PUBLIC ENTRANTS, PUBLIC EQUITY FINANCE AND CREATIVE DESTRUCTION IN THE HIGH-TECH SECTOR*

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Abstract

This paper explores the role played by new public firms teamed with public equity finance in the recent rapid ascent of the high-tech sector of U.S. manufacturing. The magnitude of stock issues, together with estimates from dynamic investment models, indicates that public equity finance was important for the very high level of R&D investment achieved by new public firms. By 2000, in five key industries, recent public entrants had obtained close to half of the industry sales and performed more than half of the total R&D. In addition, some public entrants rapidly displaced leading incumbents. Our study provides a detailed example of Schumpeterian creative destruction but with one important difference – new public firms, relying heavily on public equity, played the star role.

Key Words: public entrant, public equity finance, Schumpeterian creative destruction, high-tech, research and development

JEL Codes: D92, G32, L16, L25

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I. Introduction

A rapid transformation of U.S. manufacturing occurred in the last few decades of the 20th century. By 2000, a number of high-tech industries -- drugs, office and computing equipment, communications equipment, electronic components, industrial measuring and control instruments and medical instruments -- had grown in size to eclipse virtually all of the major industries which dominated manufacturing for much of the 20th century. By 2000, based on value added figures and the new NAICS classification system, electronic components (e.g., semiconductors) was the largest U.S. manufacturing industry, drugs was third, instruments was fifth and communications equipment was sixth. NSF figures show that in 2000 the six high-tech industries accounted for around 47% of manufacturing R&D and almost 30% of the total R&D of all firms in the U.S. economy.[1] Clearly, a very large share of the new knowledge relevant for macro economic growth arises from these industries.[2]

Between 1970 and 2004, initial public offerings led to the creation of nearly 2000 firms in the six high tech industries noted above. This constituted 54 percent of the total IPOs in manufacturing, which is a remarkably high percentage, given that the six industries accounted for less than five percent of the total three-digit SIC industries in manufacturing. Because of this concentrated pattern of entry, by 2004, roughly 48% of the publicly traded firms in manufacturing were located in the six three-digit SIC industries (out of over 130), indicating a major re-focusing of U.S manufacturing.

In this paper we explore the role played by new public firms, teamed with public equity finance, in the recent ascent of the high-tech sector of U.S. manufacturing. Little attention has been paid to the impact of new public firms and their use of public equity finance. This lack of attention is surprising. In the U.S., in modern high-tech industries, public firms account for nearly all of the output and R&D. Furthermore, it is likely that an important advantage of the public firm is access to public equity finance. This is particularly true for young high-tech firms, where debt finance is typically negligible and internal equity finance is often small or negative. Nevertheless, public equity finance has typically been ignored,

[1] For statistics on manufacturing and the entire U.S. economy, see Science Resource Statistics, National Science Foundation. Five of the six industries in our study are at the top of the list of industries with the greatest number of innovations according to Acs and Audretsch's (1988, 1990) examination of SBA innovation data.
[2] In recent years, an explosion of literature on endogenous growth focuses on technological change created by R&D of profit maximizing firms. See Aghion and Howitt (1998) for a review of the literature.

possibly due to misleading aggregate statistics suggesting that public equity finance is unimportant in the U.S. economy.

The first objective of our paper is to explore the importance of public equity finance for R&D, the main investment for high-tech firms and the pivotal investment for innovation and creative destruction. We use GMM to estimate dynamic R&D models similar to those developed in Bond and Meghir (1994) and Bond et al. (2003). To our knowledge, our study is the first to include measures of public equity finance in an R&D model. We estimate R&D regressions both for new entrants and incumbents with a variety of controls for demand. As expected, we find no evidence that public equity impacts the R&D of incumbents. For entrants, however, public equity finance is the only form of financing that is statistically significant and economically important in our regressions. We also examine the recent bubble in the Nasdaq which generated a remarkable boom and bust in the availability of public equity in the late 1990s and early 2000s. The extreme variation in public equity issues, together with the large estimated coefficients in our regressions, generates the testable prediction that there should have been a boom and bust in R&D for public entrants, but not for incumbents, who are not equity dependent firms. We in fact find that the public entrants in our sample did experience a boom and bust in R&D investment that lines up well with the boom and bust in public equity finance. In contrast, there is little change in R&D for high-tech incumbents during this period. Together, these results suggest that shifts in the availability of public equity finance had a substantial impact on the R&D of new public entrants in recent years.

The second objective of our paper is to examine whether the public entrants led to creative destruction in the high-tech tech sector of manufacturing. While there are several studies of the long-run financial performance of IPOs, we are aware of no other studies that examine the long-run economic impact of new public firms.[3] We present evidence on the impact of cohorts of new public entrants over time, similar to the approach taken in the seminal study by Dunne, Roberts and Samuelson (1988). We find that most high-tech incumbents exited the market, rates of R&D investment for new public firms were much greater than those of surviving incumbents, and R&D intensity rose rapidly over time with each successive cohort of entrants. In addition, we show that in five of the six industries, incumbents lost most of their market share of sales and R&D, with almost all of the loss due to the entry cohorts of the

1980s and 1990s. We also report descriptive regressions indicating that the evolution of shares of cohort sales and R&D are closely tied to public equity finance but not to other forms of finance. Finally, we show that a substantial number of individual public entrants, making heavy use of public equity, quickly became leading firms, overtaking many of the largest incumbents. At an aggregate level, the impact of new public firms in the six industries was very large: by 2000, new public entrants in the six high-tech industries accounted for approximately 29% of the total public-firm R&D in manufacturing and 24% of the public-firm R&D in the entire economy.

One of the main implications of our paper pertains to the process of creative destruction. The extremely high rates of R&D investment by innovative entrants and the swift displacement of many incumbents is an impressive example of creative destruction. Our findings, however, differ in one important respect from Schumpeter's (1942) description of creative destruction. Schumpeter emphasized that large established firms, diversifying from other industries and relying on internal finance, were the key innovative entrants and the primary force of creative destruction. In contrast, our study shows that, in recent decades, a primary source of creative destruction in the high-tech sector was thousands of startup companies relying heavily on external public equity finance.

II. The Ascent of the U.S. High-Tech Sector

Autos, steel, and to a lesser extent airplanes, were the leading manufacturing industries for much of the 20th century. In terms of value-added, autos, steel, aircraft and petroleum refining were the four largest three-digit SIC manufacturing industries in the period 1950-1980. In 1953, these four industries accounted for 17.0% of U.S. manufacturing value added. After 1953, their combined value added declined, falling to 11.8% by 1995. The U.S. was the world's leading producer of automobiles and steel in the first half of the 20th century but rapidly lost world leadership (to Japan) in autos and steel in the

[3] For studies of the long-run financial performance of IPOs, see Ritter (1991), Loughran and Ritter, (1995), Brav and Gompers (1997), and Gompers and Lerner (2003).

second half of the 20th century.[4] A small number of original incumbents dominated autos, steel and aircraft throughout most of the 20th century.[5]

In the second half of the 20th century, innovations and discoveries such as the computer and semiconductor led to the emergence of a new group of high-tech industries. Drugs (SIC 283), office and computing equipment (SIC 357), communications equipment (SIC 366), electronic components (SIC 367), measuring and control instruments (SIC 382) and medical instruments (SIC 384) are the industries we examine in this study. These are the leading industries listed in the United States Department of Commerce classification of high technology.[6] There are no other large high-tech industries in SIC 28, 35, 36 or 38 and SICs 366, 367, 382 and 384 make up the bulk of the sales of their respective two-digit industries.

With the exception of electronic components, all six industries appear in the U.S. Census of Manufacturing back to at least 1947. The industries accounted for only 7.4% of value added in 1970. By 2000, however, U.S. Census figures indicate that the combined U.S. manufacturing value added for the six high-tech industries stood at 18.9%, higher than the peak share of autos, steel, aircraft and petroleum refining. In 2000, based on the new NAICS (4-digit) classification system, electronic components was the largest U.S. manufacturing industry, drugs was 3rd, instruments was 5th and communications equipment was 6th.[7]

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[4] In 1950, the U.S. accounted for two-thirds of the world's auto output and 47% of the world's raw steel production. By 1980, the U.S. accounted for 21% of the world's automobile production and only 14% of the world's steel production, and Japan was the leading producer in both industries.

[5] The combined market share of GM and Ford was in excess of 80% between 1955 and 1985. The leading firms in the steel industry at the start of the century remained dominant throughout most of the 20th century. Boeing, founded in 1916, is currently the only U.S. producer of large commercial aircraft.

[6] United States Department of Commerce, "An Assessment of United States Competitiveness in High-Technology Industries," February 1983. Most of the other three-digit industries in SIC 28 (chemicals) and SIC 35 (machinery) would not currently be considered high-tech industries. We also do not consider the aerospace industry (in SIC 37), a high-tech industry in which the government supplies much of the R&D financing.

