in this equation can be interpreted as functions of the structural parameters of the original optimization problem presented in Bond and Meghir (1994). The positive coefficient on the level of the lagged dependent variable and the negative coefficient on the square both depend on discount and depreciation rates. The structural model implies that both coefficients will slightly exceed one in absolute value. The lagged sales-to-asset ratio has a positive coefficient under imperfect competition that goes to

\(^{19}\) See Hall (1992) and Himmelberg and Petersen (1994). Because R&D is treated as a current expense for accounting purposes, the $GCF$ variable adds R&D expenses to the standard measure of net cash flow (after-tax earnings plus depreciation allowances).
zero as the elasticity of demand faced by the firm approaches the competitive value. The lagged gross cash flow-asset ratio appears in the specification without financing constraints, but it has a negative sign.

To explore the role of financing constraints on R&D we add variables that correspond to the firm’s access to both internal and external equity, as discussed in sections II and III. The modified regression equation takes the form:

$$
\left( \frac{RD}{TA} \right)_{j,t} = \beta_1 \left( \frac{RD}{TA} \right)_{j,t-1} - \beta_2 \left( \frac{RD}{TA} \right)_{j,t-1}^2 + \beta_3 \left( \frac{SALES}{TA} \right)_{j,t} + \beta_4 \left( \frac{SALES}{TA} \right)_{j,t-1}
$$

(2)

$$
+ \beta_5 \left( \frac{GCF}{TA} \right)_{j,t} - \beta_6 \left( \frac{GCF}{TA} \right)_{j,t-1} + \beta_7 \left( \frac{STK}{TA} \right)_{j,t} + \beta_8 \left( \frac{STK}{TA} \right)_{j,t-1}
$$

$$
+ d_t + \alpha_j + \nu_{j,t}
$$

The key financial variables appear on the middle line of the equation. We add contemporaneous gross cash flow, the standard measure of internal equity financing in the financing constraint literature. Because contemporaneous cash flow is correlated with contemporaneous sales, we also add the contemporaneous sales-asset ratio to the regression. While cash flow effects have been widely explored in the literature, few studies have considered external equity. We include contemporaneous and lagged values of $STK/TA$, the ratio of funds raised by new stock issues to total assets. Bond and Meghir (1994) include similar variables in physical investment regressions. Stock issues are obviously endogenous, and this specification requires estimation with instrumental variables.

Following a widely used technique in empirical research on financing constraints based on the theoretical arguments summarized in section III, we split the sample of firm data to explore whether the results differ across firm groups that are more or less likely to face constraints. In this paper, we split the data into young and mature firms. The age of the firm should be a good proxy for the degree of asymmetric information relevant to financial access. Young firms have a shorter track record to establish the true quality of the business (see, for example, Gertler, 1988 and Oliner and Rudebusch, 1992). In addition, young firms are at an early stage of their life cycle when investment demand is more likely to outstrip the availability of internal finance, making financing constraints bind (see figure 3). For these reasons, we expect the baseline Euler equation 1 to best describe R&D in the mature firm sample and for the financing variables in equation 2 to have more important effects for young firms.

As discussed above, while there are advantages to grounding the empirical specification in an explicit structural model, the assumptions required to derive a tractable specification are strong. A
significant advantage of the approach taken by Bond and Meghir (1994) and Bond, et al. (2003) is that the empirical specification, although derived from an explicit optimization problem, has a form that corresponds to an intuitive, dynamic R&D regression. Thus the estimates have a readily understandable interpretation even if some assumptions of the underlying structural model do not strictly hold.20

We estimate the baseline Euler equation (1) and the equation modified with financial variables (2) with the GMM approach developed by Arellano and Bond (1991). The data are first differenced to remove the firm fixed effect. As discussed in Bond, et al. (2003, p. 159), if the error term is serially uncorrelated, instruments lagged two or more years will be valid. We take the more conservative approach, however, and use instruments lagged at least three years, which are valid even if the error term in the undifferenced specification follows an MA(1) process.

V: Data Description and Sample Characteristics

A. Industries and Construction of Sample

We study seven key high-tech industries: 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). These are the leading industries listed in the United States Department of Commerce’s classification of high-technology.21 As illustrated in figure 2, these industries accounted for a large share of aggregate R&D undertaken by all publicly traded firms. Obviously, if R&D matters for aggregate growth, the R&D in just these seven industries has important macroeconomic implications. Most of these industries are in the information technology sector, and their importance for productivity and growth is widely recognized (see Jorgenson, 2001, and Jovanovic and Rousseau, 2005).

We construct an unbalanced panel of publicly traded firms from the Compustat database during the period 1990-2004, which encompasses the R&D boom documented in figure 1. We exclude firms incorporated outside of the U.S. and firms with no stock price data. We also require firms to have at least

20 Bond, Harhoff, and Van Reenen (2003) make a similar point.
21 See “An Assessment of United States Competitiveness in High-Technology,” February 1983. We explored broader, two-digit industry classifications and obtained similar results. We focus on the three-digit classification because this is standard in the literature, and because there are no other large high-tech industries in SIC 28, 35, 36, 38 or 73. We do not include aerospace (SIC 37) because the government supplies much of its R&D financing.
six R&D observations, and we exclude firms if the sum of their cash flow-assets ratio over the sample is less than or equal to zero (discussed in more detail below). Following standard practice in the literature, we trim outliers in all key variables at the one-percent level.\textsuperscript{22} Our final sample consists of 1,347 firms that account for an average of 91.4 percent of aggregate R&D of all publicly traded firms in the seven high-tech industries from 1990 to 2004.

