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ABSTRACT

The financing of R&D provides a potentially important channel to link finance and economic growth, but there is no direct evidence that financial effects are large enough to impact aggregate R&D. U.S. firms finance R&D from volatile sources: cash flow and stock issues. We estimate dynamic R&D models for high-tech firms and 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, which implies a significant connection between finance, innovation, and growth.

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Does finance cause growth? A large empirical literature, surveyed by Levine (2005), establishes a strong connection between broad measures of financial development and economic growth. Questions remain, however, about the channels through which finance may matter for growth. One potentially important channel is the financing of R&D, a critical input to innovation and growth in modern economies. R&D is particularly interesting not only because of the knowledge spillovers it creates—a major feature of endogenous growth models—but also because R&D may be difficult to finance with external sources (e.g., Arrow (1962)).[1] While a small number of empirical studies suggest that some firms face financing constraints for R&D (see Hall (2002)), there is no direct micro evidence that these financial effects are large enough to matter for aggregate R&D. This paper fills that gap: we identify financial factors for young, high-tech firms that can explain a significant portion of the dramatic 1990s boom, and the subsequent decline, in U.S. R&D.

In the U.S., young publicly traded firms in high-tech industries finance R&D investment almost entirely with internal or external equity (that is, cash flow or public share issues). For these firms, information problems, skewed and highly uncertain returns, and lack of collateral value likely make debt a poor substitute for equity finance. Furthermore, young high-tech firms typically exhaust internal finance and issue stock as their marginal source of funds. If these firms face binding financing constraints, then exogenous changes in the supply of either internal or external equity finance should lead to changes in R&D. If such firms undertake a large fraction of aggregate R&D, then changes in the availability of finance may have macroeconomic significance. In particular, booms (or busts) in the supply of equity finance should lead to booms (or busts) in 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 dramatic boom, and subsequent decline, in R&D: the ratio of privately financed industrial R&D to GDP rose from 1.40% in 1994 to an all-time high of 1.89% in 2000 before declining to an average of 1.70% from 2002 to 2004, according to a survey from the National Science Foundation. 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. More important, virtually all of the boom was accounted for by young firms (publicly traded for less than 15 years) in these industries.

From 1994 to 2004, there was also a dramatic boom and bust in both cash flow and external equity finance in these industries. Internal finance (cash flow) for publicly traded firms increased from $89 billion in 1993 to $231 billion in 2000, and then collapsed in 2001 and 2002. External public equity finance rose from $24 billion in 1998 to $86 billion in 2000, but then plummeted 62% in 2001.

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 our knowledge, this is the first study to examine whether finance supply shifts explain large fluctuations in R&D. We use a Generalized Method of Moments procedure to estimate dynamic R&D investment models with panel data from 1,347 publicly traded firms in the seven high-tech industries from 1990 to 2004. For mature firms, the point estimates for both cash flow and external equity finance are statistically insignificant and quantitatively unimportant. For young firms, however, the point estimates for the equity finance variables are quantitatively large and highly significant. Furthermore, the financial coefficients are large enough that the financial cycles for young high-tech firms alone can explain about 75% of the *aggregate* R&D boom and subsequent decline.

Our interpretation of these 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, the specification 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 an 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, shifts in the supply of equity finance may have driven much of the R&D boom, which was likely important for the surge in labor productivity beginning in the late 1990s. Second, because the corporate tax system affects after-tax cash flow, our findings identify a potentially important channel through which business tax policies affect R&D investment. Third, while the large literature on finance and economic growth has good reasons to focus on debt and credit constraints, our results suggest that more attention should be given to equity finance, particularly for models that emphasize innovation. Finally, although empirical studies on finance and growth have examined the potential impact of stock market development, they typically 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, which has implications for the debate about the relative merits of bank-based versus market-based financial systems.

Section I describes the 1990s R&D boom and the decline beginning in 2001. This section also discusses the role of equity finance for R&D, shifts in the supply of cash flow and stock issues, and the empirical predictions that link shifts in the supply of finance to R&D. Section II provides the empirical specification and describes the estimation method. Section III discusses the sample of high-tech industries and presents sample summary statistics. The main empirical results appear in Section IV and Section V presents results from alternative specifications and tests of robustness. Section VI discusses the implications of our findings and Section VII concludes.

I. R&D and Equity Finance

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

The 1990s boom and decline after 2000 in U.S. R&D spending is likely without precedent. According to the National Science Foundation (NSF) 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 to 2000, was 9.2%, greatly exceeding the growth rates of the first two waves (6.8% from 1975 to 1986 and 5.4% from 1987 to 1992). As a result, the R&D-GDP ratio hit an all-time peak of 1.89% in 2000, 35%

greater than the 1994 figure. In 2001, however, the R&D-GDP ratio declined modestly (to 1.86) 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.

Unlike other types of investment, R&D has become highly concentrated in the seven high-tech industries listed in the introduction. Figure 1 plots R&D investment in billions of 2000 dollars (solid line) for all publicly traded firms listed in Compustat from 1980 to 2004.[2] 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 grew significantly in the past quarter century, reaching more than two-thirds in recent years. Second, there is a sharp acceleration in economywide R&D starting in 1994 and ending in 2000. Third, the seven high-tech industries account for virtually all of the cycle in R&D between 1994 and 2004.

INSERT FIGURE 1 ABOUT HERE

Figures 2a to 2c present aggregated R&D and financing data for publicly traded firms in the seven high-tech industries. Figure 2a shows R&D for all firms while Figures 2b and 2c provide separate data for young firms (publicly traded for 15 years or less) and mature firms (publicly traded for more than 15 years). Figures 2b and 2c 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 are 7.5% for mature firms and a remarkably high 11.8% for young firms. We then project post-1993 R&D with the estimated trend and define the boom as the difference between actual R&D and the projected trend. For the six years from 1996 through 2001, the level of young firm R&D averaged 65% above the trend that already incorporated almost 12% annual growth. In 2002, however, this 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 after 1993 continued to grow almost exactly at the trend rate.

INSERT FIGURES 2A, 2B AND 2C ABOUT HERE

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 likely has a substantial gestation period before it becomes productive (four to six years according to Ravenscraft and Scherer (1982)). Therefore, periods of high *cyclical* demand will have little or no impact on 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 is concentrated in young firms.

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

Financing constraints, if they exist, may restrict R&D much more than other forms of investment. Reasons include the lack of collateral value for R&D "capital" and firms' need to protect proprietary information, even from potential investors. Compared to the vast literature testing for the presence of financing constraints on capital investment, relatively little research focuses 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. and other countries face financing constraints for R&D, including Hall (1992), Himmelberg and Petersen (1994), Mulkay, Hall, and Mairese (2001), and Bond, Harhoff, and Van Reenen (2003). But previous studies have not 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.

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 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 (see Stiglitz (1985) p. 146). Second, adverse selection problems (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 they can more easily substitute high-risk for low-risk projects. Fourth, the expected marginal cost of financial distress rises rapidly with leverage for young high-tech firms because their market value depends heavily on future growth options that rapidly depreciate if they face financial distress (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 (e.g., Carpenter and Petersen (2002)). 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 perfect substitutes, however. Public stock issues incur sizeable flotation costs, and new share issues may require a "lemons premium" due to asymmetric information. 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.[3]

This discussion suggests that there is a financing hierarchy for R&D that consists almost entirely of internal and external equity finance, at least for young firms. (This is surely not the case for capital investment with collateral value, for which debt presumably plays a more important role.) The least-cost form of finance is internal cash flow. When cash flow is exhausted and debt is not an option, firms must turn to new share issues. Financial theories predict that the marginal cost of external equity will increase because of adverse selection (e.g., Myers and Majluf (1984) and Krasker (1986)). Evidence from Asquith and Mullins (1986) and Cornett and Tehranian (1994) is consistent with an upward-sloping supply curve for external equity. Hennessy and Whited ((2007) p. 1737) estimate a structural model and conclude that "small firms appear to face large financial frictions, consistent with theories emphasizing adverse selection." In addition, Altinkilic and Hansen (2000) report that the marginal cost of underwriting fees (beyond some minimum scale) increases with issue size, particularly for small firms.

C. *Shifts 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. Aggregate profits, however, stagnated in 2000 and 2001. In manufacturing, which contains most of the high-tech industries, profits collapsed in 2001 falling 87% according to the Census Bureau *Quarterly Financial Reports*. This experience mirrors the behavior of the aggregated cash flow data for the industries in our study. For young high-tech firms it is apparent from Figure 2b that there was a dramatic boom in cash flow beginning in 1994. For the six years from 1995 through 2000, cash flow averaged 90% above the value predicted by the 1980 to 1993 exponential trend. After 2000, young-firm cash flow collapses. Mature firms also experience a significant cash flow boom beginning in 1994.

It has been widely documented that corporate income (and therefore internal equity finance) is highly volatile. One explanation is the fact that labor costs are quasi-fixed so that shocks to other costs or revenues lead to disproportionate changes in profits. Goldin (2000) argues that 20th century labor markets changed from spot markets to markets with substantial investments in human capital, labor hoarding, and job security. The 1990s internal finance boom was likely the result of a number of favorable, but temporary, shocks to nominal interest rates, oil prices, and exchange rates combined with quasi-fixed labor costs particularly for highly skilled workers, the preponderance of employees at high-tech firms.

In addition to the major shifts in cash flow, fluctuations in the supply of *external* equity for the high-tech industries were also dramatic during this period. Figures 2a to 2c provide information for net public equity issues with negative issues (buybacks) set to zero. Between 1994 and 1996, young firms collectively increased their net stock issues by nearly 200%. Starting from this high base, young firms again increased stock issues by nearly 265% 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. Between 2000 and 2002, however, young-firm stock issues fell by more than 83%. 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 between 1995 and 2002.[4]

This correspondence between cycles in share issues and stock prices is probably not a coincidence. Many financial economists have argued that there was mispricing, even a bubble, in the Nasdaq in the late 1990s.[5] 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." Baker, Stein, and Wurgler ((2003) p. 970) 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." In addition, a number of studies report evidence that mispricing affects investment, particularly for equity-dependent firms (see Chirinko and Schaller (2001), Baker, Stein, and Wurgler (2003), Polk and Sapienza (2004), and Gilchrist, Himmelberg, and Huberman (2005)).