[7] Starting in 1997, the U.S. Census of Manufacturing is based on the NAICS classification system. Most of the industries have a close counterpart to the old SIC classification system. In particular, drugs, computers, communications equipment, and electronic components are all separate NAICS industries. The two instrument industries are combined into a single industry (3345). Using the mapping of 4-digit SIC industries into 5-digit NAICS industries, we computed the valued added figures for the constituent parts of SIC 382 and SIC 384 that now appear in NAICS 3345. Based on these numbers, old SIC 382 plus old SIC 384 would be the 5th largest industry in 2000. These figures are also used to compute the 18.9% value added figure for our high-tech industries for the year 2000.

In 1970, there were several large established incumbents in all six of the high-tech industries. For example, in the computer industry, IBM was the leading firm but there were several other major corporations active in the industry, including General Electric, RCA, Honeywell, DEC and Control Data.[8] In the 1990s, U.S. world market shares rose in most industries and by 2000, the U.S. was the leading producer of drugs, communications equipment, office and computing equipment, semiconductors, and medical and scientific instruments.[9]

III. Financing High-Tech Firms

Public firms account for the vast majority of R&D and output in the U.S. high-tech sector and there are almost no major private firms in high-tech manufacturing. A likely reason is the need for substantial external financing in the early years of firm development combined with the disadvantages of debt finance for most high-tech investment. For young high-tech firms, R&D investment greatly exceeds physical investment (see Table 2) and it has long been argued that it is difficult to finance intangible investments with debt.[10] In particular, limited collateral value of intangible assets may greatly restrict the use of debt, since risky firms typically must pledge collateral to obtain debt finance (Berger and Udell, 1990). Hall (2002) reviews the literature on capital structure and concludes that "the capital structure of R&D-intensive firms customarily exhibits considerably less leverage than that of other firms."[11]

Equity finance has several advantages over debt finance for young high-tech firms: there are no collateral requirements, shareholders share in upside returns and additional equity does not accentuate problems associated with financial distress. There are multiple forms of equity finance, including internal finance and private equity finance. For young high-tech firms, because of inefficient firm size and start-up costs, internal equity finance is usually small in size, and is frequently negative. Private equity

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[8] In SIC 366, Motorola, Harris Corp., and General Instrument were large incumbents. The leading producers in SIC 367 were Texas Instruments, Motorola, National Semiconductor and Fairchild. In SIC 382, Honeywell, Applera Corp., and Beckman Coulter were the major incumbents. In SIC 384, Johnson and Johnson, American Hospital, Mallinckrodt, Sybron and Becton Dickinson were the leading producers.

[9] In the late 1990s, the U.S. exported more than twice as much high-tech output as Japan, the world's second leading exporter of high-tech goods (NSF, 2002, Figure 6.5). Science & Engineering Indicators (NSF, 2002, Figure 6-3) reports that in 1998, the U.S. had a 36% share of world high-tech production, followed by Japan with a 20% share. The U.S. share of the market rose from 30% in 1988 to 36% in 1998. Japan's share fell from 26% in 1991 to 20% in 1998. France, Germany and Italy also experienced major declines in world shares.

[10] See Hall (2002), Himmelberg and Petersen (1994), and Carpenter and Petersen (2002) for summaries of the literature on why R&D-intensive firms may have very limited access to debt finance.

finance, in the form of venture capital, has become an increasingly important source of funds for young, high-tech firms, and can be viewed as a complement to public equity. VC financing, however, is designed to last for a relatively brief period (e.g., 3 to 4 years) before the firm goes public, is acquired, or is liquidated (Gompers and Lerner, 2004). While VC financing may often be a necessary condition if a start-up company is to reach the point at which it can go public, becoming a public firm is "the point of entry that gives firms expanded access to equity capital, allowing them to emerge and grow" (Fama and French, 2004, p. 229). Evidence for this conclusion can be seen in Table 7, where the leading high-tech entrants raised, on average, around 20 million (2000 dollars) in VC funding but more than one billion in public equity financing.

Limitations to debt finance, internal equity finance, and private equity finance suggests a potentially important role for public equity finance for young high-tech firms. Public equity finance, however, is typically ignored or viewed as unimportant. One reason is misleading aggregate statistics showing that *net* external equity issues are small in the U.S. economy. Because large firms often use stock buybacks as a way to distribute earnings to shareholders, aggregate net new equity figures (which include buybacks) are often small and can be negative (see Brealey and Myers, 2000, Table 14.1). Looking only at the aggregate net equity figure, however, obscures the fact that many firms, in the early stage of their life cycle, make extensive use of follow-up stock issues, as we show later in the paper. Over the last three decades, there has been a sharp upward trend in the issuance of public equity finance, particularly for young firms listed on the Nasdaq.[12]

The creation of the Nasdaq in 1971 likely greatly expanded the availability of public equity to small high-tech firms. Major improvements occurred in the early 1980s with the creation of the National Marketing System. Nearly all of the public entrants in our sample went public on the Nasdaq, which was typically their only choice because they could not have met the listing requirements (e.g., profitability) of the major exchanges. Prior to the Nasdaq, it was difficult to obtain accurate and timely information on OTC stock prices and trading of shares was cumbersome. There is a large body of evidence indicating

[11] See, for example, Friend and Lang (1988), Hall (1992) and Bhagat and Welch (1995).
[12] Jay Ritter (http://bear.cba.ufl.edu/ritter/seoall.html) identifies, for the entire economy, 1082 seasoned offerings in the 1970s, 2468 offerings in the 1980s, and 4867 offerings in the 1990s. A large fraction of offerings occur in the high-tech sectors of manufacturing (Loughran and Ritter, 1997). See also Fama and French (2005) for facts on the use of public equity finance.

that the Nasdaq improved efficiency and liquidity in equity markets.[13] Several studies, summarized by Baker (1987), find that firms listed on the Nasdaq do not appear to face a higher cost of equity finance than firms listed on the NYSE. An implication of this body of research is that the creation of the Nasdaq system in 1971, and the subsequent improvements, greatly increased the availability of public equity finance to young high-tech firms. Indeed, Fama and French (2004), based on the changing characteristics of newly listed firms (mostly on Nasdaq), conclude that a rightward shift in the supply of public equity occurred in the 1980s and 1990s.

We summarize this discussion of financing young high-tech firms as follows. For reasons noted above, internal finance is often small or negative, venture capital financing is limited in scope, and debt finance is essentially unavailable for most young firms. Though the marginal cost of public equity likely exceeds the marginal cost of internal equity, the marginal cost need not be rapidly rising, which means that small firms have the potential to raise hundreds of millions of dollars on the Nasdaq over a very brief period of time.[14] Thus, public equity is potentially a critical source of finance for many firms at the early stage of their life-cycle when heavy funding is often required to finance the R&D needed to commercialize technological breakthroughs. If there is no close substitute for public equity finance, a testable prediction is that the availability of public equity should impact the R&D investment of equity-dependent firms. Public equity should not matter, however, for incumbents who are not equity dependent. A related prediction is that booms and busts in the availability of equity will lead to corresponding fluctuations in R&D investment for public entrants only. Finally, the availability of public equity should impact the rate at which entrants take market share from incumbents.

[13] Ingebretsen (2002) discusses many other shortcomings in the OTC market prior to the Nasdaq, including large broker markups and lack of regulations, information and liquidity. He states (p. 19) that because of these problems "relatively few firms went public via the OTC market." Studies report substantial reductions in the bid-ask spread following the introduction of Nasdaq and several studies have found that the liquidity of firms traded on the Nasdaq compares favorably to firms traded on the NYSE. For a review of this literature, see Groth and Dubofsky (1987).
[14] Reasons why the marginal cost of equity may not increase rapidly include the following: i) new share issues do not require collateral and ii) new share issues do not raise the probability of financial distress.

IV. IPOs over Time and Across Industries

A. The Data

Our study begins in 1970, which is a sensible starting date for two reasons. First, each of our six industries had many large established incumbents in place in 1970. We refer to all IPOs from 1970 to the present as "new public entrants." We could choose a later date, such as 1980, as the starting date for "new entrants" and the main findings in the paper would not change. The reason is that relatively few high-tech firms went public in the 1970s, and their market share is small compared to the entry cohorts of the 1980s and 1990s (see Table 5). The second reason for our start date is that one of our primary data sources, Thompson Financial's SDC New Issues Database, begins in 1970. The SDC database is commonly used in the economics and finance literature (e.g., Loughran and Ritter, 2004) and contains information on the year and dollar size of all IPOs. We identify around 3,600 IPOs in manufacturing between 1970 and 2004.[15] We then match this list of manufacturing IPOs to the list of publicly traded firms in the Compustat database.[16] Compustat reports crucial information, such as sources of finance and R&D investment, that is typically not available to the researcher in other entry studies.

We do not include spinoffs or carve-outs in our list of IPOs, nor do we include mergers that created a new firm. While the number of spinoffs is not large, some large firms have been created through spinoffs in recent years. For example, Lucent Technologies was spunoff from AT&T in 1996, and Agilent was spunoff from Hewlett Packard in 1999. For the purposes of our study, it would be inappropriate to consider these firms "new public entrants." Rather, these firms are ex-divisions of major incumbents, and we treat them separately throughout our study.