The definition of “young” and “mature” firms is based on the number of years since the firm’s first reported stock price appears in Compustat, which is typically the year of the firm’s initial public offering of stock. Consistent with the definition used for figures 1b and 1c, a firm is classified as young for the 15 years following the year it first appears in Compustat and mature thereafter. (Our results are similar for cutoffs of 10 or 20 years, as discussed further in section VI.D.)

We are particularly interested in the R&D investment of young firms. Figure 4 shows the share of R&D in the sample accounted for by the young firms over time. There are two points worth noting. First, the young-firm share is substantial, averaging 33.8 percent for the sample period. Second, there is much variation in the share of aggregate R&D accounted for by young firms. Starting from a low of 21.7 percent, the share peaks at 45.7 percent in 1998 and then falls to 26.1 percent by 2004, consistent with the fact that young firms account for all of the recent cycle in high-tech R&D.

\textbf{B. Descriptive Statistics}

Figure 5 plots the median R&D-to-assets (the dependent variable for our regressions) for the young and mature firms in our regression sample. For young firms, median R&D-to-assets rose by 43 percent between 1990 to 1999 and then fell precipitously in 2001. After 2001, R&D ratios remained at levels prevailing in the early 1990s. For mature firms, the median R&D intensity increased in the late 1990s and declined in 2001 and 2002, but the rise and fall is much attenuated compared to young firms. We have also examined the annual means of the R&D-asset ratio as well as the 75\textsuperscript{th} percentile and the 90\textsuperscript{th} percentiles for young and mature firms. While the basic pattern is the same, the boom-bust pattern for

\footnote{\textsuperscript{22} Our results are robust to changes in the outlier rule to exclude either the 0.5 percent or 2.0 percent tails.}
young firms is magnified.\textsuperscript{23} Thus, R&D \textit{intensity} for young firms, whether measured by the median or the mean, has a cyclical pattern like the aggregate data in figure 1b.

Table 1 provides descriptive statistics for the regression variables, along with information about sources of finance for the sample firms. The three columns present information for the full sample and the young and mature firm sub-samples. For firms in these industries, R&D far exceeds capital investment (\textit{CAP}). Furthermore, both the mean and median of the R&D-assets ratio show that young firms have higher R&D intensities than more mature firms (which is also evident in figure 5). Higher R&D ratios for young firms are to be expected because, unlike physical capital and labor, new knowledge is a non-rivalrous input within the firm and thus the larger mature firms may require much less R&D per unit of production. In contrast, the sales-asset ratios for young and mature firms, both at the mean and median, are very similar.

Turning to the sources of finance, the mean and median of the cash flow ratio is slightly larger for young firms. For young firms (but not for mature firms) the mean of the cash flow ratio is substantially smaller than the sum of the means of the R&D and capital spending ratios, implying that young firms obtain significant amounts of some other form of finance. That other form of finance is new stock issues. For young firms, the mean of the ratio of stock issues to total assets is 0.268, which is larger than the cash flow ratio.\textsuperscript{24} In contrast, for mature firms, the mean of the stock issues ratio is only 0.021. The mean (and median) of the ratio of new debt finance to assets is near zero for both young and mature firms. While not reported in the table, virtually no young firm ever pays a dividend.

There is significant variation over time in the key summary statistics. As already noted (see figure 5), the R&D ratio for young firms exhibits a boom-bust pattern. This is also true for the key financial statistics. For example, for young firms, the mean of the stock issues-to-asset ratio for the boom period 1995-2000 is 0.351, while the mean of the stock ratio for the bust period 2001-2004 is only 0.070. In addition, for young firms, the mean of the cash flow-assets ratio in the 1995-2000 period is 0.246 while the mean of this ratio in the 2001-2004 period is only 0.136.

\textsuperscript{23} For example, the mean of the R&D-asset-ratio for young firms rises from 0.15 in 1990 to 0.25 in 1999, and then falls back to 0.15 in 2001 and remains below 0.17 for the remaining three years; the mature firms means exhibit little or no boom/bust pattern.

\textsuperscript{24} For young firms, median new stock issues is close to zero. This arises because high issue costs make public equity issues lumpy, so firms raise large sums in some years and have no issues in others.
The final set of statistics in table 1 reports the share of finance from each source relative to total finance raised (the sum of internal cash flow and external public equity issues and new debt) over the sample period. For young firms, the mean share of gross cash flow is 65.9 percent, the mean of public equity issues is 32.0 percent, and the mean of debt finance is just 1.5 percent. For mature firms, the mean of gross cash flow is 91.6 percent, the mean of public equity finance is 6.8 percent, and the mean of debt finance is 1.9 percent. Clearly, debt finance is usually trivial for both types of firms and thus we ignore debt for the remainder of the paper. For young firms, public equity finance is important, and a large fraction of these firms must be using public equity as their marginal source of finance. If external equity requires a cost premium, as discussed in section III, these firms will face binding financing constraints and fluctuations in the supply of both internal cash flow and external public equity finance could significantly impact their R&D. The mature firms, however, are in a different situation. Few mature firms make significant use of external finance and clearly internal cash flow is the marginal source of funds for the vast majority of mature firms. With adequate internal finance, firms in our mature sample are not likely to face binding financing constraints, even if there is a premium for external finance. For these firms, changes in the availability of equity finance should make little or no difference to R&D.