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, which lowered their cost of external equity finance. 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.

D. Empirical Predictions for R&D and Equity Finance

To motivate the empirical hypotheses we test, consider first the effect of changes in the supply of equity finance on young high-tech firms. As we will show, these firms typically exhaust their internal cash flow, make negligible use of debt, and raise substantial funds from new share issues. These facts suggest that their marginal source of finance is external equity. In the context of the financing hierarchy discussed earlier, consider two possible equity supply shifts. First, an increase in the supply of low-cost *internal* equity finance (cash flow) shifts the *entire* hierarchy of finance to the right. The consequence is a lower marginal cost of finance for any quantity of external finance raised. Second, a reduction in the cost of *external* equity shifts the rising portion of the financing hierarchy downward, also reducing the marginal cost of finance for firms that use external funds. Thus, for firms that initially exhaust internal finance, we predict that either of these supply shifts should increase the optimal quantity of R&D.

In contrast, mature firms often have cash flow (or buffer stocks of cash) in excess of demand for investment, and do not depend on stock (or debt) issues. In this case, increases in the supply of either internal or external equity finance should not affect the marginal cost of funds and hence should not change R&D. In addition, mature firms, because of established track records (see Gertler (1988) and Oliner and Rudebusch (1992)), may find that external finance (both debt and stock), should they seek it, is a very close substitute for internal finance. Thus, we predict there should be heterogeneity across young and mature firms in how R&D responds to changes in the supply of internal and external finance. This kind of heterogeneity has been widely used to test for the existence of financing constraints and helps us to empirically identify shifts in the supply of finance.

For a constrained firm, an additional dollar of finance should result in less than an additional dollar of R&D. First, firms have other uses of funds besides R&D, including physical investment and working capital. Second, R&D likely has high adjustment costs (see the discussion in Himmelberg and Petersen (1994) and Hall (2002)), possibly substantially larger than the adjustment costs for physical investment (e.g., Bernstein and Nadiri (1989)). Most R&D investment is payment to highly skilled technology workers who often require a great deal of firm-specific knowledge and training. 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.

Several recent papers criticize the use of investment-cash flow sensitivities, particularly in studies that do not control for the potential endogeneity of cash flow or neglect the possibility of external finance.

Kaplan and Zingales (1997) question heterogeneity tests by showing that it is theoretically possible for firms facing a steeper external finance schedule to display a lower investment-cash flow sensitivity than relatively less constrained firms. 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 … would display no excess sensitivity to cash flow," in which case the Kaplan-Zingales criticism does not apply. Alti (2003) and Moyen (2004) calibrate models of firms that use debt as a substitute for internal finance. They run OLS regressions on simulated data from the models to show that cash flow sensitivities can be generated even if firms do not face financing frictions. Among other issues, Alti ((2003) p. 721) considers the information content in cash flow and writes that this econometric problem is "relatively easy to handle; one can remove the effects of the surprise component of cash flow by using lagged instruments." Unconstrained firms in Moyen's (2004) study have substantial cash flow sensitivities because current period debt finance is correlated with contemporaneous cash flow and debt finance is not included in the regression. The firms in our sample use virtually no debt finance, we control for external equity issues (the relevant source of external finance), and we instrument cash flow to eliminate the contemporaneous correlation between external finance and the cash flow regression variable. In addition, Moyen ((2004) p. 2088) notes that the conventional interpretation of investment-cash flow sensitivities from Fazzari, Hubbard, and Petersen (1988) hold "[w]hen constrained firms do not have sufficient funds to invest as much as desired." As we show in Section III, this is the situation for the young firms in our sample.

II. 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 with a quadratic adjustment cost technology. 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 error orthogonal to pre-determined instruments. 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 this model 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 capital investment to the capital stock. To apply the model to R&D, it would be natural to consider profits as a function of the accumulated stock of R&D. Measurement of the R&D stock, however, is fraught with difficulties. The absence of a long time series of R&D expenditures makes perpetual inventory methods for stock computations infeasible and the 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 are quadratic in the ratio of R&D to total assets.

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

$$rd_{j,t} = \beta_1 rd_{j,t-1} + \beta_2 rd_{j,t-1}^2 + \beta_3 s_{j,t-1} + \beta_4 cf_{j,t-1} + d_t + \alpha_j + \nu_{j,t}, \tag{1}$$

where $rd_{j,t}$ is research and development spending for firm j in period t, and $s_{j,t}$ is firm sales, $cf_{j,t}$ denotes gross cash flow, the flow of internal funds defined consistent with previous literature on finance and R&D.[6] All variables are scaled by the beginning-of-period stock of firm assets. The model includes firm effects (α_j) and time effects (d_t). 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 to control for industry-specific changes in technological opportunities that could affect the demand for R&D. If firms satisfy the Euler equation period by period and use all information dated t-1 or earlier to form rational expectations, the residual term ($v_{j,t}$) will be an i.i.d forecast error. A number of factors, however, might induce a firm-specific MA(1) component in the residuals, including short-run deviations from strict rational expectations or autocorrelated optimization errors. We compare regressions with instruments that are valid with i.i.d. errors with regressions that use longer instrument lags necessary with MA(1) errors and the results are robust.

The parameters in equation (1) can be interpreted as functions of the parameters of the original optimization problem. The structural model implies that β_1 is positive and slightly larger than one and β_2 is slightly less than negative one. The lagged sales-to-asset ratio coefficient (β_3) has a positive coefficient under imperfect competition. The lagged gross cash flow-to-asset ratio appears in the specification to account for the cost of other factors of production, under constant returns to scale and the assumption that the marginal products of other factors equal their costs. As such, cash flow enters the specification even without financing constraints, but the structural model implies that the coefficient (β_4) has a negative sign. Finally, a significant advantage of this modeling approach is that the resulting empirical specification, although generated from an explicit optimization problem, has a form that corresponds to an intuitive, dynamic R&D regression (Bond, Harhoff, and Van Reenen (2003) make a similar point).

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. The modified regression equation is

$$\begin{aligned} rd_{j,t} &= \beta_1 rd_{j,t-1} + \beta_2 rd_{j,t-1}^2 + \beta_3 s_{j,t-1} + \beta_4 s_{j,t-1} \\ &\quad + \beta_5 cf_{j,t} + \beta_6 cf_{j,t-1} + \beta_7 stk_{j,t} + \beta_8 stk_{j,t-1} + d_t + \alpha_j + v_{j,t}. \end{aligned} \tag{2}$$

We add contemporaneous gross cash flow, the standard measure of internal equity financing in the financing constraint literature. We also add contemporaneous sales as an additional control for firm demand and to avoid possible omitted variable bias on β_5 due to the correlation between sales and cash flow. While cash flow effects have been widely explored in the literature, few studies have considered external equity (one exception is Brown and Petersen (2007)). We include contemporaneous and lagged values of funds raised by new stock issues scaled by beginning-of-period total assets ($stk_{j,t}$). Bond and Meghir (1994) include similar variables in capital investment regressions. As discussed in Section I, we split the data into young and mature firms. The baseline Euler equation (1) should best describe R&D for mature firms and the financing variables in equation (2) should have positive effects for young firms if financing constraints are important for R&D.

We estimate these equations using several different methods. Our primary approach is the first-difference GMM procedure developed by Arellano and Bond (1991) for dynamic panel models with lagged dependent variables.[7] We treat all right-hand side variables as potentially endogenous and use lagged levels dated *t*-3 and *t*-4 as instruments. The instruments must be lagged at least three periods if the error term follows a firm-specific MA(1) process (Bond et al. (2003) p. 159). If the error is i.i.d., however, instruments dated *t*-2 are valid and we present results with the possibly stronger *t*-2 through *t*-4 instrument set as well. We also show in Section V that the results are robust to alternative data transformations (orthogonal deviations) and dynamic panel estimation with systems GMM.

III. Data Description and Sample Characteristics

A. Industries and Sample Construction

The two-digit SIC industries 28, 35, 36, 37, 38, and 73 contain virtually the entire U.S. high-tech sector. Many of the three-digit industries in this group, however, are not considered high tech and we exclude them from our study.[8] In addition, aerospace, the high-tech part of SIC 37, has very few firms and much of its R&D is funded by the U.S. government. Excluding aerospace, by far the largest three-digit high-tech industries are 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). In 2004, these industries collectively included about 80% of all publicly traded firms in their two-digit industries. As shown in Figure 1, these industries accounted for a very large share of aggregate R&D undertaken by all publicly traded firms.

We construct an unbalanced panel of publicly traded firms in these industries from the Compustat database during 1990 to 2004. We exclude firms incorporated outside of the U.S. and firms with no stock price data. We require firms to have at least six R&D observations, and we exclude firms if the *sum* of their cash flow-to-assets ratio over the sample is less than zero (discussed in more detail below). We trim outliers in all key variables at the 1% level. The results are robust to changes in the outlier rule to exclude either the 0.5% or 2.0% tails. After imposing these restrictions, the regression sample consists of 1,347 firms that account for over 90% of the public-firm R&D in these industries.

The definition of “young” and “mature” firms is based on the number of years since the firm’s first stock price appears in Compustat, which is typically the year of the firm’s initial public offering. Consistent with the definition used for Figures 2b and 2c, 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 V.C.)

We are particularly interested in the R&D investment of young firms. Figure 3 shows the share of R&D in the sample accounted for by the young firms over time. Note that the young-firm share is substantial, averaging 33.8% for the sample period. Also, there is much variation in the share of aggregate R&D accounted for by young firms. Starting from a low of 21.7%, the share peaks at 45.7% in 1998 and then falls to 26.1% by 2004, consistent with the fact that young firms account for all of the recent cycle in high-tech R&D.