For all our tables, we examined the results for each high-tech industry, and only pool the six industries if there are no outlier industries. For some issues that we believe are of secondary importance,

[15] An additional 187 firms went public in a non-manufacturing sector, but at some point in their lives were primarily manufacturing firms. We do not include them in the initial count of IPOs, but we do allow them to enter our data in the years they were primarily in manufacturing. Similarly, firms entering in a manufacturing industry and subsequently leaving are dropped once the primary SIC code reported by Compustat is outside of manufacturing.

[16] For approximately 7% of the IPOs we were not able to find coverage of the firm in Compustat. In these situations, as discussed in the Appendix, we attempted to gather data from company stock reports. The primary source for this was Moody's. There were only 60 manufacturing IPOs for which we were not able to find balance sheet information.

we briefly summarize our findings but do not report the results in a table. In all such cases, tables are available on request. In most cases we provide information on different cohorts of entrants, similar to the approach in Dunne, Roberts and Samuelson (1988). We divide the entrants into seven five-year cohorts, beginning with 1970-1974 and ending with 2000-2004.

B. IPOs by Three-digit Industries

Table 1 reports the breakdown of IPOs for the six key high-tech industries in our study. We focus on the last two rows which report the total number of high-tech IPOs and their share of all IPOs in manufacturing for a given time period. The second column indicates that at the start of 1970 the six industries contained a large number of publicly traded *incumbents* (254), which amounted to 14% of the public firms in manufacturing. The number of IPOs in the 1970s (174) was relatively small, but IPOs exploded in the 1980s (627) and the 1990s (869). High-tech IPO numbers, however, fell off substantially in the 2000-2004 period (261), following the sharp bust in the Nasdaq. The second to the last column shows that there were 1931 IPOs in the six high-tech industries between 1970 and 2004, which accounted for 54% of the total IPOs in manufacturing during the 35 year period. This is a remarkable share, as there are more than 130 three-digit SIC industries in U.S. manufacturing.

The final column reports that at the end of 2004, the six high-tech industries contained 1532 surviving public firms, or 48% of the publicly traded firms in manufacturing.[17] Again, this is remarkable, given that the six industries account for less than five percent of the industries in U.S. manufacturing. Table 1 shows that public firms in manufacturing have become ever more concentrated in a small number of high-tech industries because of the concentrated pattern of IPOs in the 1980s and 1990s.

C. Characteristics of the IPO

We briefly summarize the key characteristics of the IPOs in our sample. Firms are typically very young at the time they go public, with a median age of around six years in both the 1980s and 1990s.[18]

[17] While not reported in the table, of the 1532 firms in existence in 2004, 59 were surviving incumbents, 1034 were surviving IPOs from the period 1970-2004, and 439 were "other" firms, which are new public firms in Compustat not identified as IPOs. These firms include spinoffs and best effort offerings and are described at the start of section six. "Other" firms account for only a small share of economic activity.

[18] Most of the age data was graciously provided by Laura Field and Jay Ritter. See Field and Karpoff (2002) and Loughran and Ritter (2004). For a small number of the IPOs we compiled age data from various issues of Moody's, from Hoover's Online, and from the International Directory of Company Histories.

Firms are generally small at the time of the IPO, with a median employment of around 80 workers. Firms use almost no debt, with a median leverage ratio of close to zero at the time of the IPO during the 1990s and 2000s. Finally, the size of IPO proceeds has increased dramatically over time. The median IPO for the 1970-74 cohort was only $6.36 million (in 2000 dollars). For the 1995-1999 cohort, the median IPO was $27.57 million, or more than twice the size of existing firm assets. These results highlight the increasing importance of the first infusion of public equity for high-tech public entrants.

V. The Role of Public Equity Finance

One goal of the paper is to explore the importance of public equity for public entrants in the high-tech sector. We begin this section by providing information on financing after the IPO. We then provide regression results for a dynamic R&D investment model, including results for a narrow window containing the recent bubble in the Nasdaq, a period of dramatic changes in the availability of public equity finance.

A. Investment and Financing After the IPO

Table 2 reports information on investment and financing over the first two five-year intervals (t = 1 to t = 5 and t = 6 to t = 10) following the IPO. The first two columns are for firms in the six high-tech industries and the rest of the table is for all other new public firms in manufacturing. (We present the numbers for the rest of manufacturing to provide a basis for comparison.) All investment and financing variables are cumulative: we sum the annual values over the respective five-year periods and scale by beginning of period firm assets. We report medians and means that are winsorized at the 1% level to avoid undue influence of extreme values. Since we are summing over each five-year period, we report numbers only for firms that survive all five years of the particular period in question. To measure internal equity finance we add R&D investment to the firm's reported cash flow because R&D is treated as an expense and we want, for purposes of comparison, the broadest possible measure of internal equity finance (see Hall 1992).

For the six high-tech industries, the median and mean R&D ratios are 0.71 and 1.17 in the first period, and 0.55 and 1.02 in the second period. For physical investment, the median and mean values are only roughly 40 percent as large as the corresponding R&D values. The mean for total investment (R&D

plus physical) is 1.66 in the first period and 1.40 in the second period. Turning to sources of finance, the median values of cumulative new total debt are 0.02 and 0.00 in the first two periods, indicating a general lack of debt financing for high-tech entrants. For cumulative gross cash flow, the medians across the two periods are 0.41 and 0.55, while the means are 0.52 and 0.55. For cumulative new stock issues, the medians are 0.46 and 0.19 and the means are 1.36 and 1.08. A comparison of the *medians* of cash flow and new stock issues indicates that the *typical* firm relies more on follow-up stock issues than cash flow in the initial years after the IPO. A comparison of the *averages* indicates that public equity is more than twice as large as internal equity in each of the five-year periods, highlighting the extensive use of new share issues by many firms in the first decade following the IPO. The last two rows of the table indicate that gross cash flow is negative for a substantial fraction of observations and that high-tech firms rarely pay dividends. Overall, these numbers identify a far more important role for follow-up equity issues than is generally recognized.

Turning to the rest of manufacturing, there are some noteworthy differences compared to high-tech firms. In particular, R&D is far smaller, with medians of only 0.08 in each of the first two periods.[19] As a consequence, total investment, either at the median or the mean, is much lower in the rest of manufacturing. Furthermore, cumulative stock issues are also far smaller than the values for the six high-tech industries.

For us, the big question is: How do young high-tech firms manage to finance such high levels of intangible investment in the years immediately following the IPO? From a pure accounting point of view, the mean of cash flow plus debt financing is approximately half the size of total investment in both periods. Furthermore, given the nature of intangible investment, there is likely little scope for raising additional debt financing and dividends are zero for virtually all high-tech observations. This leaves public equity financing as the likely key *marginal* source of finance. Note that public equity finance does not appear to play this role in the non-high tech sector, presumably because intangible investment is small, resulting in little need for additional financing beyond internal cash flows and debt.

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[19] R&D is often reported as missing for firms in the non-high-tech industries (this is seldom the case in the high-tech industries). Missing R&D observations are excluded from the R&D ratios reported in Table 2. If we set the missing values to zero, the R&D ratios are considerably smaller for non-high-tech firms but essentially unchanged for firms in the high-tech industries.

B. Regression Analysis

We focus on R&D investment because it is the main investment of young high-tech firms and is the investment associated with creative destruction. We modify a dynamic investment model developed by Bond and Meghir (1994) and Bond et al. (2003) to examine the role of financial effects for investment. Both of these studies derive an Euler equation for optimal physical capital accumulation with adjustment costs for imperfectly competitive firms.[20] Bond et al. (2003, p. 153) state that an advantage of their approach is 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."

To extend their model to R&D investment, it is important to note that R&D is also subject to costs of adjustment and there is considerable evidence that these adjustment costs are large, perhaps even larger than physical investment.[21] It is natural to consider profits as a function of the accumulated stock of R&D and an estimating equation for R&D (based on the Euler condition) can be derived that is analogous to the physical investment equation in Bond and Meghir (1994). The stock of R&D (the analog of the stock of physical investment used in investment studies) is not reported by the firm and can only be crudely approximated. We therefore scale all regression variables by total assets, which follows the approach in Baker, Stein, and Wurgler (2003) who also use total assets as a scale variable in firm-level regressions for both physical capital and R&D.

With the modification noted above, the estimating equation in the absence of financing constraints becomes:

$$(1) \qquad \left(RD/TA\right)_{j,t} = \beta_1\left(RD/TA\right)_{j,t-1} - \beta_2\left(RD/TA\right)^2_{j,t-1} - \beta_3\left(GCF/TA\right)_{j,t-1} + \beta_4\left(SALES/TA\right)_{j,t-1} + d_{i,t} + \alpha_j + \nu_{j,t}$$

[20] The Euler equation estimation approach eliminates terms in the solution to the optimization problem that depend on unobservable expectations 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.

[21] See Himmelberg and Petersen (1994) for a discussion of adjustment costs for R&D and a list of studies that find that adjustment costs for R&D may be considerably higher than for physical investment.