As noted above, we exclude any firm—young or mature—for which the sum of its gross cash flow ratios over the sample is negative. We refer to these firms as the “negative cash flow” firms. Notice that we do not exclude firms simply because they have some negative gross cash flow observations—rather we exclude firms for which the sum of these observations is negative. These are almost always very small startup companies. Summary statistics for these firms (together with the pooled sample used in our study) appear in Table 1A in the appendix. For the negative cash flow firms, just 25 percent of the cash flow observations are positive (compared to 85 percent in the pooled sample). In 1990, 1997 and 2004, these firms account for just 0.8 percent, 3.2 percent and 4.3 percent of aggregate R&D in the seven high-tech industries. Median sales for these firms is less than $4 million. The median cash flow ratio is -0.172 (the mean of this ratio is -4.669). The mean stock ratio is 10.663. The cash flow share is negative while external public equity finance accounts for over 100 percent of total financing. The small size of the negative cash flow firms often leads to ratios that are both highly variable and very large (in absolute value), meaning these firms would have disproportionate impact on our regression results. Therefore,
given how unimportant these firms are for aggregate R&D, we exclude them from our primary regression sample. We do, however, report regression results for these firms in section VI.D.

VI. Econometric Results

A. Pooled Sample Estimates

Table 2 presents GMM coefficient estimates and standard errors for the 1990-2004 sample of high-tech firms. We report regressions with aggregate time dummies, as is standard in the literature, and also regressions with industry-level time dummies. The first two columns give the baseline Euler equation specification (equation 1 from section IV). The p-values for m1 and m2 statistics indicate the presence of first-order autocorrelation in the estimated errors, but cannot reject the null of no second-order autocorrelation, which supports the use of instruments lagged three periods. The Sargan test rejects the validity of the instruments in the regression with aggregate time dummies (a sign of misspecification), but does not reject with industry-level time dummies. The third and fourth columns report pooled regressions with the financial variables. The results strongly indicate the impact of both internal and external equity finance on R&D. Contemporaneous gross cash flow and contemporaneous new stock issues both have a statistically significant positive effect. In the regressions that include financial variables, the Sargan tests do not reject instrument validity with aggregate or industry-level time dummies. We note, however, that the coefficients on the lagged R&D-asset ratio and its square are well below the theoretical values predicted by the structural model from Bond and Meghir (1994) that exceed unity in absolute value. We will make more progress in understanding these results by splitting the sample.

B. Comparison of Young and Mature Firms

Table 3 presents regressions for young and mature firm sub-samples. Again, we present separate regressions with aggregate and industry-level time dummies. For the mature firms, none of the financial variables have significant effects in either regression, with the exception of a small coefficient for lagged cash flow. For both cash flow and new stock issues, chi-square tests do not reject the hypothesis that the sum of the current and lagged coefficients equals zero. In addition, the coefficients on the level and square of the lagged dependent variable conform reasonably well with the perfect capital markets Euler
equation for the mature firms. The point estimate on the lagged level of the dependent variable has a coefficient less than one, but a one-percent confidence interval for this estimate includes unity. One cannot reject a coefficient of negative one for the square of the lagged R&D-asset ratio as predicted by the structural model. These results are consistent with the summary statistics that imply the absence of binding financing constraints in the mature-firm sample.

For young firms, in contrast, the results are strongly consistent with the presence of binding financing constraints. For these firms, the contemporaneous gross cash flow and stock effects are statistically significant, and chi-square tests strongly reject the hypothesis that the sum of the current and lagged coefficients is zero. Furthermore, the point estimates (between 0.148 and 0.166) suggest a similar and economically important effect of internal and external equity finance on R&D. While the positive and statistically significant coefficient on the lagged dependent variable implies persistence of R&D, the coefficients on the lag and lag squared of the R&D ratio do not conform to the structural model proposed in Bond and Meghir (1994). This outcome is expected if young firms face financing constraints because the structural Euler equation is derived under the assumption of perfect capital markets.

As table 3 shows, the change in the estimates are negligible when the industry time dummies replace the aggregate year dummies. This comparison shows that our results are not much affected by unobserved industry technology shocks or any other industry-level variable correlated with R&D investment opportunities. This result strongly supports our hypothesis: if correlation of financial variables with investment opportunities were an important source of bias, then our estimated financial coefficients should decline substantially when we include industry-level time dummies.

Four main features of these regression results and the evidence discussed previously, taken together, support our hypothesis that the 1990s R&D boom and subsequent contraction were driven to a significant degree by shifts in the supply of internal and external equity finance. First, there was a boom and bust in equity finance that was closely correlated with the dramatic R&D cycle. Second, our summary statistics imply that financing constraints, if they exist, should be binding only for young firms: young firms (but not mature firms) have demand for total investment that substantially exceeds their internal funds. Third, the R&D cycle is confined entirely to young firms, consistent with the equity supply interpretation. Finally, and most important, the regressions identify significant effects of internal
and external equity finance on R&D for young firms, but not mature firms, in specifications that control for R&D demand in a variety of ways.

C. Quantitative Implications

The coefficient estimates in table 3 suggest that young firms invest approximately 15 percent of additional equity funds in R&D during the year in which the funds arrive. The fact that the cash flow and stock coefficient estimates are close in magnitude is consistent with the financing constraint interpretation. Once inside the firm, financial resources are fungible and an additional dollar of equity finance should have a similar effect on R&D regardless of whether it comes from internal or external sources. As discussed in section III, we expect the magnitude of these coefficients to be substantially less than one for several reasons, including the fact that firms use equity finance to purchase other assets besides R&D and the likelihood that firms smooth R&D relative to finance shocks because of adjustment costs. The latter point is supported by the significant positive effect of the lagged R&D-asset ratio.