INSERT FIGURE 3 ABOUT HERE

B. Descriptive Statistics

Figure 4 plots the median R&D-to-assets ratio (the dependent variable for our regressions) for the firms in the regression sample. For young firms, this ratio rose by 43% between 1990 to 1999 and then fell precipitously in 2001. For mature firms, median R&D intensity largely follows a smooth upward trend with little, if any, cycle. The basic pattern for young and mature firms is similar at the mean and 75^{th} and 90^{th} percentiles, though the boom-bust pattern for young firms is magnified. Thus, R&D *intensity* for young firms has a cyclical pattern like the aggregate data in Figure 2b.

INSERT FIGURE 4 ABOUT HERE

Table I provides descriptive statistics for the regression variables and the sources of finance for the sample firms. For firms in the sample, R&D far exceeds capital expenditure (*capex*). Furthermore, young firms have higher R&D intensities than mature firms (and the differences are highly significant). In contrast, the sales-to-asset ratios (*s*) for young and mature firms are similar. Turning to the sources of finance, the cash flow ratio is slightly larger for young firms. For young firms (but not mature firms) the mean of the cash flow ratio (*cf*) is substantially smaller than the sum of the R&D and capital spending ratio means, implying that young firms must obtain significant funds from an external source. This source is new stock issues. For young firms, the mean of 0.268 for the ratio of stock issues to assets (*stk*) is larger than the cash flow ratio.[9] In contrast, for mature firms, the mean of the stock issues ratio is only 0.021. New debt finance (*dbt*) is near zero for both young and mature firms. While not reported, virtually no young firm ever pays a dividend.

INSERT TABLE I ABOUT HERE

There is significant boom-bust variation in the key financial statistics. For example, for young firms, the mean of the stock issues ratio for 1995 to 2000 is 0.351, while the mean of the stock ratio for 2001 to 2004 is only 0.070. In addition, for young firms, the mean of the cash flow ratio in the 1995 to 2000 period is 0.246 while the mean of this ratio in the 2001 to 2004 period is only 0.136.

The final statistics in Table I report the share of finance from each source relative to total finance raised (the sum of internal cash flow, external public equity issues, and new debt). For young firms, the mean share of gross cash flow is 65.9%, the mean of public equity issues is 32.0%, and the mean of debt finance is just 1.5%. For mature firms, the mean of gross cash flow is 91.6%, the mean of public equity finance is 6.8%, and the mean of debt finance is 1.9%. 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 rely on public equity as their marginal source of finance. If external equity requires a cost premium, as discussed in Section I, 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 usually their marginal source of funds. Firms in our mature sample are therefore not likely to face binding financing constraints. For these firms, equity finance supply shifts 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. 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 IA in the Appendix. For the negative cash flow firms, just 25% of the cash flow observations are positive (compared to 85% in the rest of the sample). In 1990, 1997, and 2004, these firms account for just 0.8%, 3.2% and 4.3% of aggregate R&D in the high-tech industries. Their median cash flow ratio is -0.172 (the mean 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% of total financing. The small size of these firms often leads to ratios that are highly variable and very large (in absolute value), which could give them disproportionate impact on the results. Considering how unimportant these firms are for aggregate R&D, we exclude them from our primary sample, but report their regression results in Section V.E.

IV. Econometric Results

A. Pooled Sample Estimates

Table II presents one-step GMM coefficient estimates and standard errors for the 1990 to 2004 sample of high-tech firms. We report one-step estimates because the standard errors from two-step GMM are known to be downward biased in small samples (e.g., Arellano and Bond (1991) and Windmeijer (2005)). The standard errors are robust to heteroskedasticity and any arbitrary pattern of within-firm serial correlation. The instruments are lagged values dated *t*-3 and *t*-4, which are valid even if the error structure is MA(1). We report separate regressions with aggregate and industry-level time dummies. The first two columns give the baseline Euler equation specification (equation (1) from Section II). The *p*-

values for the *m*1 statistic indicate first-order autocorrelation in the errors, which is expected with first-difference estimation. The *m*2 statistics do not reject the null of no second-order autocorrelation. The Sargan test rejects the validity of the instruments in the regression with aggregate time dummies, but does not reject with industry-level time dummies. The third and fourth columns report pooled regressions with the financial variables. The results indicate a strong 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. The Sargan tests do not reject instrument validity. We note, however, that the dynamic effects of lagged R&D and its square are well below the theoretical values of approximately one and negative one predicted by the structural model. We make more progress in understanding these results by splitting the sample.

INSERT TABLE II ABOUT HERE

B. Comparison of Young and Mature Firms

Table III presents regressions for young and mature firm subsamples 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 estimated dynamics conform reasonably well with the Euler equation predictions for the mature firms (confidence intervals for rd_{t-1} and rd_{t-1}^2 coefficients that include one and negative one, respectively). These results are consistent with the summary statistics that imply the absence of binding financing constraints in the mature-firm sample.

INSERT TABLE III ABOUT HERE

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. Furthermore, in the two regressions, the point estimates for contemporaneous cash flow (0.166 and 0.150) and contemporaneous stock (both 0.148) 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 predictions of the structural model. This outcome is expected if young firms face financing constraints because the Euler equation is derived under the assumption of perfect capital markets.

Comparison of the regressions with aggregate and industry time dummies shows that our results are not much affected by unobserved industry technology shocks or other time-varying industry-level variables correlated with R&D investment opportunities. If a correlation of financial variables with investment opportunities were an important source of bias, then the financial coefficients should decline substantially when we include industry-level time dummies.

Four main features of the 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. Third, the aggregate 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 estimates in Table III suggest that young firms invest approximately 15% of additional equity funds in R&D. As discussed in Section I, we expect the magnitude of these coefficients to be substantially less than one. 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.

Can the effects estimated here for young firms explain a substantial portion of the 1990s R&D boom? While a structural answer to this question is beyond the scope of our study, we can use the results from Table III to perform a simple, but suggestive, calculation. As described earlier, we estimate an exponential trend in aggregate R&D from 1980 to 1993 for all young firms in the seven high-tech industries. We then define the amount of "boom" R&D, for 1994 through 2000, as the difference between the actual values and the predicted trend values. We use the same procedure to define "boom" amounts of gross cash flow and new stock issues. These calculations are done just for young firms because there is evidence of an R&D boom and significant financial effects only for young firms. With these definitions and the estimated coefficients from Table III (with industry time dummies) the cash flow and stock issue booms explain 72% of the 1994 to 2000 R&D boom in the seven high-tech industries. From 2001 to the end of the sample in 2004, the bust in both internal and external finance explains 78% 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 new share issues. Because the recent cycle in R&D for the U.S. economy is concentrated almost entirely in young firms from the industries we study, this calculation suggests that the financial effects have important macroeconomic implications.

D. Was the Level of R&D Excessive in the Late 1990s?

Our interpretation of the evidence presented here is that relaxed financing constraints in the 1990s allowed young high-tech firms to raise R&D investment closer to the level consistent with perfect capital markets. In addition, due to spillovers created by R&D, the *socially* optimal level of R&D may be even greater than what is privately optimal (see the reviews in Griliches (1992) and Jaffe (1996)). For example, Jones and Williams (1998) link the theoretical models of new growth theory to the empirical findings in the productivity literature and 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." Another possibility, however, is that young firms invested excessively in R&D—possibly even compared to the social optimum—to cater to irrational investors who focused on the high Nasdaq valuations in the late 1990s and wanted to see more

R&D in these firms. Several pieces of evidence, however, are inconsistent with this alternative interpretation of our findings.

First, recall that Figure 2c shows little or no boom in R&D for mature firms and mature firms have no significant financial effects in the regressions. If young firms responded excessively to high stock prices, why did mature firms not behave similarly? One possibility is that stock market valuations did not rise much for mature firms. Between 1990 and 1999, however, the average Tobin's *q* for mature firms rose 78%. While this figure is less than the young firm increase (122%), one would have expected some mature firm financial effects on R&D if the primary source of these effects were an attempt to impress irrational investors with excessive R&D activity.

The behavior of capital investment is also helpful in assessing the alternative view. Firms that seek to cater to irrational investors would likely expand physical investment at least as much as R&D for two reasons.[10] First, unlike R&D (which is expensed), capital investment does not reduce accounting profits. Second, as discussed previously, there is substantial evidence of lower adjustment costs for capital investment than for R&D. The comparison of physical and R&D investment, however, is inconsistent with the view that catering explains the financial effects we find for R&D. Starting in 1990 the median capital investment-to-assets ratio rises just 23.6% to its peak, while the R&D ratio rises 42.6%. Therefore, the financial boom appears to have had a smaller, not a greater, effect on physical investment than on R&D. Furthermore, using a parallel regression specification, the financial coefficients for capital investment are substantially smaller than for R&D. There is a small positive (but insignificant) cash flow effect and a significant contemporaneous stock effect for young firms in the capital spending regressions, but the coefficient (0.045) on the stock variable is only 30% of the corresponding effect for R&D.

We conduct two additional tests to evaluate the "overinvestment" hypothesis. First, we explore how the relationship between finance and R&D differed across firms with strong and weak governance characteristics (as measured by the Gompers, Ishii, and Metric (2003) index, averaged over the sample period for each firm). If the shifts in supply of finance led to excessive R&D, then we would expect to see a stronger relationship between finance and R&D in firms with weak corporate governance. In fact, we find no difference in the relationship between stock issues and R&D across strong and weakly governed firms, while the R&D-cash flow sensitivity is actually lower in the firms with the weakest governance characteristics.[11] Second, we examine whether the financial effects were larger in firms with less experienced managers. If managers with longer tenures are less responsive to short-run investor sentiment (see, e.g., Narayanan (1985)), and if the financial effects we identify reflect overinvestment, then the financial effects on R&D should be largest in firms with the least experienced managers. We find no significant differences between firms with the least experienced managers and the remainder of the sample.

V. Alternative Tests and Robustness

We explore a wide variety of alternative specifications and a number of different estimation approaches. 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.

A. Financial Variables and Expectations

The specification and the industry-level time dummies control for expectations and demand factors. Moreover, the heterogeneity we obtain in the results for financial variables across young and mature firms helps assure that the financial variables in the regressions are not simply proxies for expectations. Nonetheless, we pursue two additional sets of tests that add confidence to the interpretation we offer for the results above.

