Working Paper Series

R&D and Internal Finance: A Panel Study of Small Firms in High–Tech Industries

Charles P. Himmelberg and Bruce C. Petersen

Working Papers Series
Issues in Macroeconomics
Research Department
Federal Reserve Bank of Chicago
December 1991 (WP-91-25)

FEDERAL RESERVE BANK
OF CHICAGO

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

R&D and Internal Finance: A Panel Study of Small Firms in High-Tech Industries[1]

Charles P. Himmelberg
New York University

Bruce C. Petersen
Washington University
Federal Reserve Bank of Chicago

(First submitted: March 23, 1990)
June 12, 1991

[1]The authors would like to thank Joe Altonji, Charles Calomiris, Steve Fazzari, Zvi Griliches, Ken Kuttner, Dorothy Petersen, Rob Porter, F. M. Scherer, Steve Strongin, two anonymous referees, and seminar participants at the Federal Reserve Bank of Chicago, Miami University at Oxford, Northwestern University, the University of Chicago, the University of Wisconsin at Madison and Washington University for helpful comments and suggestions. Remaining errors are our own. This research was begun while both authors were at the Federal Reserve Bank of Chicago.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

Abstract

Since Schumpeter, economists have argued that internal finance should be an important determinant of R&D expenditures. Yet almost without exception, previous empirical studies have not found evidence of such a relation. Using newly available data, we investigate this puzzle with a panel of 179 small firms in high-tech industries. Under each of the different estimation strategies we employ, we find an economically large and statistically significant relationship between R&D expenditures and internal finance. Our results are consistent with the view that, because of capital market imperfections, the flow of internal finance is the principal determinant of the rate at which small, high-tech firms acquire technology through R&D.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

Since Schumpeter,[1] economists have argued that internal finance is an important determinant of R&D expenditures. For example, Kamien and Schwartz (1978, p.252) state, "Among the leading characteristics commonly associated with industrial research and development, one of the most prominent is the virtual necessity for it to be financed internally from a firm's current profits and accumulated funds." Yet almost without exception, previous empirical studies have not found evidence of such a relationship. In this paper, we investigate this puzzle with new data on small firms in high-tech industries.

The arguments why internal finance, for some firms, may be the principal determinant of R&D are becoming ever more refined with the development of the economics of information. Arrow (1962) was among the first to argue that moral hazard problems hinder external financing of highly risky business activities such as innovation. More recently, Stiglitz and Weiss (1981) and Myers and Majluf (1984), among others, have developed formal models of moral hazard and adverse selection in markets for debt and equity which apply particularly well to high-tech investments.[2] These papers provide a formal justification for models of the firm which assume that the rate at which small, growing firms acquire capital, including R&D, is determined by access to internal finance (e.g., Kamien and Schwartz (1978) and Spence (1979)).

Our empirical findings are based on a panel of 179 small firms in high-tech industries. While the initial size of the firms in our study is under $10 million in capital stock, Acs and Audretsch (1988) show that firms in this size range account for a major fraction of new innovation in U.S. manufacturing. Until recently, it would have been nearly impossible to assemble such a data base.[3] Previous R&D studies emphasizing financial considerations focused on large firms and did not have access to recently developed panel data techniques.

While our major focus is on the effect of internal finance on R&D expenditures, we also

[1]For Schumpeter's views on the potential importance of internal finance for innovation, see Schumpeter (1942, ch.8). One of Schumpeter's defenses of monopoly practices was that they could provide resources for financing the innovation process. This remains an provocative though controversial idea.

[2]We note that adverse incentive and selection problems are compounded by the absence of collateral value for investments like R&D. The importance of collateralizable net worth has been emphasized by Bernanke and Gertler (1989), Calomiris and Hubbard (1990) and Hubbard and Kashyap (1990). Since small, high-tech firms hold most of their value in growth opportunities and scientific knowledge, they are likely to have little or no collateralizable net worth.

[3]Compustat expanded coverage to such small corporations only recently.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

consider its effect on physical investment. There are several reasons why it is useful to do so. First, this approach permits a comparison of our findings to the existing literature on physical investment under capital market imperfections. Second, it is inappropriate to view the firm as having access to separate sources of finance for R&D and physical investment. And finally, as argued by Schumpeter, new knowledge must be embodied in the production process through investment in new plant and equipment. Hence, the physical investment of R&D-intensive firms can likely be characterized by a similarly high degree of asymmetric information.