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.[22] The variable *GCF* denotes gross cash flow, the flow of internal funds defined consistently with the previous literature on finance and R&D.[23] The variable d_{it} is a time-specific effect (defined at the industry level, *i*) and α_j is a firm-specific effect. The parameters in equation (1) can be interpreted as functions of the structural parameters of the original optimization problem presented in Bond and Meghir (1994).[24] We expect that the structural parameters for incumbent firms (who are not likely to face binding financing constraints) to line up relatively closely to the predictions of the null model discussed in the footnote above.

The main difference (besides our focus on R&D) between equation (1) and the estimating model in Bond and Meghir (1994) is the treatment of time dummies. While Bond and Meghir (1994) employ aggregate time dummies, in all of our regressions we include time dummies (d_{it}) disaggregated to the three-digit industry level. This broader set of time dummies controls for industry-specific changes in technological opportunities that could affect the demand for R&D.

Equation (1) is the baseline equation for our study. To examine the relationship between R&D and public equity finance, we add current period and lagged new share issues (STK/TA) to equation (1), precisely as is done in Bond and Meghir (1994, Table 3). To examine the role of internal equity finance, we also add current period cash flow (GCF/TA). We ignore debt because of its lack of importance as a source of finance (see Table 2).

We estimate R&D regressions for all public entrants and incumbents in our sample that have sufficient Compustat data on R&D and financial variables over the 1970 to 2004 period. It is standard practice in the literature to trim the upper and lower tails of all equation variables, and we trim at the 0.5%

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[22] In Bond and Meghir (1994) (but not Bond et al. 2003), the baseline specification also includes a *stock* of debt term. Including this term has no impact on our main results (consistent with low levels of debt) and we therefore leave this term out of our specification. Additionally, in their specification, the beginning-of-period sales term controls for imperfect competition, something which may be of limited relevance for small public firms in the high-tech sector.

[23] 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).

[24] 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 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.

level. Following Bond and Meghir (1994) and Bond et al. (2003), we employ the Arellano and Bond (1991) General Methods of Moments estimator to obtain consistent estimates of equation (1). To briefly summarize, we use a first-differenced GMM estimator where lagged values of endogenous variables are employed as instruments and all right-hand-side variables are treated as endogenous. Like Bond and Meghir (1994), we use instruments dated t-3 and t-4, as instruments dated t-2 are not valid if the error term in levels is an MA(1). Sargan tests do not reject the null, at conventional levels, that the over-identifying restrictions are valid. We also report tests for first-order (m1) and second order (m2) autocorrelation in the first differenced residuals. As Arellano and Bond (1991) discuss, the GMM estimator is inconsistent if second-order serial correlation is present. The tests of no first-order serial correlation are rejected, but we can never reject the null of no second-order autocorrelation for public entrants. Finally, for each type of finance, we report a chi-squared test of the null hypothesis that the sum of the current and lagged coefficients is equal to zero.

The first four columns in Table 3 report the R&D regression results for both entrants and incumbents over the full sample period 1970-2004. The point estimates are in bold. The first pair of regressions is the baseline specification (equation 1 above). For the entrants, the coefficients for lagged R&D and its square have the correct sign, but the coefficients are somewhat below the theoretical values predicted by the structural model (which slightly exceed unity in absolute value) derived under no financing constraints. Bond and Meghir obtained similar findings, which they attribute to the presence of financing constraints. In the baseline specification for incumbents, lagged R&D and it square are close to the predicted values, as would be expected if the null (of no financing constraints) were correct.

The next pair of regressions (columns three and four) adds the financial variables (GCF/TA and STK/TA). We also add contemporaneous sales (SALES/TA) as an additional control for demand. For the entrants, the point estimates for current and lagged cash flow are small and statistically insignificant. The small coefficients for cash flow are not surprising, given the large fraction of negative cash flow observations for entrants reported in Table 2.[25] On the other hand, the point estimate for current stock issues is large (0.151) and highly statistically significant. In contrast, for incumbents, there are small,

[25] If we restrict our sample to firms with at least ten years of data, the fraction of negative cash flow observations is greatly reduced, and we recover cash flow coefficients that are positive and statistically significant; the coefficients for new share issues are only slightly smaller than those reported in Table 3.

positive coefficients on current and lagged cash flow, and small, negative coefficients on current and lagged net stock issues. It is important to keep in mind that the financial variables are instrumented with lagged values dated t-3 and t-4, and thus there is little concern of reverse causation between new entrant equity issues and R&D.

To summarize, stock issues is the only financial variable that is statistically significant and quantitatively important for new entrant investment in R&D. Our interpretation is that public equity is the marginal source of finance and its availability is a binding constraint on R&D. Furthermore, the fact that the estimated baseline coefficients for the *incumbents* are close to the theoretical values predicted by the structural model, together with the negligible financial variables for these firms, provides additional confidence that our finding of a stock effect for *entrants* is not due to mis-specification in the regression equation. This kind of heterogeneity has been widely used to test for the existence of financing constraints and helps to empirically identify shifts in the supply of finance.[26]

C. Further Analysis: The Nasdaq Bubble

A strong test of causality would be to examine the behavior of new entrant R&D during a time period when access to public equity finance disappeared. The closest "natural experiment" we have is the recent Nasdaq bubble.[27] The Nasdaq Index stood a 1,574 at the start of 1998, reached 2,207 by the start of 1999 and then jumped to 4,186 by the start of 2000. The Nasdaq broke 5,000 briefly in 2000, but began a swift decent at the end of 2000, reaching approximately 1,100 in August, 2002. As discussed below, the bubble and its collapse generated a remarkable boom and bust in the use of public equity finance for public entrants, permitting additional tests of the importance of this form of finance for R&D.

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

[26] Kaplan and Zingales (1997) criticize heterogeneity tests. 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.
[27] 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.

(1990, p. 160) note that for firms facing financing constraints, overpriced equity lowers the cost of capital and may allow 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) examine the "equity finance channel," including the key prediction "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 regress various measures of investment (including the sum of physical and R&D investment) on measures of Tobin's Q and show that equity-dependent firms are the most sensitive to Q as well as the realization of future stock prices. In addition, a number of other studies report empirical evidence that stock market mispricing affects the investment of equity-dependent firms. [28]

Collectively, our sample of high-tech *entrants* exhibit a pronounced boom and bust in equity usage that lines up well with the view that firms exploited mispricing in the Nasdaq by issuing new shares. Between 1998 and 2000, total public equity issues by new entrants (IPOs plus follow-up issues measured in 2000 dollars) rose from $8.51 billion to $45.34 billion (over 400 percent), while follow-up stock issues rose from $6.67 billion to $29.24 billion (over 300 percent). Following the collapse in the Nasdaq prices, total stock issues by public entrants fell dramatically, equaling $7.86 billion in 2002 before a modest recovery in 2003 and 2004.

Given the extremely large variation in public equity issues, it is important to check whether our regression results hold up for narrow windows around the Nasdaq bubble. The final pair of regressions in Table 3 examines one such window, the time period 1997-2002.[29] The results for this narrow period are very similar to those for the full period (1970-2004). For incumbents, the coefficients for the financial

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[28] Polk and Sapienza (2004) find that firm physical investment is positively related to a 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.

[29] We examined other windows surrounding the Nasdaq bubble and obtained similar results.

variables are quantitatively small and insignificant. For public entrants, the point estimates for current and lagged cash flow are quantitatively small and chi-squared tests reject statistical significance. In contrast, the point estimate for current stock issues is positive (0.179) and statistically significant.

The facts noted above lead to two predictions. First, if the supply of external public equity finance is a binding constraint on new entrant R&D, then the regression results suggest that the extremely large variation in public equity issues during the late 1990s and early 2000s should have resulted in a sharp rise and subsequent decline in R&D investment for pubic *entrants*. We note that large fluctuations in R&D are not common, and thus are not likely to occur simply because of chance. The second prediction is that *incumbent* firms, who are not equity dependent, should not exhibit a boom or bust in R&D.

In our sample, new entrant investment in R&D does in fact exhibit a boom and bust pattern. For new entrants, the *median* R&D-to-asset ratio in 1998 was 0.154, nearly identical to the median for the decade of the 1990s (0.152). By 2000, at the peak of the Nasdaq bubble, the median ratio had jumped to 0.182, an 18 percent increase over the 1998 figure. By 2002, the median ratio had fallen to 0.128, a 30 percent decline (compared to the 2000 figure), and well below the median ratio for the 1990s.[30] A Wilcoxon signed-rank test shows that the median R&D ratio in 2000 was statistically different from the median ratios in both 1998 and 2002.[31] We also computed *average* R&D ratios that were winsorized at the 1% level to minimize the impact of outliers. The average R&D ratio among new entrants in the decade of the 1990s is 0.259. The averages for 1998, 2000, and 2002 are 0.229, 0.348 and 0.204, which exhibit substantially larger percentage changes than do the medians. Again, the 2000 figure is statistically different from the 1998 and 2002 figures.[32]

For *incumbents*, on the other hand, there is no evidence of a boom and bust pattern. The median R&D-to-assets ratio among incumbents actually *fell* between 1998 and 2000 (0.089 to 0.073), and was largely unchanged between 2000 and 2002 (0.073 to 0.068). Similarly, the *average* R&D ratios for 1998, 2000 and 2002 were 0.095, 0.083 and 0.083.