First, we include various measures of Tobin's q as an additional proxy for expectations that might affect R&D demand. Although recent literature identifies a number of measurement problems with q (see, for example, Erickson and Whited (2000)), it has been widely used as a forward-looking control for investment opportunities. We include both beginning-of-period q, as is common in the literature, and, in a particularly strong test, we include end-of-period q that conveys all contemporaneous information available from the stock market. The financial results change very little.

Second, following the lead of Bond et al. (2003), we estimate simple forecasting equations for future profits for both the young and mature firms. These OLS regressions predict cash flow from the first and second lags of R&D, sales, capital expenditure, and cash flow. Not surprisingly, in these reduced-form regressions, cash flow lags have some forecasting power for future cash flow. Importantly, however, cash flow appears to be a better proxy for future profitability in mature firms.[12] Since our R&D specification finds no significant cash flow effect for mature firms, the forecasting results provide additional confidence that the significant cash flow coefficients we identify for young firms are not due simply to cash flow signaling expected future profits.

B. Physical Capital Adjustment Costs

The assumptions used to derive the baseline regression specification require that the marginal product of all factors except R&D equal their marginal costs within the one-year data period. With this assumption, the researcher does not need to specify the particular form of the production function to estimate the Euler equation, as discussed by Bond and Meghir (1994). In our context this assumption requires that physical capital not face rising marginal adjustment costs, which may be unrealistic.[13] We note, however, that the firms in our study invest relatively little in physical capital compared to R&D (see Table I) and some studies find that capital adjustment costs are modest (e.g., Cooper and Haltiwanger (2006) p. 623).

Nevertheless, we consider the possibility that capital adjustment costs drive a wedge between the marginal product of capital and its user cost. In this case, the marginal product of capital would enter as an additional term in the Euler equation. Marginal products are functions of the factor inputs. Thus, we add linear terms for the inputs of capital and employment, scaled by assets, to the baseline regressions from Table III. This approach provides a first-order approximation to the marginal products of capital and labor for general production functions. The capital variable is marginally significant for young firms, but not for mature firms. Employment is not significant at the 5% level for either young or mature firms. Most important, however, the financial effects and their statistical significance in this more general specification remain almost the same as those in Table III.

C. Alternative Sample Split Criteria

To explore how the results are affected by the choice of the classification criterion for the young and mature firm subsamples, we change 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 subsample of firms that have been public for 10 or fewer years. The contemporaneous gross cash flow coefficient rises to 0.176 and the contemporaneous stock coefficient is almost identical for this subsample. If we redefine the mature firms to be public for at least 20 years, financial effects remain insignificant.

In addition, we consider two other frequently used criteria (e.g., Gilchrist and Himmelberg (1995)) for splitting the sample according to firms' a priori likelihood of facing financing constraints: presence of a bond rating and payout ratio (dividends plus stock buybacks divided by total assets). For the firms with either no bond rating or low payout (less than 1% of assets), we obtain cash flow and stock coefficients similar in magnitude and significance to those for young firms reported in Table III. The financial coefficients for the "unconstrained" firm groups in the alternative sample splits are also very similar to the results for mature firms in Table III.[14]

D. Alternative Instruments and Estimation Methods

The use of instrumental variable techniques to address concerns about endogeneity in panel data studies of financial constraints has been successful in recent research (see the survey in Bond and Van Reenen (2007)). A number of authors have raised concerns, however, about the weakness of lagged levels as instruments in first-difference GMM regressions. Blundell and Bond (1998) show that a weak instrument problem arises if the time-series process for the regression variables is close to AR(1). For both young and mature firms we easily reject the hypothesis of a unit root for each of our regression variables. Indeed, GMM estimates of the AR(1) coefficient for all our regression variables in both young and mature firms are well below 0.5, except for mature-firm sales (0.518).[15] These results give us confidence that weak instruments are not a significant source of bias for the first-differenced GMM results in Table III.

Nonetheless, we consider whether the results change with a possibly stronger instrument set or different estimation methods that may be less affected by the weak instrument problem. The instruments for the estimates in Table III are lagged at least three years, as is necessary if the original regression error is MA(1). If the original error structure is i.i.d., however, instruments lagged two years are valid, which could improve the relevance of the instruments. The first column (for mature firms) and the third column (for young firms) of Table IV report estimates with t-2 instruments added. The second and fourth columns of Table IV provide results from an "orthogonal deviations" regression in which the fixed effects are eliminated by subtracting the forward means of each regression variable (Arellano and Bover (1995)). This method preserves some of the level information in the data that is eliminated with standard first difference methods. The results in Table IV are quite similar to those in Table III. In particular, the financial effects are similar in magnitude (and significant) for young firms while the financial effects are quantitatively small (and mostly insignificant) for mature firms.[16]

INSERT TABLE IV ABOUT HERE

A "system" GMM estimator (Arellano and Bover (1995) and Blundell and Bond (1998)) also addresses a potential weak instrument problem and has been applied to the study of finance and growth by Beck, Levine, and Loayza (2000) and Beck and Levine (2004). This system approach can both improve asymptotic efficiency and reduce estimation bias in finite samples, but it requires additional moment restrictions to hold in the data. Again, Blundell and Bond (1998) show that the benefits of the system approach rise as the AR(1) coefficient for the regression variables approaches unity, which is not the case in our data. The financial effects estimated with the system GMM technique are quite similar to those reported in Tables III and IV. For young firms, however, the Sargan test rejects the validity of the additional instruments needed for system GMM, suggesting that the necessary moment conditions for this approach are not satisfied in our data.

E. Negative Cash Flow Firms

In Section III, we discuss the characteristics of the "negative cash flow" firms that we exclude from the primary regression sample. The *sum* of the gross cash flow-to-assets variable for these firms is negative over the entire sample. The gross cash flow regression coefficients are negative (although not significant) for this subsample. This result is not surprising since these firms have not reached the stage at which internal equity is a source of funds. They must obtain all financing from outside equity (see appendix Table IA for summary statistics for these firms). It is therefore also not surprising that the young firms in this subsample have a positive and significant coefficient on the stock variable (0.079, standard error of 0.019). Recall that these firms account for a trivial amount of aggregate R&D.

F. Results for Firms Outside of High Tech

Figure 1 shows that the 1990s boom in R&D investment was confined almost entirely to the seven high-tech industries that are the focus of our study. It is therefore interesting to examine the summary statistics and regression results for all other young publicly traded firms covered by Compustat. The summary statistics for other firms (with positive R&D) are very different from the numbers reported in Table I for the high-tech industries. For other young firms, the overall median R&D-to-asset ratio is low (0.030) compared to the median figure in Table I (0.137 for young high-tech firms), consistent with the fact that firms outside high tech have relatively low demand for R&D. In addition, the sum of the median R&D and capital spending ratios for all other firms (0.077) is much lower than their median cash flow (0.132), suggesting that the typical young firm outside of high tech may not face binding financing constraints. We estimate dynamic R&D regressions for these firms and find that financing effects are small (and generally insignificant) compared to those reported in Table III.[17] These results are consistent with both the summary statistics (indicating no binding financing constraints) and the absence of a finance-driven R&D boom beyond the seven high-tech industries.

VI. Economic Implications

Our interpretation of the empirical findings presented here is that a major shift in the availability of internal and external equity finance relaxed financing constraints for a large number of young high-tech companies in the mid and late 1990s, which contributed significantly to the aggregate R&D boom. Furthermore, finance shifts help explain the reversal of R&D growth in 2001 to 2004. We briefly consider some of the implications of these findings 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. 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 labor productivity growth. Indeed, non-farm labor productivity growth began to rise in 1996, two to three years after the beginning of the R&D boom. The high-tech industries responsible for the recent R&D boom include the chief information technology industries, frequently 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 likely contributed to robust productivity growth in the "new economy" era.

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

The U.S. currently has the second highest corporate income tax among OECD countries. 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. Our regression results imply that lower cash flow reduces R&D for constrained firms (young firms in this study) independent 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.

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 (see the introduction) to introduce financing constraints into the modern endogenous growth literature focus on the role of intermediation and debt finance.[18] While the historical absence of public equity finance in most countries certainly justifies analysis of debt, recently stock market capitalization has grown tremendously in both developed and developing countries (see Rousseau and Wachtel (2000)). 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 finds that measures of the degree of stock market development are positively correlated with growth (for example, Atje and Jovanovic (1993), Levine and Zervos (1998), Arestis, Demetriades, and Luintel (2001), Rousseau and Wachtel (2000), and Beck and Levine (2002, 2004)). In particular, using dynamic panel data techniques, Beck and Levine (2004) find that both stock market and bank development have an economically large impact on economic growth. These studies, however, do not emphasize equity markets as an important *source* of finance; rather, they focus on how stock markets provide exit options for investors, more liquidity, or better information.[19] 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 should consider the possibility that stock markets contribute to economic growth by directly funding innovation, particularly for young companies.

A country with closed equity markets can obtain a significant new source of equity finance—foreign investors—by liberalizing its stock markets. Bekaert, Harvey, and Lundblad ((2005) p. 4) argue that "equity market liberalization directly reduces financing constraints in the sense that more foreign capital becomes available, and foreign investors could insist on better corporate governance, which indirectly reduces the cost of internal and external finance." The empirical findings in Bekaert, Harvey, and Lundblad (2001, 2005) show that equity market liberalization is associated with a substantial increase in economic growth. These results, along with our findings that link equity finance to R&D, suggest that equity market liberalization may have a disproportionate impact on a country's rate of intangible investment and innovation.

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, find evidence that a country's financial architecture may matter (see Tadesse (2002), for example). Our findings also suggest that 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, and their world share of high-tech production has fallen substantially, exactly the opposite of the U.S.

VII. Summary

This paper explores 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 to 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, variables that measure access to both internal and external equity finance 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 to 2004 aggregate R&D cycle.

These results contribute to the understanding of 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 causal 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 causality in this relationship. Our work complements these findings 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. 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.