Can the effects estimated here for young firms explain a substantial portion of the 1990s R&D boom? A complete answer to this question is beyond the scope of our study. We can, however, use the young-firm results in table 3 to perform a simple, but suggestive, calculation. As described earlier, we projected the exponential 1980-1993 trend in aggregate R&D in the seven high-tech industries for all young firms. We then defined the amount of “boom” R&D, for 1994 through 2000, as the difference between actual R&D and the projected values from the earlier trend. We used the same procedure to define “boom” amounts of gross cash flow and new stock issues. These calculations were done for young firms only because there is evidence of an R&D boom relative to trend and significant financial effects only for young firms. With these definitions and the estimated model from table 3 (with industry time dummies) the cash flow and stock issue booms explain 72 percent of the 1994-2000 R&D boom. From 2001 to the end of the sample in 2004, using a similar approach, the bust in both internal and external finance explains 78 percent of the reduction in R&D. In both the boom and bust periods, cash flow accounts for just under two thirds of the changes in R&D predicted by the financial variables, with the remainder explained by variations in new share issues. Because the recent cycle in R&D for the U.S. economy is concentrated almost entirely in young firms from the seven industries we study, it is clear that the financial effects have important macroeconomic implications.
D. Alternative Specifications and Robustness

We explored a wide variety of alternative specifications. The interpretation we give to the baseline results reported above is largely unchanged in these regressions. This subsection summarizes a few of the most interesting results.

Although the structural specification and the industry-level time dummies control for expectations and demand factors, we included Tobin’s $q$ as an additional proxy for expectations that might affect R&D demand. The use of $q$ to account for investment demand is widely employed in the financing constraint literature. We included both beginning-of-period $q$ as is common in the literature, and, in a particularly strong test of the robustness of our results, we also included end-of-period $q$ that conveys all contemporaneous information available from the stock market about expectations. The financial results changed very little. The gross cash flow and stock coefficients for the young firms dropped by 0.016 to 0.034 in various regressions, but remained highly significant. The financial variable coefficients in the mature firm regressions changed negligibly.

To explore how the results are affected with the choice of the classification criterion for the young and mature firm subsamples, we changed the sample split criterion to both 10 years and 20 years. The results are consistent with the interpretation we give to our baseline results with the 15-year cutoff. The financial variables have somewhat stronger effects in a sub-sample of firms that have been public for 10 or fewer years. The contemporaneous gross cash flow coefficient rises to 0.176 for this sub-sample, from 0.150 in the results with industry time dummies from table 3 (the contemporaneous stock coefficient is almost identical). We expect stronger financial effects in a younger sample if the probability that firms face binding financial constraints rises as their age declines. If we re-define the mature firms to be public for at least 20 years, financial effects remain insignificant.\textsuperscript{25}

In section V, we discussed the characteristics of the “negative cash flow” firms that we exclude from the primary regression sample. The sum of the gross cash flow-assets variable for these firms is negative over the entire sample. The gross cash flow regression coefficients are negative (although not highly significant) for this sub-sample. This result is not surprising since these firms have not reached the

\textsuperscript{25} Comparison of results for firms publicly traded for less than 10 years with those for firms publicly traded for more than 20 years virtually eliminates the effect of firms that switch from young to mature status during the sample period because in such a comparison “switchers” would be excluded from the mature sample for 10 years.
stage of development at which internal equity is a source of funds. They must obtain all financing from outside equity (see appendix table 1A for summary statistics for these firms). It is therefore also not surprising that the young firms in this sub-sample have a positive and significant coefficient on the stock variable (0.079 with a standard error of 0.019). Recall that these firms account for a trivial amount of aggregate R&D.

VII. Economic Implications

Our interpretation of the empirical findings presented here is that a major shift in the availability of internal and external equity finance significantly relaxed financing constraints for a large number of young high-tech companies in the mid and late 1990s. Furthermore, our results suggest that the R&D response of these firms to the finance shift was large enough to potentially account for much of the aggregate R&D boom in the late 1990s as well as the reversal of R&D growth in 2001-2004. These findings have potentially important implications for several major economic issues, which are discussed briefly in this section.

A. The R&D Boom and Labor Productivity

At the micro level, many studies have found a strong relationship between R&D investment and labor productivity.\(^{26}\) If R&D is an important determinant of technical change, the 1990s R&D boom should have had an impact, with some lag, on the 1990s revival of strong labor productivity growth. Indeed, the rise in non-farm labor productivity growth began in 1996, two to three years after the beginning of the R&D boom.\(^{27}\) Our paper has focused on the seven industries responsible for the recent R&D boom and these industries include the chief information technology industries that have frequently been cited as critical to the recent productivity revival (see, for example, Jorgenson, 2001). Our findings therefore suggest that the boom in internal and external equity finance may have contributed to recent robust productivity growth in the “new economy.”

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\(^{26}\) At the aggregate level, testing for R&D effects is complicated by the fact that not all of R&D is equally productive. For example, in the 1960s and 1970s, much of the R&D investment occurred in the defense industry and was financed by the federal government while privately financed industrial R&D was rarely above one percent of GDP, far below the numbers prevailing in the 1990s.