These findings provide evidence of a causal relationship between public equity finance and new entrant R&D. The lack of an R&D boom and bust for incumbents strongly suggests that sudden

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[30] Furthermore, the median R&D ratio in 2003 and 2004 remained well below the overall median for the 1990s.
[31] The z-values from the Wilcoxon tests are 4.26 for 1998-2000 and -6.94 for 2000-2002.
[32] The t-statistic is 6.59 for 1998 to 2000 and -7.92 for 2000 to 2002.

technological demand shocks for R&D are not driving our results. Instead, our evidence is consistent with major supply shifts in public equity finance, which should only matter for equity-dependent firms. Greater access to public equity enabled entrants to sharply increase R&D in 1999 and 2000, and entrants were then forced to curtail R&D when equity finance largely disappeared after 2000. These results strengthen our overall case that access to public equity finance is important for R&D and that many public entrants have no close substitutes, at the margin, for public equity.

D. Quantitative Interpretation and Robustness

To evaluate the quantitative importance of public equity, consider what our findings in Table 3 indicate about the response of R&D to the sharp reduction in new stock issues during the 2000-2002 period. During this period the mean STK/TA ratio declined by 0.963 (1.124 to 0.161). Our estimated coefficient for public equity finance is approximately 0.15, suggesting that each dollar change in new stock issues translates into a change in current R&D of around 15 cents. Thus, our findings suggest a decline in RD/TA of 0.963*0.15 = 0.14 between 2000 and 2002, which almost exactly matches the actual decline in the mean R&D ratio just discussed (0.348 to 0.204).

We considered a large range of robustness tests for the empirical results presented above. We estimated all regressions using two-stage least squares (instead of GMM) and the main finding, once again, is that the only financial variable in the R&D regression that is economically important (and statistically significant) is new share issues. We also used lags for the instruments beginning at t-2 (instead of t-3) and instruments with lags from t-3 to either t-5 or t-6, and there were no quantitative changes in the results. We also explored different scale factors (in place of total assets in the R&D regression) and more severe trimming rules that excluded both the 1% and 2% tails and the main findings were unchanged. Finally, we estimated a set of error correction models identical to those in Bond et al. (2003, equation 4). Specifically, we added financial variables to a baseline error-correction model that contained lagged investment, current and lagged sales growth and an error-correction term. In the R&D regressions, new share issues has nearly the same point estimate and is highly statistically significant, while cash flow remains statistically insignificant.

VI. The Impact of Public Entrants and Creative Destruction

The findings presented so far suggest that recent public entrants had the potential to have a major impact on the high-tech sector. In particular, our results have shown that a very large number of new public firms were created in the high-tech sector, these firms received heavy funding in their formative years, and this funding appears to have had a large impact on R&D, the type of investment most relevant for creative destruction. The rest of the paper explores whether these new entrants led to creative destruction in the high-tech sector.

In the tables that follow, we report results for the drug industry separately. The reason the drug industry is an outlier is straightforward. Drug companies in the U.S. must go through protracted clinical trials, often lasting one decade or more, before obtaining FDA approval. Furthermore, a large percentage of drug companies go public during clinical trials. As a consequence, these firms often have little or no sales for many years after the IPO. This lag in sales will be apparent in the tables that follow.

A. Survival by Cohort

By 2000, 71% of the incumbents had exited, underscoring the notion of creative destruction. For new entrants, the 5-year, 10-year, 15-year and 20-year survivor rates are very similar across most cohorts. For example, the middle four cohorts have five-year survival rates of approximately 78% and ten-year survival rates of approximately 58%. These survival rates are much higher than reported in the literature, including the seminal studies by Dunne, Roberts and Samuelson (1988 and 1989), which enhances the possibility of public entrants having a large impact on incumbents.[33]

B. R&D Intensity by Cohort

Table 4 reports median R&D-to-sales ratios for entry cohorts and incumbents for selected years. We examined the ratios for each high-tech industry and found no meaningful differences except for drugs, which is excluded from Panel A and reported separately in Panel B. In Panel A, moving down the diagonal, new cohorts of entrants have generally become more R&D intensive over time, culminating with the year 2000, where the 1995-1999 cohort has a median R&D-to-sales ratio of 0.180, three times larger than the median R&D ratio in 1975 (for the 1970-1974 cohort). This pattern is consistent with our regression results and the greater availability of equity finance in the 1980s and 1990s. The final cohort (2000-2004), however, has a smaller median R&D ratio than the 1995-1999 cohort. Moving along the rows, R&D ratios have generally risen over time for each cohort. It is interesting, however, that median R&D ratios in 2004 are lower than those in 2000 in all cohorts but one, consistent with the decline in equity availability in 2001-2003. Note also that the R&D ratios of incumbents also rose over time. An increase in the innovative activity of incumbents in response to the threat of entry is a key component of the Schumpeterian Paradigm of growth developed by Aghion and Howitt (1992 and 1998). Incumbent's R&D ratios, however, lag well behind the median R&D intensities of all entry cohorts. The much higher R&D intensities of new entrants is consistent with a process of creative destruction driven by innovation.[34]

Panel B reports values for the drug industry. We do not report figures for the first two cohorts because of the small number of observations. Median R&D ratios are very high and are probably not especially meaningful given that new drug firms often have little or no sales for many years after the IPO while they await FDA approval.

C. Share of Sales

Table 5 reports the share of sales accounted for by incumbents and entry cohorts over time. Each firm's sales is assigned to a single three-digit industry, and then an aggregate sales figure is computed for the set of five high-tech industries (Panel A) and drugs (Panel B). Diversification is a potential problem as the largest firms are often diversified across multiple three-digit industries. However, for our application, diversification is not likely to be a significant issue, because when high-tech firms diversify, most of their sales are contained within the *set* of the five high-tech industries that make up Panel A of Table 5. We do, however, have a direct way of checking on possible problems created by diversification. Beginning in the late 1990s, Compustat regularly reports each firm's sales disaggregated into its main four-digit SIC industries (business segment data). We used these numbers to compute share of sales of entrants and incumbents for 2000 and 2004 (see Appendix for details). These numbers should be very

[33] See also Audretsch (1991, Table 1) and Klepper (2002).
[34] The much higher R&D intensity of entrants is consistent with Acs and Audrestsch's (1988, 1990) findings that small firms (under 500 employees) have a much higher innovation-per-employee ratio than large firms in many high-tech industries, including our six high-tech industries.

accurate and provide a check on our other figures. A check of these numbers (in Appendix) shows that they are nearly identical to those reported in Table 5.

For completeness, Table 5 reports information on the share of sales of "other" firms, who are firms that had no Compustat coverage prior to 1970 and were not listed in Thompson Financial's SDC New Issues data base. Fama and French (2004) also document a sizable number of new listings in CRSP which do not show up in their IPO data base, and they believe many of these firms are "best effort" offerings.[35] We examined all large "other" firms and checked to see if they should be reclassified as incumbents or IPO firms. The large "other" firms are almost exclusively spinoffs, such as Lucent and Agilent. As is apparent in the tables, "other" firms, with the exception of 2000, account for only a small share of economic activity.[36]

Starting with the high-tech firms in Panel A, there are a number of interesting findings. First, going down the diagonal, the four cohorts of the 1980s and 1990s have much greater initial shares than the two cohorts of the 1970s. The final cohort (2000-2004), however, has a smaller share than the cohorts in the 1980s and 1990s. Second, moving along the rows, most cohorts had rising market shares over time. This is the opposite of Dunne, Roberts and Samuelson (1988, Table 9), who find that new cohorts lose market share fairly rapidly over time.[37] The third (and most important) finding is that incumbents lose a great deal of market share to new public entrants.[38] By 2000, entrants had acquired almost 48% of high-tech sales, while incumbent market share had fallen to just 38.6% (37.0% using business segment data). Incumbent's loss of market share is largest in the 1990s, the period of greatest availability of public equity. By 2004, however, incumbents experience a modest rebound in their market share.[39] This

[35] In a "best effort offering," the underwriter acts as a broker, doing its best to sell the firm's offering to the public but never taking a personal position in the shares. The firms conducting a best efforts offering are typically very small and may not be traded initially on the major exchanges.

[36] The market share of "other firms" is small until 2000, where three large spinoffs drive the share to nearly 13%. Spinoffs Lucent, Agilent and Avaya accounted for almost 60% of the total sales in the "others" category in 2000.

[37] The explanation for the difference is likely due to multiple factors, including the fact that high-tech *public* entrants had high survival rates and very high real growth rates in the last two decades. In addition, the Dunne et al. (1988) study covers the time period 1963 to 1982, and our study shows that the impact of new public entrants is fairly small in the 1970s, even for high-tech industries.

[38] For Tables 5 and 6, we leave IBM in industry SIC 357 through 2000, even though IBM's primary SIC code changes to 737 (which is outside of manufacturing) in 1998. Because IBM is a very large incumbent, allowing IBM to switch would significantly increase the reported market shares of IPO firms.