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FOOTNOTES

[1] Recent efforts to incorporate financing into models of endogenous growth include King and Levine (1993), De la Fuente and Marin (1996), Morales (2003), Aghion, Howitt, and Mayer-Foulkes (2005), and Aghion et al. (2005).

[2] Public firms undertake nearly all of U.S. R&D: the sum of R&D for public firms tracked by Compustat was equal to 90.1% of total industrial R&D reported by the NSF for 2003.

[3] One reason may be the very low aggregate net equity statistics (see Brealey and Myers (2000), Table 14.1). These statistics, however, greatly understate the importance of public equity issues because mature firms often use large stock buybacks to distribute earnings to shareholders. Many firms make extensive use of follow-up stock issues early in their life cycle (e.g., Rajan and Zingales (1998)). Brown (2007), Fama and French (2005), and Frank and Goyal (2003) present facts on the increasing use of public equity.

[4] The Nasdaq Index jumped from 1,574 at the start of 1998 to over 5,000 in 2000, only to bottom out at approximately 1,100 in August 2002.

[5] For example, Bond and Cummins ((2000) p. 100) conclude that there are "serious anomalies in the behavior of share prices" in the 1990s. See Chen, Hong, and Stein (2002), Wurgler and Zhuravskaya (2002), Kumar and Lee (2006), and Sadka and Scherbina (2007) for explanations of persistent mispricing on stock markets.

[6] See Hall (1992) and Himmelberg and Petersen (1994). Because R&D is treated as a current expense for accounting purposes, the *cf* variable adds R&D expenses to the standard measure of net cash flow (after-tax earnings plus depreciation allowances).

[7] For early examples of dynamic panel techniques applied to issues of financial development and economic growth, see Beck, Levine, and Loayza (2000) and Beck and Levine (2004).

[8] See "An Assessment of United States Competitiveness in High-Technology," United States Department of Commerce, February 1983 for a list of three-digit high-tech industries.

[9] 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.

[10] We thank an associate editor for this line of argument.

[11] When we interact cash flow with the Gompers, Ishii, and Metric (2003) index we obtain negative coefficients that are jointly significant at the 10% level, suggesting that cash flow effects decline as governance characteristics weaken. An associate editor points out that managers of well-governed firms might actually be *more* willing to cater to market sentiment. As we have discussed, however, the relationship between R&D and stock issues is neither stronger nor weaker for firms with strong governance characteristics.

[12] Conditional on the other variables, a one dollar increase in both current and lagged cash flow predicts a 20 cent increase in next year's cash flow for young firms but a 46 cent increase in future cash flow for mature firms.

[13] We thank an anonymous referee for this observation.

[14] The results are available on request. There is no statistically or economically significant stock effect for either bond-rated or high-payout firms. Furthermore, contemporaneous cash flow coefficients are near zero and insignificant. As is the case in Table III, the lagged cash flow coefficient is positive for bond-rated and positive-payout firms. These lagged coefficients are slightly larger than the corresponding coefficient for mature firms in Table III, but a chi-squared test does not reject the null of no effect for the high-payout case.

[15] As discussed in Bond et al. (2003), the first-difference GMM estimates of the AR(1) coefficient will be biased downward if the data have a unit root. But even OLS estimates of the AR(1) coefficients for our variables, which are biased upward without firm fixed effects, strongly reject a unit root.

[16] The outlier trim is designed for the first difference method, and we do not change it for the orthogonal deviations regressions to maintain comparability. One young firm, however, had a large effect on the estimated dynamics in

the orthogonal deviations regression and is eliminated from the regression reported in the fourth column of Table IV. The elimination of this firm has negligible effects on the financial coefficients.

[17] There is a relatively small and marginally significant coefficient for current stock issues in young non-high-tech firms of 0.053 (0.025).

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

[19] Perhaps one reason for the lack of emphasis on stock markets as a source of finance is the finding that liquidity measures (such as trading volume) are significant for growth while measures of stock market capitalization typically are not. (See Levine (2005); an exception is Arestis, Demestraides, and Luintel (2001)). Stock market capitalization, however, is an imperfect proxy for new stock issues. In addition, most studies examine data from the late 1970s through the early 1990s, predating most of the recent surge in the development of stock markets and the use of external equity finance.

Table 1
Sample Descriptive Statistics

The regression sample is constructed from publicly traded high-tech firms with coverage in the Compustat database during 1990 to 2004. We exclude firms incorporated outside of the U.S., firms with no stock price data, and firms without at least six R&D observations. We also exclude firms if the sum of their cash flow-to-assets ratio over the sample period is less than or equal to zero. All variables are scaled by beginning-of-period total assets. Outliers in all variables are trimmed at the 1% level. 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. The final column reports *p*-values for tests that the mean and median values differ across young and mature firms. By three-digit SIC code, the high-tech industries are: 283, 357, 366, 367, 382, 384, and 737.

Variable and Statistic	Full Sample	Young Firms	Mature Firms	Difference (*p*-value)
rd_t				
Mean	0.170	0.194	0.098	0.000
Median	0.116	0.137	0.074	0.000
Std. Dev.	0.217	0.240	0.100	
90th Percentile	0.350	0.395	0.186	
$capex_t$				
Mean	0.064	0.069	0.049	0.000
Median	0.041	0.042	0.039	0.000
Std. Dev.	0.149	0.171	0.042	
90th Percentile	0.130	0.143	0.102	
s_t				
Mean	1.212	1.227	1.167	0.000
Median	1.083	1.076	1.099	0.145
Std. Dev.	0.993	1.095	0.597	
90th Percentile	2.122	2.213	1.837	
cf_t				
Mean	0.205	0.217	0.172	0.000
Median	0.185	0.194	0.166	0.000
Std. Dev.	0.369	0.398	0.261	
90th Percentile	0.457	0.495	0.347	

stk_t				
Mean	0.204	0.268	0.021	0.000
Median	0.006	0.010	0.001	0.000
Std. Dev.	1.160	1.338	0.155	
90^{th} Percentile	0.427	0.643	0.050	
dbt_t				
Mean	0.009	0.009	0.007	0.515
Median	0.000	0.000	0.000	0.655
Std. Dev.	0.344	0.394	0.113	
90^{th} Percentile	0.061	0.058	0.067	
Sum Cash Flow / Net Finance				
Mean	0.686	0.659	0.916	0.000
Median	0.731	0.692	0.957	0.000
Std. Dev.	0.399	0.421	0.627	
90^{th} Percentile	1.139	1.110	1.357	
Sum New Stock / Net Finance				
Mean	0.289	0.320	0.068	0.000
Median	0.219	0.247	0.027	0.000
Std. Dev.	0.367	0.381	0.419	
90^{th} Percentile	0.807	0.850	0.484	
Sum New Debt / Net Finance				
Mean	0.021	0.015	0.019	0.820
Median	0.000	-0.001	0.000	0.002
Std. Dev.	0.182	0.194	0.382	
90^{th} Percentile	0.229	0.230	0.378	

Table II
Dynamic R&D Regressions: Pooled Results

Dynamic R&D regressions on the sample of high-tech firms described in Table I are estimated with one-step GMM in first differences to eliminate firm effects. The dependent variable is rd_t. Variable definitions with Compustat data codes are provided in the Appendix. Level variables dated *t*-3 and *t*-4 are used as instruments. Aggregate or industry–specific year dummies are included in all regressions (as indicated in the table). Standard errors robust to heteroskedasticity and within-firm serial correlation appear below point estimates. The statistics *m*1 and *m*2 test the null of no first- and second-order autocorrelation in the first-differenced residuals. The *cf Chi*2 statistic is a Chi-square test of the null that the sum of the current and lagged cash flow coefficients is zero; *stk Chi*2 is the corresponding test for stock issues. Sargan is a test of the null that that the overidentifying restrictions are valid.

Variable	Baseline Euler Equation		Euler Equation with Financial Variables	
rd_{t-1}	0.808	0.789	0.380	0.403
	(0.215)	(0.200)	(0.134)	(0.130)
rd_{t-1}^2	-0.400	-0.384	-0.145	-0.153
	(0.139)	(0.130)	(0.076)	(0.075)
s_t			-0.020	-0.007
			(0.018)	(0.018)
s_{t-1}	-0.007	-0.013	-0.015	-0.022
	(0.016)	(0.017)	(0.009)	(0.009)
cf_t			0.170	0.158
			(0.041)	(0.040)
cf_{t-1}	-0.015	-0.004	0.001	0.006
	(0.045)	(0.045)	(0.016)	(0.016)
stk_t			0.151	0.149
			(0.017)	(0.017)
stk_{t-1}			-0.018	-0.017
			(0.004)	(0.004)
Time Dummies	Aggregate	Industry-level	Aggregate	Industry-level
*m*1 (*p*-value)	0.000	0.000	0.000	0.000
*m*2 (*p*-value)	0.401	0.311	0.249	0.345
*cf Chi*2 (*p*-value)			0.000	0.000
*stk Chi*2 (*p*-value)			0.000	0.000
Sargan (*p*-value)	0.002	0.889	0.138	1.000
Observations	12,248	12,248	12,224	12,224

Table III
Dynamic R&D Regressions for Separate Young and Mature Firm Samples

Dynamic R&D regressions on the samples of young and mature high-tech firms described in Table I are estimated with one-step GMM in first differences to eliminate firm effects. The dependent variable is rd_t. Variable definitions with Compustat data codes are provided in the Appendix. Level variables dated *t*-3 and *t*-4 are used as instruments. Aggregate or industry–specific year dummies are included in all regressions (as indicated in the table). Standard errors robust to heteroskedasticity and within-firm serial correlation appear below point estimates. The test statistics reported at the bottom of the table are described in the caption for Table II.