\(^{27}\) Labor productivity growth remained high in the early 2000s, which is consistent with the privately financed industrial R&D to GDP figures cited earlier in this paper. While the R&D/GDP ratio in 2002-2004 was below the peak in 2000 and 2001, the numbers in 2002-2004 are still high compared to figures in the 1980s or early 1990s.
We also note that higher labor productivity caused by a rightward shift in the supply of equity finance has implications for modern endogenous growth models that emphasize R&D and technological change. For example, Aghion and Howitt (1998, page 71), following King and Levine (1993), show how the effective cost of funds in their basic endogenous growth model can be modified to incorporate capital market imperfections. They show that a cost premium for external finance raises the effective interest rate for innovating firms and lowers R&D. An increase in the availability of external equity finance lowers this effective interest rate for constrained firms, which would bring about a higher rate of R&D, improved labor productivity, and a higher rate of steady-state growth in their model. Thus, the supply of equity has implications similar to other economic factors, such as the aggregate rate of saving, that have received considerable attention in the endogenous growth literature.

B. Corporate Income Taxation and the Supply of Internal and External Equity Finance

Compared to other types of investment, corporate tax rates should have a disproportionate impact on R&D, because R&D is financed mainly with equity and equity income is not protected from the corporate tax. This point implies that the standard cost-of-capital channel through which corporate taxation affects investment will be more significant for R&D than for fixed capital investment. Fixed capital is usually financed in part by debt that has returns shielded from taxation. In addition, the presence of financing constraints on R&D introduces a potentially more significant, but less studied, channel through which business taxation affects R&D. Business tax payments reduce after-tax cash flow, which therefore reduce the quantity of internal equity finance (lower CF₀ in figure 3). Our regression results imply that lower cash flow reduces R&D for constrained firms (young firms in this study) independently of any effect on the marginal cost of capital. This argument suggests that business tax policies have larger effects on R&D than predicted by conventional models without financial constraints.

We note that in the last six years, most OECD nations (but not the U.S.) have substantially reduced their rate of corporate income taxation. One consequence is that the U.S. currently has the second highest corporate income tax rate among OECD countries, which, other things equal, should adversely affect its comparative advantage in R&D and high-tech production. In addition, a number of

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28 See “U.S. Lagging Behind OECD Corporate Tax Trends,” The Tax Foundation, May 5, 2006. This report shows that the OECD average corporate tax rate is considerably lower than that of the U.S and that only Japan has a higher corporate income tax rate.
countries have implemented an R&D tax credit. Our results imply that the effectiveness of these credits depends on a cash-flow channel, as well as a traditional-cost-of-capital channel.

C. Growth and Finance: External Equity as a Source of Finance?

Levine (2005) surveys the enormous macroeconomic literature that studies finance and growth, and one of his main conclusions (p. 3) is that “better functioning financial systems ease external financing constraints.” Most recent efforts to introduce financing constraints into the modern endogenous growth literature focus on the role of intermediation and debt finance. Recent examples include King and Levine (1993), De la Fuente and Marin (1996), Morales (2003), Aghion, Howitt, and Mayer-Foulkes (2005), and Aghion, Angeletos, Banerjee, and Manova (2005). While there are good reasons to focus on debt (e.g., historical lack of public equity finance in most countries), in recent years stock market capitalization has grown tremendously in both developed and developing countries (see Rousseau and Wachtel, 2000). In addition, our findings show that stock markets can be an important source of finance, suggesting that it may be useful for growth models focusing on innovation and financing constraints to consider the role of both debt and equity finance.

A growing empirical literature has found that measures of the degree of stock market development or liquidity are positively and significantly correlated with growth (e.g., Atje and Jovanovic, 1993; Levine and Zervos, 1998; Arestis, Demetriades and Luintel, 2001; Rousseau and Wachtel, 2000; and Beck and Levine, 2002). These studies, however, do not emphasize equity markets as an important source of finance, but rather that stock markets provide exit options for investors, more liquidity, or better information. Likewise, these studies do not include measures of equity issues as indicators for the importance of equity markets. Our findings suggest that future empirical tests of the role of stock markets should consider the possibility that stock markets contribute to economic growth by directly funding innovation, particularly for young companies.

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29 The U.S. has had an R&D credit since 1981, although it is not permanent. Many other countries have implemented such credits and they are often more generous than in the U.S. Some U.S. states have begun to provide R&D credits. See Wilson (2005).

30 Fazzari, Hubbard, and Petersen (1988, p. 203) report that the cash flow effect of an investment tax credit for fixed investment is much larger than the standard incentive effect for financially constrained firms.