[39] Much of the rebound is the acquisition of Compaq (of the cohort 1980-1984) by Hewlett-Packard in 2002. When we recomputed the numbers without this acquisition, the incumbent's share of sales in 2004 is virtually unchanged compared to the 2000 figure.

temporary stabilization of market share of incumbents stands in contrast to the sharp loss of market share in the 1990s. This is expected, given the decline in availability of public equity after 2000 that curtailed the entry of new firms and slowed the expansion of previous entry cohorts.

Panel B explores the drug industry, which had over four hundred public entrants, concentrated heavily in 1990s. Yet as of 2000, incumbents have a market share exceeding eighty percent. We believe the main reason is that most entry was relatively recent and the process of running clinical trials and obtaining FDA approval can be very lengthy.

A natural question to ask is why incumbents in modern high-tech industries lost so much market share to entrants in the 1980s and 1990s, a time period long removed from the initial commercialization of the computer, the semi-conductor, etc. Our short explanation is improvement in access to public equity finance. Traditionally, it appears that the initial entrants (i.e., incumbents) have been exposed to the "perennial gale of creative destruction" for a relatively brief period of time.[40] In contrast, the Nasdaq came on line in 1971 and permitted a few thousand new firms in the six high-tech industries to go public and raise unprecedented sums of external finance. This process occurred with little interruption in the 1980s and 1990s until the collapse in Nasdaq prices, which temporarily reduced the availability of public finance and, in turn, curtailed the number of new entrants and stopped incumbent loss of market share.

To briefly explore the association between incumbent loss of market share and public finance, we ran a simple descriptive regression relating the evolution of cohort share of sales and sources of finance. The data points are share of sales figures (at five-year intervals) as shown in Panel A of Table 5. Let *j* stand for the cohort and *t* represent a particular period (e.g., 1975, 1980, etc.). The left-hand side variable is $\Delta SALES_{jt}$, which is the change in *share* of sales between period *t* and *t-1* for cohort *j*, while the right-hand side variables are the flows of finance ($CASHFLOW_{jt}$, $STOCK_{jt}$, and $DEBT_{jt}$, measured in hundreds of billions) raised by the cohort in the corresponding five-year period. The regression results (with standard errors) for the five-tech industries shown in Panel A, are as follows:

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[40] To put this question in perspective, consider the important findings in Klepper and Graddy (1990) and Klepper (2002). They study the evolution of new industries (mostly arising well before 1950) and show that the initial stage is characterized by rapid growth in the number of producers while the second stage is a "shakeout" where the number of firms falls sharply. The rapid growth stage is typically fairly short (e.g., less than 20 years for autos and tires).

$$\Delta SALES_{jt} = -0.012\ CASHFLOW_{jt} + 0.278\ STOCK_{jt} - 0.052\ DEBT_{jt}, \quad \text{adj. } R^2 = 0.12 \qquad (2)$$
$$(.029) \qquad (.143) \qquad (.341)$$

These results show that only public equity issues are positively (and significant at the 6% level) associated with $\Delta SALES_{jt}$. This is consistent with the fact that the cohorts in the 1980s and 1990s tended to have both the sharpest gains in share of sales as well as the largest IPOs and the heaviest use of follow-up equity. The results are quantitatively similar if we include the drug industry. We ran the identical regression using firm level data (instead of cohort data) and obtained qualitatively similar results.

D. Share of R&D

Table 6 reports the shares of R&D for the entry cohorts and the incumbents over time. The findings in Table 6 are similar to those in Table 5. First, in Panel A, the four cohorts of the 1980s and 1990s have much greater initial shares than the two cohorts of the 1970s. Second, cohort shares of R&D tend to rise over time. Third, by 2000, new public entrants' share of R&D reached 51.8% and incumbent's share had fallen to only 32%, less than their share of sales. Most of the incumbent's loss of R&D share occurs in the 1990s and no loss occurs in the period 2000-2004, consistent with Table 5. Panel B is also broadly consistent with the findings in the corresponding panel in Table 5, though public entrants in the drug industry account for a larger share of R&D than sales by the end of the sample period.

We ran a descriptive regression identical to equation (2) but replaced $\Delta SALES_{jt}$ with $\Delta R\&D_{jt}$. The data points are now the share of R&D figures as shown in Panel A of Table 6. The regression results are as follows:

$$\Delta R\&D_{jt} = -0.055\ CASHFLOW_{jt} + 0.543\ STOCK_{jt} - 0.525\ DEBT_{jt}, \quad \text{adj. } R^2 = 0.40 \qquad (3)$$
$$(.026) \qquad (.130) \qquad (.309)$$

Once again, the results show that only public equity issues are positively associated with $\Delta R\&D_{jt}$. A comparison of the estimated coefficients for $STOCK_{jt}$ in regressions (2) and (3) indicates a stronger relationship between share of R&D and public equity. Given the nature of intangible investment, this is what we would expect. Once again, the results are quantitatively similar if we include the drug industry or use firm level data instead of cohort data. While (2) and (3) are only descriptive regressions, they are consistent with our argument that public equity finance played a significant role in the process of creative destruction in the high-tech sector.

E. Leading Firms

As is apparent in Table 7, many new public entrants quickly became leading firms in their respective industries. Because of space limitations, we present detailed information for two of the largest industries in our study: office and computing equipment (Panel A) and electronic components (Panel B). For these two industries, Table 7 reports information for the top ten firms (based on sales) for the year 2000.

In Panel A, by 2000, new public entrants, mostly founded in the 1980s, had displaced most of the original leading incumbents in office and computing equipment. While incumbents Hewlett-Packard and IBM had the largest sales, Compaq and Dell were close behind.[41] With the exception of Xerox, the rest of the ten leading firms in office and computing equipment – Cisco, Sun Microsystems, Gateway, EMC, and Apple – were all new public entrants. Five of the seven new public entrants received significant venture capital financing. Most of the IPOs were large, with four firms raising more than $90 million. Most of the seven new public entrants made heavy use of follow-up equity financing, with Cisco raising nearly $2.82 billion and Compaq raising $1.16 billion.[42]

Electronic components (Panel B) is an even better example of an industry where new public entrants rapidly displaced the leading incumbents. By 2000, Intel and Solectron were the two leading firms, ahead of Texas Instruments and Motorola (also semiconductor producers), the leading firms of the late 1960s and 1970s. Five of the six new public entrants received venture capital. All six new public entrants made heavy use of follow-up public equity, with four firms raising over $1 billion. In addition to the two industries discussed above, many new public entrants also became leading firms in the other four high-tech industries.

VII. Schumpeterian Creative Destruction and Other Implications

Our findings, including the swift displacement of many leading high-tech incumbents by R&D-intensive entrants are, in most ways, an excellent example of Schumpeter's (1942) perspective on

[41] By 2003, Dell had the world's largest market share (approximately 15%) of personal computers despite Hewlett-Packard's purchase of Compaq in 2002 (Wall Street Journal, 5/12/2004).
[42] We recognize the life-cycle feature of new equity financing and sum *net* new equity issues until the firm becomes a net buyer of its equity (see Appendix). All financing figures are expressed in 2000 dollars.

competition as a "process of creative destruction." There is, however, at least one important difference. Schumpeter envisioned entrants to be large established firms with the deep pockets needed to finance innovation. Schumpeter (1942, p. 101) argues that large-scale establishments "not only arise in the process of creative destruction, but in many cases of decisive importance they provide the necessary form for that achievement." Schumpeter (1942, p. 106) describes the large established firm as "the most powerful engine of economic progress." He does not praise young startup companies as engines of progress and is generally pessimistic about the ability of markets characterized by large numbers of small firms to be innovative. Contrary to Schumpeter's vision, our results suggest that new public entrants were the main source of creative destruction in the U.S. high-tech industry, especially in the 1980s and 1990s. Furthermore, the ability of young high-tech firms to raise large amounts of public equity finance runs strongly counter to Schumpeter's views on the need for market power to self-finance innovation.

The findings we present are also likely relevant for understanding the relative performance of U.S. and Europe in recent decades. Several recent studies, summarized in Aghion and Howitt (2005), have advanced a "Schumpeterian Paradigm" of economic growth characterized by creative destruction through the entry of new innovators and the exit of former innovators. In this paradigm, entry, and the threat of entry, is the key determinate of economic performance.[43] Aghion and Howitt argue that the Schumpeterian Paradigm can readily explain the productivity gap that exits between the U.S. and Europe. They state (2005, p. 8) that competitive policy in Europe has paid insufficient attention to entry, that entry rates have been low, and that "the lower degree of turnover in Europe compared to the US is an important part of the explanation for the relatively disappointing European growth performance over the past decade…"

A plausible explanation for part of the recent low rate of firm formation in France, Germany and Italy is past problems in equity markets. Gompers and Lerner (2004, Chapter 14) discuss the nature of the decline in the availability of external equity finance in Europe in the late 1980 and the 1990s. In Europe there has been much public policy discussion concerning both the low numbers of high-tech public entrants and the lack of venture capital and follow-up public equity financing in the late 1980s and

[43] See also Aghion, Blundell, Griffith, Howitt and Prantl (2004), and Aghion and Howitt (1992 and 1998).