Variable	Mature Firms		Young Firms	
rd_{t-1}	0.632	0.626	0.382	0.392
	(0.179)	(0.172)	(0.137)	(0.130)
rd_{t-1}^2	*-0.831*	*-0.830*	*-0.142*	*-0.144*
	(0.277)	(0.226)	(0.077)	(0.074)
s_t	0.049	0.048	-0.023	-0.006
	(0.016)	(0.015)	(0.020)	(0.019)
s_{t-1}	-0.031	-0.031	-0.015	-0.023
	(0.011)	(0.010)	(0.010)	(0.009)
cf_t	-0.015	-0.005	0.166	0.150
	(0.032)	(0.031)	(0.044)	(0.043)
cf_{t-1}	0.041	0.040	0.003	0.012
	(0.020)	(0.018)	(0.017)	(0.017)
stk_t	0.031	0.034	0.148	0.148
	(0.029)	(0.030)	(0.017)	(0.017)
stk_{t-1}	-0.010	-0.010	-0.019	-0.017
	(0.011)	(0.011)	(0.004)	(0.004)
Time Dummies	Aggregate	Industry-level	Aggregate	Industry-level
*m*1 (*p*-value)	0.000	0.000	0.000	0.000
*m*2 (*p*-value)	0.795	0.880	0.294	0.432
*cf Chi*2 (*p*-value)	0.382	0.212	0.000	0.000
*stk Chi*2 (*p*-value)	0.539	0.470	0.000	0.000
Sargan (*p*-value)	0.633	1.000	0.103	1.000
Observations	3,393	3,393	8,831	8,831

Table IV
Dynamic R&D Regressions for Separate Young and Mature Firm Samples: Robustness

Dynamic R&D regressions corresponding to the first-differenced GMM results in Table III are estimated with alternative data transformations (first differences and orthogonal deviations) and instrument sets. The dependent variable is rd_t. Variable definitions with Compustat data codes are provided in the Appendix. One-step GMM estimates using first differences to remove firm effects are presented with level variables dated *t*-2 to *t*-4 used as instruments. GMM estimates using a forward orthogonal deviations transformation to remove firm effects are presented with level variables dated *t*-1 to *t*-3 used as instruments. Industry–specific year dummies are included in all regressions. Standard errors robust to heteroskedasticity and within-firm serial correlation appear below point estimates. The test statistics reported at the bottom of the table are described in the caption for Table II.

	Mature Firms		Young Firms	
Variable	First Differences with *t*-2 to *t*-4 Instruments	Orthogonal Deviations with *t*-1 to *t*-3 Instruments	First Differences with *t*-2 to *t*-4 Instruments	Orthogonal Deviations with *t*-1 to *t*-3 Instruments
rd_{t-1}	0.600	0.556	0.403	0.411
	(0.152)	(0.104)	(0.118)	(0.122)
rd_{t-1}^2	-0.785	0.077	-0.151	-0.147
	(0.263)	(0.130)	(0.068)	(0.069)
s_t	0.035	0.046	-0.004	0.015
	(0.014)	(0.009)	(0.016)	(0.014)
s_{t-1}	-0.026	-0.035	-0.023	-0.029
	(0.009)	(0.007)	(0.008)	(0.008)
cf_t	0.019	0.004	0.156	0.175
	(0.027)	(0.021)	(0.034)	(0.037)
cf_{t-1}	0.039	0.015	0.008	-0.016
	(0.017)	(0.015)	(0.016)	(0.018)
stk_t	0.043	0.051	0.138	0.131
	(0.021)	(0.032)	(0.015)	(0.014)
stk_{t-1}	-0.013	-0.040	-0.017	-0.016
	(0.012)	(0.016)	(0.004)	(0.005)
*m*1 (*p*-value)	0.000	0.027	0.000	0.000
*m*2 (*p*-value)	0.733	0.207	0.421	0.306
*cf Chi*2 (*p*-value)	0.035	0.374	0.000	0.000
*stk Chi*2 (*p*-value)	0.226	0.656	0.000	0.000
Sargan (*p*-value)	1.000	0.427	0.975	0.083
Observations	3,393	3,393	8,831	8,822

Appendix: Variable Definitions with Compustat Data Codes

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

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

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

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

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

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

Appendix Table IA: Summary Statistics for Firms with Negative Sum of cf_t

	Negative Cash Flow Firms	Sample Firms
Firms	633	1347
Share cf_t Observations Positive		
mean	0.25	0.85
median	0.24	0.90
Share of Aggregate R&D		
1990	0.008	0.992
1997	0.032	0.968
2004	0.043	0.957
Sales (millions of dollars)		
mean	21.89	478.80
median	5.27	55.18
rd_t		
mean	0.844	0.170
median	0.190	0.116
cf_t		
mean	-4.669	0.205
median	-0.172	0.185
stk_t		
mean	10.663	0.204
median	0.067	0.006
dbt_t		
mean	-0.034	0.009
median	0.000	0.000
Sum Cash Flow / Net Finance		
mean	-0.134	0.686
median	-0.275	0.731
Sum New Stock / Net Finance		
mean	1.117	0.289
median	1.199	0.219
Sum New Debt / Net Finance		
mean	0.044	0.021
median	0.004	0.000

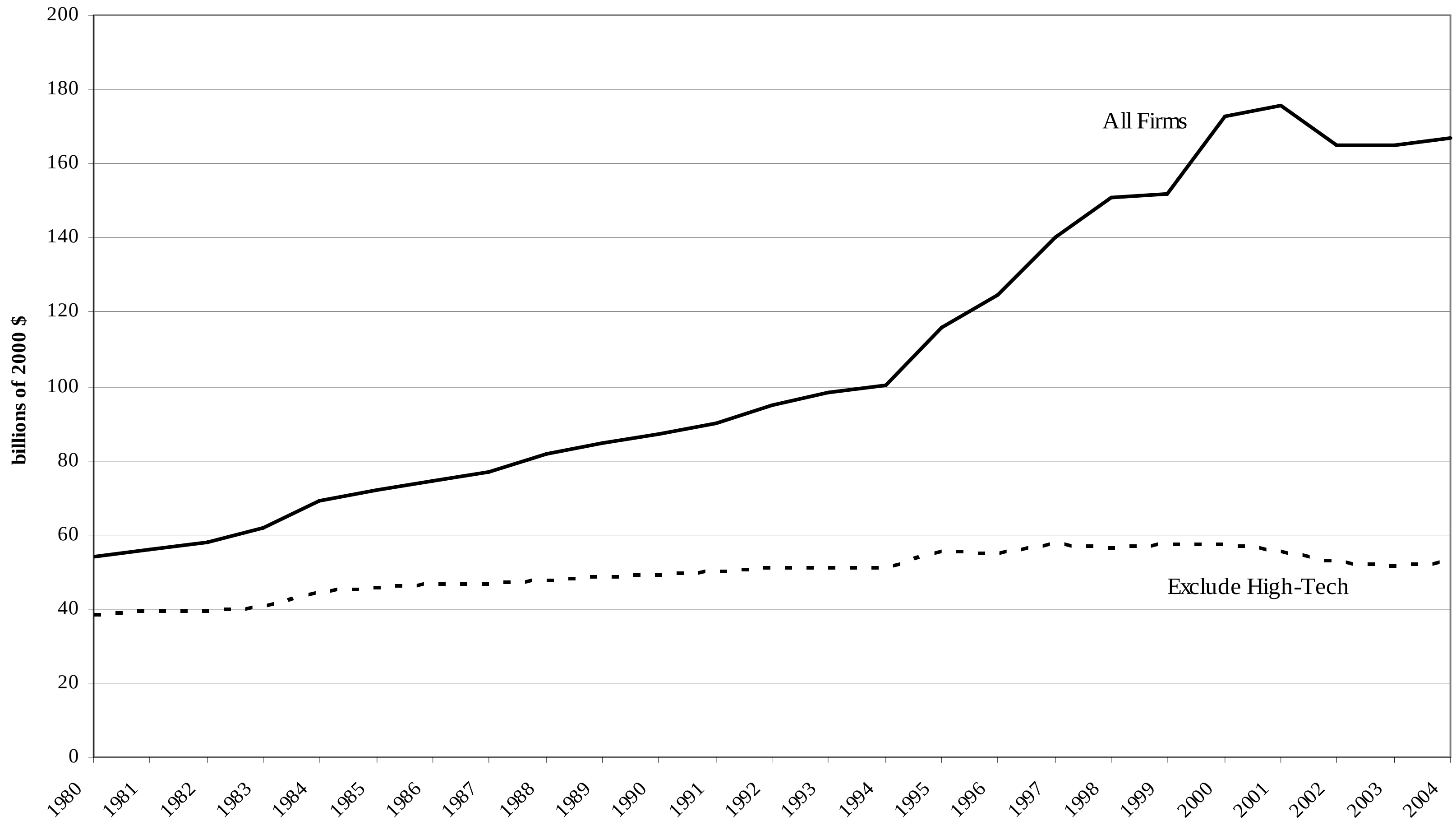

Figure 1. R&D investment. The solid line plots the sum of R&D for all publicly traded companies with coverage in Compustat (financial firms and utilities are excluded) over time. The dashed line plots the sum of R&D for firms in all industries *except* the seven high-tech industries with SIC codes 283, 357, 366, 367, 382, 384, and 737.