31 Exceptions that consider stock markets include Levine (1991) and Bencivenga, Smith, and Starr (1995).

32 Rajan and Zingales (1998, p. 569) support the importance of equity markets as a source of finance. They note that “the amount of money raised through [equity issues] is more suitable” for measuring the effect of equity markets on growth, but this measure is not usually available in the data employed in most of the finance and growth literature.
D. Bank-Based Versus Market-Based Financial Systems

In his survey of the growth-finance nexus, another of Levine’s (2005) main conclusions is that “the degree to which a country is bank-based or market-based does not matter much.” Some studies, however, have found evidence that a country’s financial architecture may matter. For example, Tadesse (2002, p. 450) finds that “across countries with developed financial sectors, industries supported by market-based financial systems grow faster than industries with bank-based systems” and the opposite holds across countries with underdeveloped systems. Our findings also suggest that the financial architecture may make a difference. In the U.S. during the 1980s and 1990s, thousands of young high-tech firms obtained a tremendous amount of finance from various external equity markets. These new entrants had very high levels of R&D investment. In contrast, during this same period, bank-based economies such as Germany and France had comparatively less success in creating new high-tech firms (consistent with the evidence in Tadesse, 2002), and their world share of high-tech production has fallen substantially, exactly the opposite of the U.S.\footnote{33 See Levine (2005) for a discussion of strengths and weaknesses of various financial systems. The bank-based system may be optimal for countries away from the global technological frontier because such economies implement existing technologies which are often embodied in physical capital and therefore may have good collateral value. For countries approaching the frontier, a market-based system may be better suited to financing the intangible and risky high-tech investment of young startup companies. Such a possibility is consistent with Aghion and Howitt (2005, p. 9) who emphasize that some economic institutions may be ideal for countries far away from the global frontier but are not optimal for countries close to the frontier.}

VIII. Summary

From 1994 to 2004, there was an unprecedented boom, and subsequent decline, in aggregate R&D investment. As we show, the recent remarkable cycle in R&D investment was driven by seven high-tech industries and was confined entirely to young firms. During the same period, there was also a dramatic boom and bust in the availability of both internal cash flow and external equity finance.

The objective of this paper has been to explore whether supply shifts in finance can explain a significant portion of the 1990s R&D boom and subsequent decline. We examine firm-level, panel data for 1,347 publicly traded, high-tech firms from 1990-2004. Using a GMM procedure to estimate dynamic R&D models, we find very sharp differences when we disaggregate the data into young and mature firms. For mature firms, the point estimates for the financial variables are quantitatively unimportant and
statistically insignificant. For young firms, the financial variables have significant effects, both statistically and economically. These findings, together with the fact that there was no boom in R&D for mature firms, are consistent with a shift in supply of finance and are difficult to explain with a demand-side story. The financial effects for the young, high-tech firms alone are large enough to explain most of the 1994-2004 aggregate R&D cycle. To our knowledge, no other study has provided evidence that supply shifts in finance could have an aggregate effect on R&D investment.

As discussed in section VII above, these findings have implications for a wide range of economic issues. The most important implication, however, is for understanding the link between finance and economic growth. A number of recent endogenous growth models incorporate capital market imperfections to provide a theoretical foundation for a causative finance-growth link. A large literature demonstrates that broad macroeconomic indicators of financial development correlate with economic growth across countries, and significant progress has been made to establish causation in this relationship (see the extensive survey in Levine, 2005). Our work complements the findings in this literature by using microeconomic data to look more deeply at a key mechanism that connects finance and growth. Focusing on the dramatic 1990s R&D boom, we uncover an empirical effect of finance on R&D, the key innovative activity in most modern models of endogenous growth. We believe that these results provide further support for the view that finance, financial development, and the institutional structure of financial markets are important factors driving economic growth.
Figure 1a: R&D, Cash Flow and New Share Issues
High-Tech Aggregates (All Firms)

Note: Sum of variables for all firms with stock prices in Compustat in high-tech industries: 283, 357, 366, 367, 382, 384 and 737.
Figure 1b: R&D, Cash Flow and New Share Issues
High-Tech Aggregates (Young Firms Only)

Note: Sum of variables for all firm observations less than or equal to 15 years from the initial appearance of a stock price in Compustat; high-tech industries: 283, 357, 366, 367, 382, 384 and 737.
Figure 1c: R&D, Cash Flow and New Share Issues
High-Tech Aggregates (Mature Firms Only)

Note: Sum of variables for all firm observations more 15 years after the initial appearance of a stock price in Compustat; high-tech industries: 283, 357, 366, 367, 382, 384 and 737.
Figure 2: Economy-Wide R&D Investment

Note: Sum of R&D for publicly traded companies in Compustat; high-tech industries: 283, 357, 366, 367, 382, 384 and 737.
Figure 3a: Change of Internal Equity

Figure 3b: Change of External Equity
Figure 4: Young Firm Share of Sample R&D

Note: Data from regression sample as described in the text. Young firm observations are those less than or equal to 15 years from the initial appearance of a stock price in Compustat.

Figure 5: Median R&D-to-Assets Ratios (Regression Sample)

Note: Regression sample as described in the text. Young firm observations are those less than or equal to 15 years from the initial appearance of a stock price in Compustat; mature firm observations are more than 15 years from the appearance of a stock price.
Table 1: Sample Descriptive Statistics  
High-Tech Firms 1990-2004