1990s.[44] For example, Bottazzi and Da Rin (2002) state that "there is a growing perception that Europe's growth problems may be caused not as much by rigidities in labor markets, as by weaknesses in capital markets, and in particular in the access to risk capital." The decline in equity availability may explain why Germany, France and Italy had comparatively few public entrants in the last two decades and why Europe lagged behind the U.S. in high-tech production.[45] For example, in the period 1980-1998, Germany, France and Italy experienced declines of between 33% and 41% in high-tech world market shares.[46] These facts, along with our findings, suggest that the state of development of a country's equity markets may play an important role in determining the quantity and quality of a country's high-tech public entrants, and therefore the performance of its high-tech sector.

VIII. Conclusion

The goal of our paper has been to explore the role played by new public entrants and public equity finance in the recent ascent of the high-tech sector of U.S. manufacturing. Public equity finance, largely ignored in the literature, became increasingly important in the 1980s and 1990s and it was typically the main form of finance for high-tech public entrants early in their life-cycle. For public entrants, our estimates from a dynamic investment model indicate that public equity is the only form of finance that shares a statistically significant and economically important relationship with R&D investment. No such relationship exists for incumbents, consistent with the fact that they make relatively little use of public equity finance. Additional evidence emerges from the recent bubble in the Nasdaq which generated enormous variation in stock issues. We find that only equity-dependent entrants experienced a boom and bust in R&D investment between 1998-2002, consistent with supply shifts in equity finance. Together, these results suggest that shifts in the availability of public equity finance had a substantial impact on the R&D of new public entrants in recent years.

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[44] See for example the European Commission (1998). Venture capital has a much smaller impact in Europe compared to the United States (Bottazzi and Da Rin, 2002). In addition, while most of U.S. venture capital is directed towards the high-tech sector (Gompers and Lerner, 2004), this is not the case in Europe (European Commission, 1999). Furthermore, follow-up equity financing for small high-tech firms is much lower in Europe compared to the U.S. (European Commission, 1998).

[45] According to Loughran, Ritter and Rydqvist (1994, updated in 2004 at http://bear.cba.ufl.edu/ritter/Int.pdf), for the entire economy, France had 571 IPOs between 1983-2000, Germany had 407 between 1978-1999 and Italy 181 between 1985-2001. This contrasts with the more than 6600 IPOs in the U.S. economy between 1980-2000 (SDC New Issues Data Base).

We have also shown that new public firms, especially those in the 1980s and 1990s, restructured the high-tech sector. Between 1970 and 2004, nearly 2000 IPOs occurred in the six key high-tech industries in our study. In all industries but drugs, the flood of new entrants caused incumbents to lose most of their pre-1970 share of sales and R&D, with the largest losses coming in the 1990s. Descriptive regressions show that the evolution of shares of cohort sales and R&D are closely tied to new equity finance but not to other forms of finance. In addition, a substantial number of individual new public firms rapidly became leading firms in their respective industries. Our study documents the potentially powerful impact of new public firms, something that has been ignored in the literature. It also provides an interesting example of Schumpeterian creative destruction, but with a twist – new public firms, relying heavily on public equity, played the star role.

[46] See The National Science Foundation, *Science and Engineering Indicators --2002*, Chapter 6.

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Data Appendix

We use Thompson Financial's SDC New Issues database to identify the firms that conducted an IPO between 1970 and 2004. We were able to find Compustat coverage for approximately 93% of the IPO firms identified by SDC. Firms are only included in our dataset if Compustat reports a primary SIC code within manufacturing and a U.S. incorporation code. Spinoffs and firms going public after a reorganization are not included in the set of IPO firms. For the IPOs without coverage in Compustat, we collected balance sheet information from company reports if the SDC database listed a primary industry code in manufacturing and a U.S. incorporation code. The primary source for the balance sheet information was Moody's, and we were able to find data for all but 60 IPOs listed by SDC. Any newly listed firm that was not identified as an IPO or an original incumbent was placed in the "other" category, which appears to consist primarily of spinoffs and best efforts offerings. The final dataset contains 3596 firms conducting an initial public offering in U.S. manufacturing between 1970 and 2004. There are an additional 187 IPOs that initially had a non-manufacturing primary SIC code but at some point thereafter move into manufacturing.

We explored the share of sales (Table 5) using Compustat's segmented data base. Since segment sales are reported at the four-digit level, we aggregate across four-digit industries to compute a segmented sales figure for each firm at the 3-digit level. If segmented data was missing for a firm, we used the firm level sales figure reported on the Compustat's Industrial Annual database and placed the entire amount in the firm's primary industry (this was seldom necessary). Using sales figures from this segmented data base, IPO cohort shares in 2000 are virtually identical (e.g., starting with the 1970-1974 cohort, the shares are 0.072, 0.009, 0.114, 0.132, 0.100 and 0.057), while incumbent's share of sales falls to 37% and "other firms" share increases slightly (to 0.146).

Table 7 reports follow-up equity financing for leading firms in two key industries. We seek to measure the magnitude of new equity financing in the period of a firm's life cycle when it is a net seller of equity. To do this we summed net new equity finance until we reached a year in which the firm was a net buyer of equity (i.e., until net new share issues were negative). We then compared this value to the value generated by summing net equity finance over all years following the IPO (or, for incumbents, all the years between 1970 and 2000). We report the larger of the two values in Table 7. Stopping at the first time the firm is a net buyer of equity has the potential to greatly understate the firm's use of equity finance, as firms may have a year or more when both sales and purchases of equity are quite small, resulting in a small negative values for net new share issues.

Table 1: IPOs in Six High-Tech Industries: 1970 - 2004

Industry *Three-digit SIC Code*	**# of Firms at Beginning of 1970 (Incumbents)**	**1970-1974**	**1975-1979**	**1980-1984**	**1985-1989**	**1990-1994**	**1995-1999**	**2000-2004**	**1970-2004**	**# of Firms at End of 2004**
283	35	11	3	44	55	136	122	94	465	446
357	42	41	16	106	77	78	81	20	419	219
366	32	27	6	51	33	44	63	28	252	204
367	63	21	3	40	35	51	67	52	269	230
382	59	18	4	46	27	26	43	25	189	171
384	23	14	10	68	45	73	85	42	337	262
Total	**254**	**132**	**42**	**355**	**272**	**408**	**461**	**261**	**1931**	**1532**
Share of Manufacturing	**0.14**	**0.27**	**0.54**	**0.62**	**0.47**	**0.51**	**0.59**	**0.75**	**0.54**	**0.48**

Note: The IPO numbers are based on 3-digit industry classification at the time of the IPO. The industries are pharmaceuticals (SIC 283), office and computing equipment (SIC 357), communications equipment (SIC 366), electronic components (SIC 367), industrial measuring and control instruments (SIC 382) and surgical instruments (SIC 384).

Table 2: New Public Firms: Investment & Financing After the IPO

	Six High-Tech Industries		All Other Manufacturing	
Interval Relative to IPO:	***t = 1 to t = 5***	***t = 6 to t = 10***	***t = 1 to t = 5***	***t = 6 to t = 10***
cumulative R&D / assets (beginning of period)				
median	0.71	0.55	0.08	0.08
mean	1.17	1.02	0.26	0.23
cumulative physical investment / assets (beginning of period)				
median	0.28	0.21	0.27	0.18
mean	0.47	0.38	0.41	0.27
cumulative total investment / assets (beginning of period)				
median	1.08	0.83	0.36	0.24
mean	1.63	1.40	0.57	0.41
cumulative new total debt (net) / assets (beginning of period)				
median	0.02	0.00	0.10	0.02
mean	0.28	0.19	0.33	0.13
cumulative gross cash flow / assets (beginning of period)				
median	0.41	0.55	0.31	0.31
mean	0.52	0.55	0.41	0.41
cumulative new stock issues (net) / assets (beginning of period)				
median	0.46	0.19	0.02	0.01
mean	1.36	1.08	0.35	0.14
Share of observations with negative gross cash flow	0.32	0.25	0.21	0.17
Share of observations with positive dividends	0.04	0.08	0.25	0.33

Note: The high-tech idustries included are SICs 283, 357, 366, 367, 382 and 384.
The year in which the firm conducts its IPO is t = 0.
Only firms surviving until the end of the period are included in the reported values.
Ratios are winsorized at the 1% level.