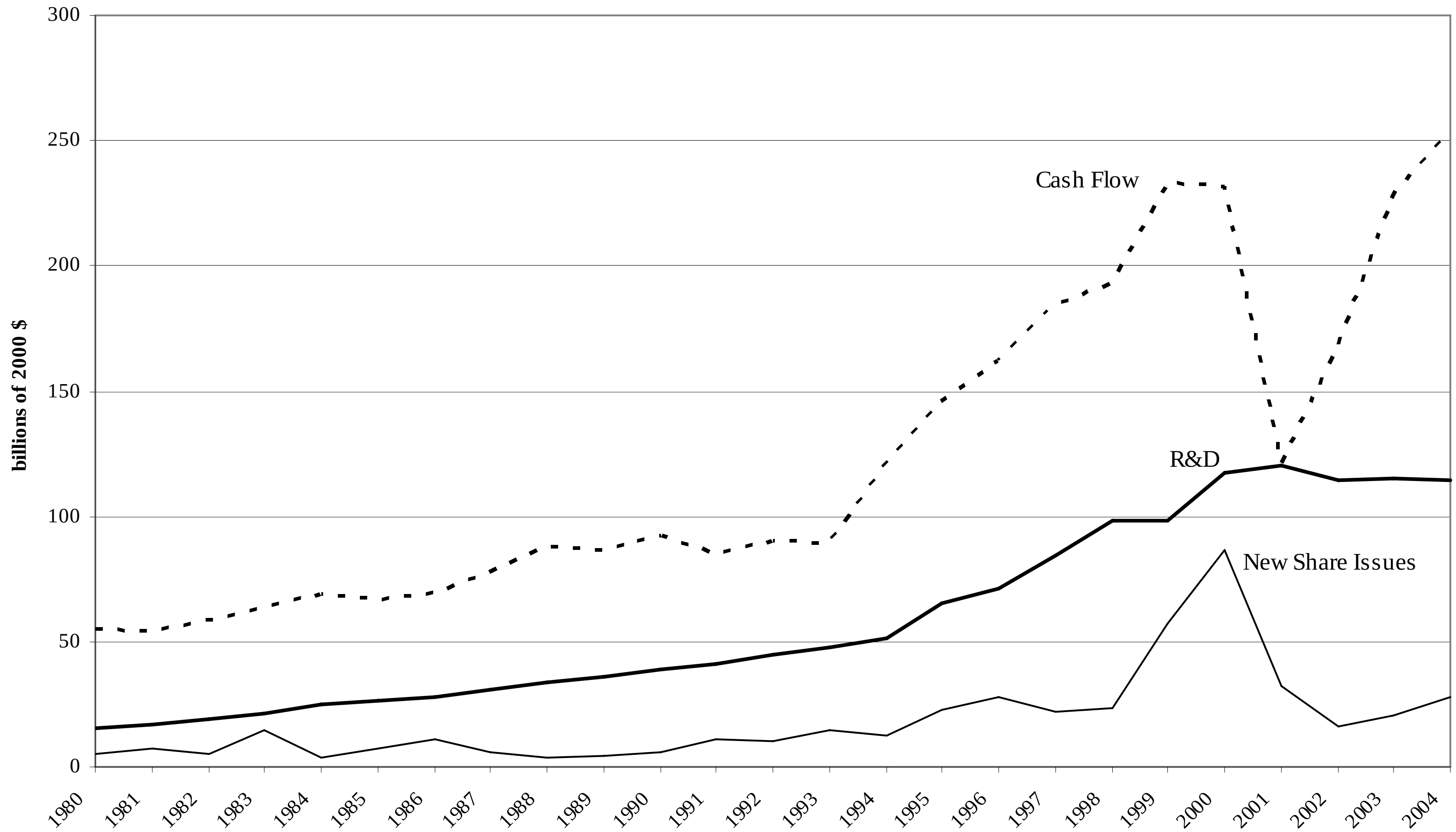

Figure 2a. High-tech R&D, cash flow, and new share issues (all firms). The sample is all publicly traded companies in high-tech industries 283, 357, 366, 367, 382, 384, and 737 with coverage in Compustat. The heavy line plots the sum of R&D for all high-tech firms, the dashed line plots the sum of gross cash flow, and the thin line plots the sum of net new stock issues with negative net issues set equal to zero.

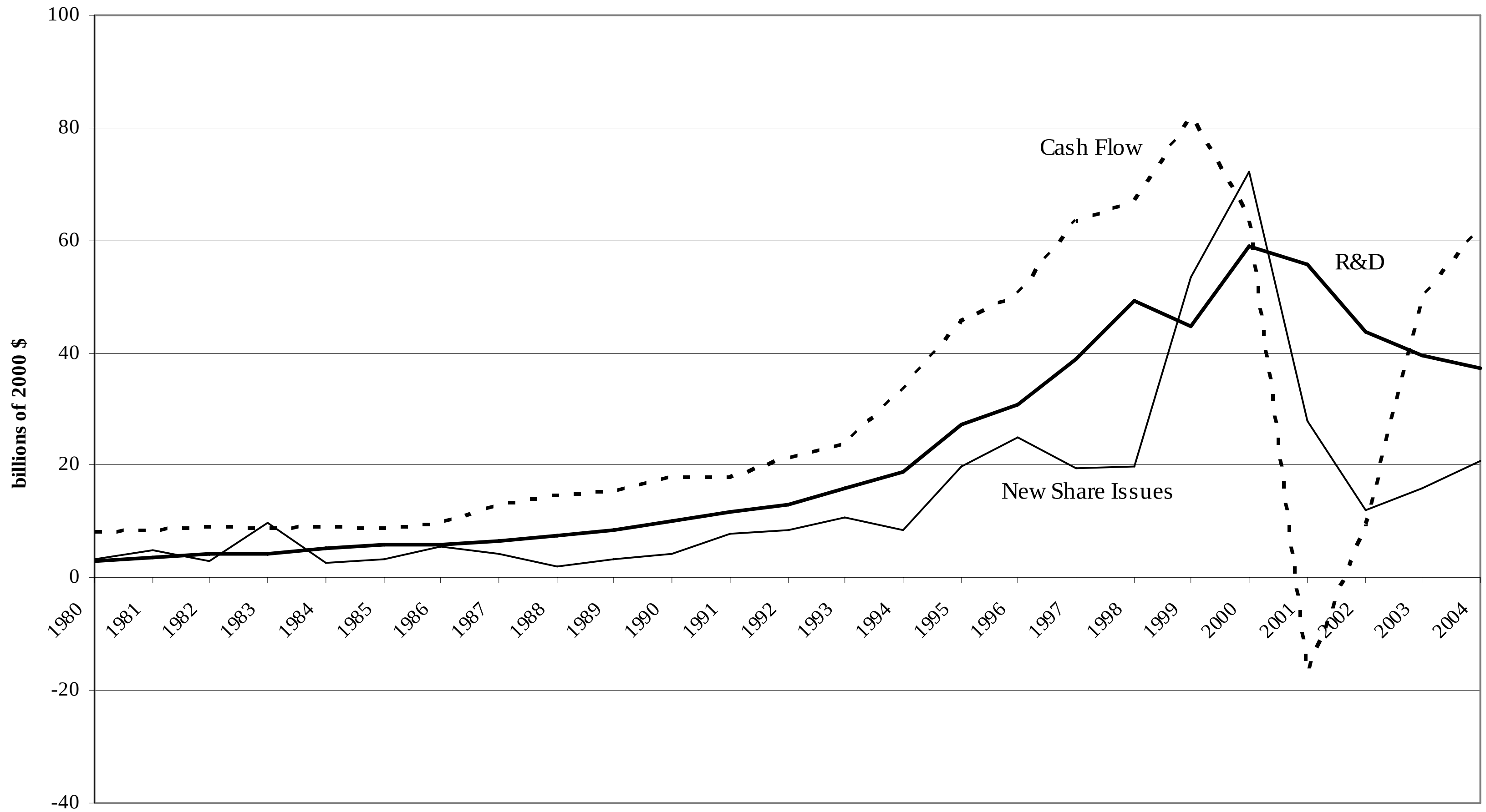

Figure 2b. High-tech R&D, cash flow, and new share issues (young firms). The sample is all young high-tech firms with coverage in Compustat. A firm is classified as young for the first 15 years following the year it first appears in Compustat with a stock price. The high-tech industries are SICs 283, 357, 366, 367, 382, 384, and 737. The heavy line plots the sum of R&D for all young high-tech firms, the dashed line plots the sum of gross cash flow, and the thin line plots the sum of net new stock issues with negative net issues set equal to zero.