<table>
<thead>
<tr>
<th>Variable and Statistic</th>
<th>Full Sample</th>
<th>Young Firms</th>
<th>Mature Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>(RD / TA)ₜ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.170</td>
<td>0.194</td>
<td>0.098</td>
</tr>
<tr>
<td>Median</td>
<td>0.116</td>
<td>0.137</td>
<td>0.074</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.217</td>
<td>0.240</td>
<td>0.100</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>0.350</td>
<td>0.395</td>
<td>0.186</td>
</tr>
<tr>
<td>(CAP / TA)ₜ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.064</td>
<td>0.069</td>
<td>0.049</td>
</tr>
<tr>
<td>Median</td>
<td>0.041</td>
<td>0.042</td>
<td>0.039</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.149</td>
<td>0.171</td>
<td>0.042</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>0.130</td>
<td>0.143</td>
<td>0.102</td>
</tr>
<tr>
<td>(SALES / TA)ₜ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1.212</td>
<td>1.227</td>
<td>1.167</td>
</tr>
<tr>
<td>Median</td>
<td>1.083</td>
<td>1.076</td>
<td>1.099</td>
</tr>
<tr>
<td>Std. Dev.</td>
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<td>1.095</td>
<td>0.597</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>2.122</td>
<td>2.213</td>
<td>1.837</td>
</tr>
<tr>
<td>(GCF / TA)ₜ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.205</td>
<td>0.217</td>
<td>0.172</td>
</tr>
<tr>
<td>Median</td>
<td>0.185</td>
<td>0.194</td>
<td>0.166</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.369</td>
<td>0.398</td>
<td>0.261</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>0.457</td>
<td>0.495</td>
<td>0.347</td>
</tr>
<tr>
<td>(STK / TA)ₜ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.204</td>
<td>0.268</td>
<td>0.021</td>
</tr>
<tr>
<td>Median</td>
<td>0.006</td>
<td>0.010</td>
<td>0.001</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>1.160</td>
<td>1.338</td>
<td>0.155</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>0.427</td>
<td>0.643</td>
<td>0.050</td>
</tr>
<tr>
<td>(DBT / TA)ₜ</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.009</td>
<td>0.009</td>
<td>0.007</td>
</tr>
<tr>
<td>Median</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.344</td>
<td>0.394</td>
<td>0.113</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>0.061</td>
<td>0.058</td>
<td>0.067</td>
</tr>
</tbody>
</table>
Table 1 (Continued): Sample Descriptive Statistics
High-Tech Firms 1990-2004

<table>
<thead>
<tr>
<th>Variable and Statistic</th>
<th>Full Sample</th>
<th>Young Firms</th>
<th>Mature Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum GCF / Net Finance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.686</td>
<td>0.659</td>
<td>0.916</td>
</tr>
<tr>
<td>Median</td>
<td>0.731</td>
<td>0.692</td>
<td>0.957</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.399</td>
<td>0.421</td>
<td>0.627</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>1.139</td>
<td>1.110</td>
<td>1.357</td>
</tr>
<tr>
<td>Sum STK / Net Finance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.289</td>
<td>0.320</td>
<td>0.068</td>
</tr>
<tr>
<td>Median</td>
<td>0.219</td>
<td>0.247</td>
<td>0.027</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.367</td>
<td>0.381</td>
<td>0.419</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>0.807</td>
<td>0.850</td>
<td>0.484</td>
</tr>
<tr>
<td>Sum DBT / Net Finance</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.021</td>
<td>0.015</td>
<td>0.019</td>
</tr>
<tr>
<td>Median</td>
<td>0.000</td>
<td>-0.001</td>
<td>0.000</td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>0.182</td>
<td>0.194</td>
<td>0.382</td>
</tr>
<tr>
<td>90th Percentile</td>
<td>0.229</td>
<td>0.230</td>
<td>0.378</td>
</tr>
</tbody>
</table>

Note: Regression sample as described in the text, excluding firms with negative sum of (GCF/TA), and outliers defined by the one percent tails of each variable. Young firm observations are those less than or equal to 15 years from the initial appearance of a stock price in Compustat; mature firm observations are more than 15 years from the appearance of a stock price.
Table 2: Dynamic R&D Regressions: Pooled Results  
High-Tech Firms 1990-2004  
Dependent Variable \((RD/TA)_t\)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline Euler Equation</th>
<th>Euler Equation with Financial Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>((RD/TA)_{t-1})</td>
<td>0.808 (0.215)</td>
<td>0.380 (0.134)</td>
</tr>
<tr>
<td>((RD/TA)_{t-1}^2)</td>
<td>-0.400 (0.139)</td>
<td>-0.145 (0.076)</td>
</tr>
<tr>
<td>((SALES/TA)_t)</td>
<td>-0.020 (0.018)</td>
<td>-0.007 (0.018)</td>
</tr>
<tr>
<td>((SALES/TA)_{t-1})</td>
<td>-0.007 (0.016)</td>
<td>-0.015 (0.009)</td>
</tr>
<tr>
<td>((GCF/TA)_t)</td>
<td>0.170 (0.041)</td>
<td>0.158 (0.040)</td>
</tr>
<tr>
<td>((GCF/TA)_{t-1})</td>
<td>-0.015 (0.045)</td>
<td>0.001 (0.016)</td>
</tr>
<tr>
<td>((STK/TA)_t)</td>
<td>0.151 (0.017)</td>
<td>0.149 (0.017)</td>
</tr>
<tr>
<td>((STK/TA)_{t-1})</td>
<td>-0.018 (0.004)</td>
<td>-0.017 (0.004)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time Dummies</th>
<th>Aggregate</th>
<th>Industry-Level</th>
<th>Aggregate</th>
<th>Industry-Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m1 (p-value))</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>(m2 (p-value))</td>
<td>0.401</td>
<td>0.311</td>
<td>0.249</td>
<td>0.345</td>
</tr>
<tr>
<td>(Sargan (p-value))</td>
<td>0.002</td>
<td>0.889</td>
<td>0.138</td>
<td>1.000</td>
</tr>
<tr>
<td>Observations</td>
<td>12,248</td>
<td>12,248</td>
<td>12,224</td>
<td>12,224</td>
</tr>
</tbody>
</table>