Table 3: Dynamic Investment Regressions: GMM Estimates

Dependent Variable: RD/TA

Time Period:	*1970-2004*		*1970-2004*		*1997-2002*	
	(1) **Entrants**	(2) **Incumbents**	(3) **Entrants**	(4) **Incumbents**	(5) **Entrants**	(6) **Incumbents**
$(RD/TA)_{t-1}$	**0.198**	**0.830**	**0.141**	**0.688**	**0.170**	**0.244**
	(0.129)	*(0.158)*	*(0.086)*	*(0.120)*	*(0.188)*	*(0.441)*
$(RD/TA)_{t-1}^2$	**-0.029**	**-1.577**	**0.000**	**-1.183**	**-0.009**	**-0.305**
	(0.057)	*(0.727)*	*(0.036)*	*(0.512)*	*(0.075)*	*(1.606)*
$(SALES/TA)_t$			**0.036**	**0.031**	**0.051**	**0.040**
			(0.018)	*(0.005)*	*(0.039)*	*(0.012)*
$(SALES/TA)_{t-1}$	**-0.043**	**-0.001**	**-0.018**	**-0.019**	**-0.026**	**-0.006**
	(0.019)	*(0.005)*	*(0.007)*	*(0.004)*	*(0.016)*	*(0.011)*
$(GCF/TA)_t$			**0.027**	**0.033**	**0.026**	**0.000**
			(0.041)	*(0.016)*	*(0.072)*	*(0.035)*
$(GCF/TA)_{t-1}$	**0.058**	**0.033**	**0.017**	**0.016**	**0.025**	**-0.040**
	(0.036)	*(0.019)*	*(0.012)*	*(0.013)*	*(0.019)*	*(0.035)*
$(STK/TA)_t$			**0.151**	**-0.034**	**0.179**	**-0.051**
			(0.019)	*(0.012)*	*(0.035)*	*(0.034)*
$(STK/TA)_{t-1}$			**-0.015**	**-0.014**	**-0.018**	**-0.026**
			(0.004)	*(0.006)*	*(0.008)*	*(0.024)*
m1 (p-value)	0.000	0.000	0.000	0.000	0.000	0.025
m2 (p-value)	0.079	0.080	0.231	0.041	0.311	0.417
GCF Chi2 (p-value)			0.265	0.024	0.467	0.450
STK Chi2 (p-value)			0.000	0.001	0.000	0.076
Observations	11018	3174	10853	3092	3975	277
Firms	1309	195	1307	195	966	73

Note: Robust standard errors are reported in parenthesis. Industry-specific year dummies are included in each regression. Lagged levels dated t - 3 and t - 4 are used as instruments. Sargan tests do not reject the validity of the instruments in any specifications. Outliers are trimmed at the 0.5% level.

Table 4: Median R&D to Sales Ratios

Year:	1975	1980	1985	1990	1995	2000	2004
IPO Cohort	**Panel A: Five High-Tech Industries**						
1970 - 1974	0.059	0.059	0.085	0.086	0.095	0.101	0.091
1975 - 1979		0.065	0.099	0.083	0.091	0.085	0.080
1980 - 1984			0.093	0.081	0.076	0.097	0.089
1985 - 1989				0.096	0.087	0.107	0.126
1990 - 1994					0.121	0.131	0.124
1995 - 1999						0.180	0.166
2000 - 2004							0.168
Incumbents	*0.033*	*0.037*	*0.055*	*0.051*	*0.053*	*0.062*	*0.055*
	Panel B: Drugs (SIC 283)						
1970 - 1974							
1975 - 1979							
1980 - 1984			0.284	0.347	0.226	0.175	0.195
1985 - 1989				0.916	1.125	0.626	0.856
1990 - 1994					1.682	1.239	1.182
1995 - 1999						1.756	2.242
2000 - 2004							2.758
Incumbents	*0.043*	*0.048*	*0.074*	*0.089*	*0.094*	*0.104*	*0.142*

Note: The five high-tech industries are SICs 357, 366, 367, 382 and 384.
Incumbents are firms in place at the beginning of 1970.
No ratios are reported for the first two cohorts in Panel B due to a limited number of observations.

Table 5: Share of Sales by IPO Cohort

Year:	1975	1980	1985	1990	1995	2000	2004
IPO Cohort				**Panel A: Five High-Tech Industries**			
1970 - 1974	0.029	0.035	0.037	0.039	0.073	0.078	0.079
1975 - 1979		0.015	0.022	0.025	0.018	0.009	0.013
1980 - 1984			0.072	0.096	0.140	0.118	0.036
1985 - 1989				0.054	0.079	0.131	0.144
1990 - 1994					0.078	0.097	0.118
1995 - 1999						0.053	0.066
2000 - 2004							0.031
Incumbents	*0.941*	*0.913*	*0.820*	*0.733*	*0.571*	*0.386*	*0.433*
Others	*0.030*	*0.037*	*0.049*	*0.052*	*0.042*	*0.129*	*0.080*
				Panel B: Drugs (SIC 283)			
1970 - 1974	0.010	0.012	0.012	0.015	0.016	0.024	0.016
1975 - 1979		0.003	0.003	0.001	0.002	0.002	0.001
1980 - 1984			0.010	0.021	0.036	0.046	0.070
1985 - 1989				0.004	0.004	0.009	0.014
1990 - 1994					0.024	0.024	0.041
1995 - 1999						0.018	0.020
2000 - 2004							0.026
Incumbents	*0.967*	*0.978*	*0.946*	*0.944*	*0.884*	*0.849*	*0.778*
Others	*0.023*	*0.008*	*0.028*	*0.015*	*0.035*	*0.027*	*0.034*

Note: The five high-tech industries are SICs 357, 366, 367, 382 and 384.
Incumbents are firms in place at the beginning of 1970.
Others are newly listed firms in Compustat that are not identified as IPOs (such as spinoffs and best efforts offers).

Table 6: Share of R&D by IPO Cohort

Year:	1975	1980	1985	1990	1995	2000	2004
IPO Cohort	**Panel A: Five High-Tech Industries**						
1970 - 1974	0.037	0.055	0.062	0.058	0.083	0.097	0.121
1975 - 1979		0.026	0.035	0.043	0.028	0.008	0.014
1980 - 1984			0.080	0.100	0.118	0.084	0.053
1985 - 1989				0.067	0.087	0.087	0.098
1990 - 1994					0.098	0.143	0.137
1995 - 1999						0.099	0.091
2000 - 2004							0.055
Incumbents	*0.936*	*0.881*	*0.781*	*0.695*	*0.551*	*0.320*	*0.331*
Others	*0.027*	*0.037*	*0.043*	*0.036*	*0.036*	*0.162*	*0.099*
	Panel B: Drugs (SIC 283)						
1970 - 1974	0.012	0.007	0.006	0.012	0.011	0.012	0.007
1975 - 1979		0.000	0.001	0.000	0.000	0.000	0.000
1980 - 1984			0.030	0.057	0.091	0.074	0.095
1985 - 1989				0.032	0.030	0.019	0.028
1990 - 1994					0.083	0.070	0.089
1995 - 1999						0.094	0.055
2000 - 2004							0.061
Incumbents	*0.967*	*0.988*	*0.934*	*0.887*	*0.761*	*0.695*	*0.640*
Others	*0.021*	*0.005*	*0.029*	*0.013*	*0.023*	*0.036*	*0.025*

Note: The five high-tech industries are SICs 357, 366, 367, 382 and 384.
Incumbents are firms in place at the beginning of 1970.
Others are newly listed firms in Compustat that are not identified as IPOs (such as spinoffs and best efforts offers).

Table 7: Leading Firms in Selected Industries in 2000

Company	IPO Year	Segment Sales	Venture Capital	IPO Proceeds	New Equity Finance (Post-IPO)
		Panel A: Office and Computing			
Hewlett-Packard	Incumbent	41,165.00			1,025.04
IBM	Incumbent	37,811.00			4,623.88
Compaq	1983	35,038.00	18.98	102.43	1,164.51
Dell	1988	31,888.00	32.47	39.71	403.65
Cisco	1990	18,928.00	21.10	62.28	2,817.89
Xerox	Incumbent	17,156.00			2,316.36
Sun Microsystems	1986	11,971.00	56.29	90.84	638.57
Gateway	1993	9,600.60		148.66	150.71
EMC	1986	8,872.82	0.44	58.62	654.10
Apple	1980	7,983.00	18.17	189.65	34.78
		Panel B: Electronic Components			
Intel	1971	27,297.00	26.77	28.72	1,234.23
Solectron	1989	14,137.50	11.25	14.25	1,607.86
Texas Instruments	Incumbent	10,267.00			1,708.14
SCI Systems	Incumbent	8,342.58			114.29
Motorola	Incumbent	7,876.00			4,045.92
Lucent Technologies	Spinoff	6,953.00			3,057.04
Micron Technology	1984	6,278.40	12.42	43.99	1,300.48
Advanced Micro Devices	1972	4,644.19	6.70	32.25	1,208.53
Sanmina	1993	3,911.56	13.59	26.14	687.64
Jabil Circuit	1993	3,558.32		19.89	803.76

Note: All values are in millions of 2000 dollars.
Venture capital received comes from Venture Economics.
IPO proceeds are taken from the SDC New Issues database.
Post-IPO new equity finance comes from Compustat.
New equity finance is the sum of net equity issues until the firm becomes a net buyer of its equity.
Sales in 2000 come from Compustat's line of business data.
Compaq merged with Hewlett-Packard in 2002.
SCI Systems merged with Sanmina in 2001.