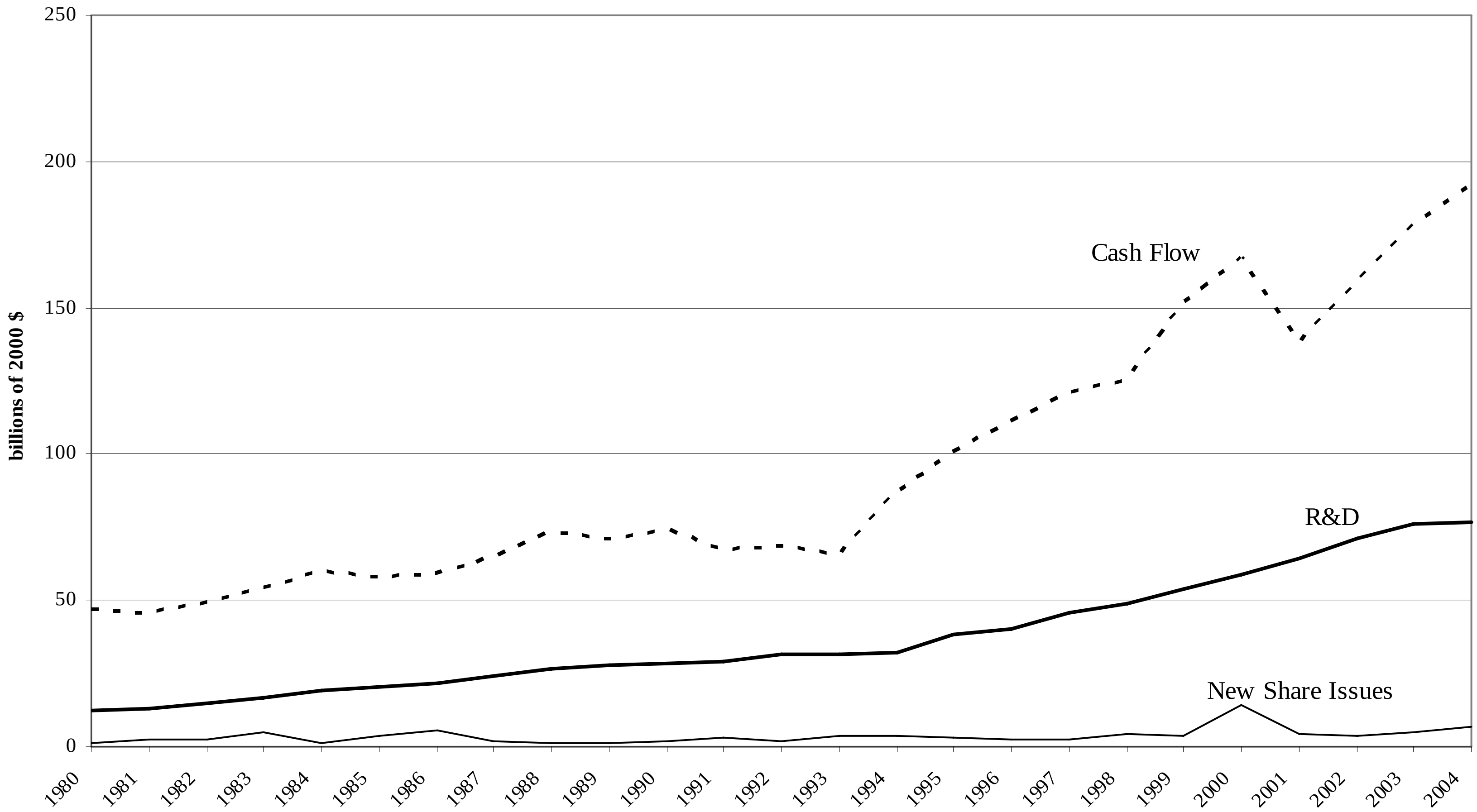

Figure 2c. High-tech R&D, cash flow, and new share issues (mature firms). The sample is all mature high-tech firms with coverage in Compustat. A firm is classified as mature if it is more than 15 years after the year it first appears in Compustat with a stock price. The high-tech industries are SICs 283, 357, 366, 367, 382, 384, and 737. The heavy line plots the sum of R&D for all mature high-tech firms, the dashed line plots the sum of gross cash flow, and the thin line plots the sum of net new stock issues with negative net issues set equal to zero.

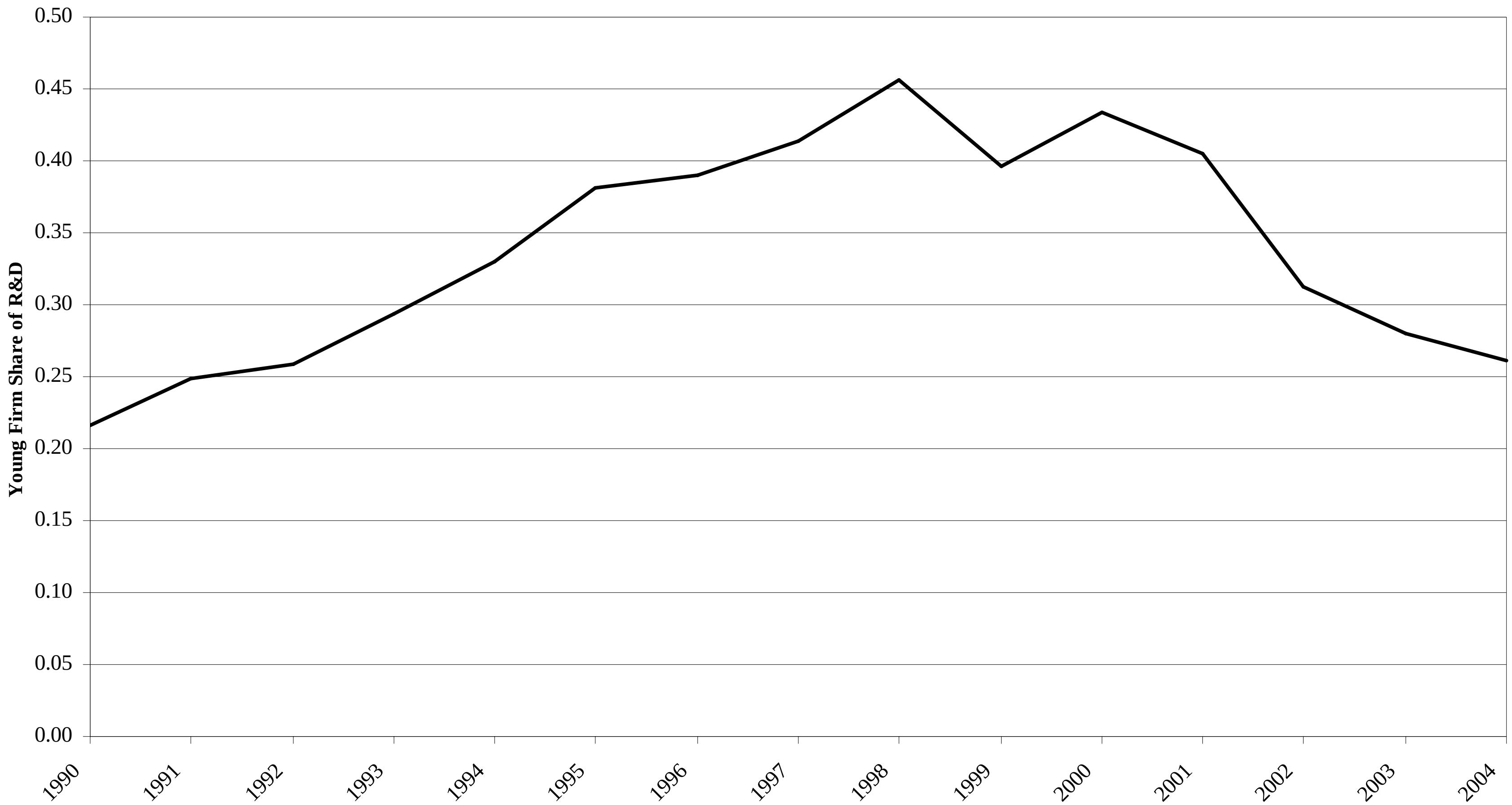

Figure 3. Young firm share of total R&D (regression sample). The line plots the share of regression sample R&D accounted for by young firms over time. A firm is classified as young for the first 15 years following the year it first appears in Compustat with a stock price. The regression sample is described in Section III.A of the paper.

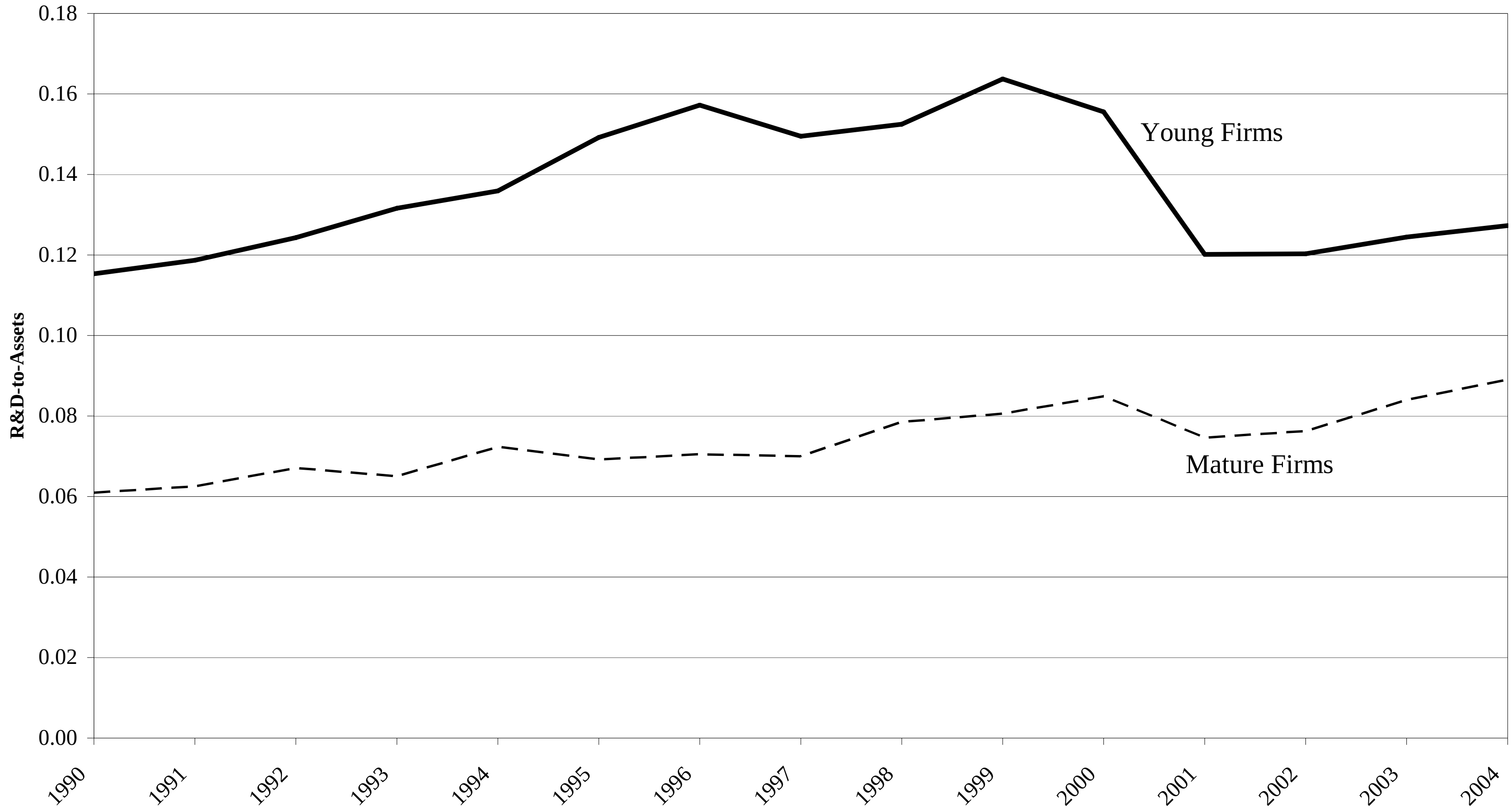

Figure 4. Median R&D-to-assets ratios (regression sample). The solid line plots the median R&D-to-assets ratio for young firms in the regression sample over time, and the dashed line plots the median R&D-to-assets ratio for mature firms. A firm is classified as young for the first 15 years following the year it first appears in Compustat with a stock price, and mature thereafter. The regression sample is described in Section III.A of the paper.