Note: Equations estimated with GMM in first differences to eliminate firm effects. Level variables dated \(t-3\) and \(t-4\) used as instruments. Aggregate or industry–specific year dummies are included in all regressions (as indicated in the table). Robust standard errors appear below point estimates.
Table 3: Dynamic R&D Regressions for Separate Young and Mature Firm Samples
High-Tech Firms 1990-2004
Dependent Variable \((RD/TA)_t\)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mature Firms</th>
<th></th>
<th>Young Firms</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>((RD/TA)_{t-1})</td>
<td>0.632</td>
<td>(0.179)</td>
<td>0.382</td>
<td>(0.137)</td>
</tr>
<tr>
<td>((RD/TA)_{t-1}^2)</td>
<td>-0.831</td>
<td>(0.277)</td>
<td>-0.142</td>
<td>(0.077)</td>
</tr>
<tr>
<td>((SALES/TA)_t)</td>
<td>0.049</td>
<td>(0.016)</td>
<td>-0.023</td>
<td>(0.020)</td>
</tr>
<tr>
<td>((SALES/TA)_{t-1})</td>
<td>-0.031</td>
<td>(0.011)</td>
<td>-0.015</td>
<td>(0.010)</td>
</tr>
<tr>
<td>((GCF/TA)_t)</td>
<td>-0.015</td>
<td>(0.032)</td>
<td>0.166</td>
<td>(0.044)</td>
</tr>
<tr>
<td>((GCF/TA)_{t-1})</td>
<td>0.041</td>
<td>(0.020)</td>
<td>0.003</td>
<td>(0.017)</td>
</tr>
<tr>
<td>((STK/TA)_t)</td>
<td>0.031</td>
<td>(0.029)</td>
<td>0.148</td>
<td>(0.017)</td>
</tr>
<tr>
<td>((STK/TA)_{t-1})</td>
<td>-0.010</td>
<td>(0.011)</td>
<td>-0.019</td>
<td>(0.004)</td>
</tr>
<tr>
<td>Time Dummies</td>
<td>Aggregate</td>
<td>Industry-</td>
<td>Aggregate</td>
<td>Industry-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Level</td>
<td></td>
<td>Level</td>
</tr>
<tr>
<td>(m1\ (p-value))</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>(m2\ (p-value))</td>
<td>0.795</td>
<td>0.880</td>
<td>0.294</td>
<td>0.432</td>
</tr>
<tr>
<td>(GCF\ Chi2\ (p-value))</td>
<td>0.382</td>
<td>0.212</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>(STK\ Chi2\ (p-value))</td>
<td>0.539</td>
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<tr>
<td>(Sargan\ (p-value))</td>
<td>0.633</td>
<td>1.000</td>
<td>0.103</td>
<td>1.000</td>
</tr>
<tr>
<td>Observations</td>
<td>3,393</td>
<td>3,393</td>
<td>8,831</td>
<td>8,831</td>
</tr>
</tbody>
</table>

Note: Young firm observations are those less than or equal to 15 years from the initial appearance of a stock price in Compustat; mature firm observations are more than 15 years from the appearance of a stock price. Equations estimated with GMM in first differences to eliminate firm effects. Level variables dated \(t-3\) and \(t-4\) used as instruments. Aggregate or industry–specific year dummies are included in all regressions (as indicated in the table). Robust standard errors appear below point estimates.
Appendix

Variable Definitions with Compustat Data Codes

(RD/TA): Research and development expense (data46) in period $t$ divided by the book value of total assets (data6) at the beginning of period $t$.

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

(SALES/TA): Net sales (data12) in period $t$ divided by the book value of total assets (data6) at the beginning of period $t$.

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

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

(DBT/TA): Net new long-term debt period $t$ divided by the book value of total assets (data6) at the beginning of period $t$, where net new long-term debt is equal long-term debt issuance (data111) minus long-term debt reduction (data114).

Appendix Table 1A: Summary Statistics for Firms with Negative Sum of GCF/TA

<table>
<thead>
<tr>
<th></th>
<th>Negative Cash Flow Firms</th>
<th>Sample Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firms</td>
<td></td>
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</tr>
<tr>
<td>Share GCF Observations Positive</td>
<td>mean</td>
<td>0.25</td>
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<tr>
<td></td>
<td>median</td>
<td>0.24</td>
</tr>
<tr>
<td>Share of Aggregate R&amp;D</td>
<td>1990</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>1997</td>
<td>0.032</td>
</tr>
<tr>
<td></td>
<td>2004</td>
<td>0.043</td>
</tr>
<tr>
<td>Sales (millions of dollars)</td>
<td>mean</td>
<td>21.89</td>
</tr>
<tr>
<td></td>
<td>median</td>
<td>5.27</td>
</tr>
<tr>
<td>RD/TA</td>
<td>mean</td>
<td>0.844</td>
</tr>
<tr>
<td></td>
<td>median</td>
<td>0.190</td>
</tr>
<tr>
<td>GCF/TA</td>
<td>mean</td>
<td>-4.669</td>
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<tr>
<td></td>
<td>median</td>
<td>-0.172</td>
</tr>
<tr>
<td>STK/TA</td>
<td>mean</td>
<td>10.663</td>
</tr>
<tr>
<td></td>
<td>median</td>
<td>0.067</td>
</tr>
<tr>
<td>DBT/TA</td>
<td>mean</td>
<td>-0.034</td>
</tr>
<tr>
<td></td>
<td>median</td>
<td>0.000</td>
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References


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