We find an important role for internal finance in explaining both the R&D and physical investment expenditures of the firms in our panel. Controlling for unobservable firm effects, which has not been done in previous R&D studies, we obtain a large and statistically significant relationship between both forms of investment and internal finance. However, the conventional within-firm estimates imply an elasticity for R&D that is less than half the elasticity for physical investment.[4] We argue that this is due to high adjustment costs for R&D. These adjustment costs induce a downward bias in the within-firm estimator if firms smooth R&D in response to transitory shocks in cash flow. Following a procedure outlined by Griliches and Hausman (1986), which they apply to a similar problem in the labor literature, we obtain instrumental variable estimates that imply internal finance elasticities of 0.670 for R&D and 0.822 for physical investment.

The remainder of the paper is organized as follows. The next section briefly reviews the theoretical motivation and outlines the empirical predictions. Section 2 explains the construction of our panel and provides summary statistics. Section 3 reports our empirical results, and Section 4 concludes.

1 Theoretical and Empirical Issues

There is an excellent review of the empirical literature on internal finance and R&D in Kamien and Schwartz (1982, p.98). They conclude that "the empirical evidence that ei-

[4]We adopt the terminology conventionally employed by panel studies by using "between-firm" to refer to differences in firm-specific averages across firms, where the averages are computed over time; the term "within-firm" is used to refer to deviations of variables from these firm-specific means.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

ther liquidity or profitability are conducive to innovative effort or output appears slim." Cross-sectional studies such as Scherer (1965), Mueller (1967) and Elliott (1971) find no relationship between internal finance and R&D.[5] It is important to point out, however, that previous empirical studies considered only large firms, very often only firms in the Fortune 500. Because these firms typically generate much more cash flow then they need for investment purposes, it is unlikely that the existence of financing constraints would have any effect. This point is made elegantly in a theoretical framework in Kamien and Schwartz (1978).[6]

In contrast to the R&D literature, there is a large literature dating back to Meyer and Kuh (1957) which documents the relationship between internal finance and *physical* investment. Most of these studies find an important role for internal finance.[7] For example, a recent study by Fazzari, Hubbard and Petersen (1988) of a panel of U.S. manufacturing firms finds that a large fraction of the within-firm variation in physical investment can be explained by variation in cash flow for firms that exhaust their internal finance. There are also recent studies which document the relationship between physical investment and internal finance for Japanese and U.K. firms.[8]

1.1 The Role of Internal Finance

Arguments for why R&D must be funded primarily by internal finance are usually based on the existence of information asymmetries between firms and suppliers of external finance. Information asymmetries are easy to motivate, particularly for small, high-tech firms. The very nature of R&D and innovation-based physical investment precludes outsiders from making accurate appraisals of value. In addition, even when firms can costlessly transmit information to outsiders, strategic considerations may induce firms to actively *maintain*

[5] An exception is Grabowski (1968, p.296). He examines a cross section of large firms in the chemical, drug and petroleum industries and finds an economically large and statistically significant relationship between R&D intensity and internal finance only in the drug industry.

[6] They show that, under quite plausible assumptions, even if *all* firms relied entirely on internal finance to fund R&D, only small firms would find these constraints to be binding.

[7] See, for example, Fazzari and Athey (1987). For a review of this literature, see Fazzari, Hubbard and Petersen (1988)

[8] See Hoshi, Kashyap and Scharfstein (1991) for evidence on Japanese firms and Devereux and Schiantarelli (1989) for evidence on U.K. firms.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

information asymmetries. Levin, Klevorick, Nelson and Winter (1987) report that firms in most industries view patents as an ineffective method of appropriating the returns to R&D, and instead often prefer to use secrecy.

The effect of information asymmetries on the market for new share issues has been examined by Myers and Majluf (1984) through an extension of Ackerlof's (1970) well-known "market-for-lemons" argument.[9] Myers and Majluf explain why firms may be forced to sell stock at a discount (pay a "lemons premium") if they can sell shares at all. The adverse selection problems which they describe can be particularly severe for high-tech firms since the range of actual (but unobservable) values between "good firms" and "lemons" can be large. [10] Like equity markets, debt markets are also vulnerable to adverse selection problems because of asymmetric information about risk characteristics and default probabilities. Stiglitz and Weiss (1981) argue that banks may ration credit rather than use interest rates to clear the market because increases in interest rates may cause low risk borrowers to exit the application pool. Again, this outcome seems particularly plausible for high-tech firms where the probability of default can vary widely over a set of observationally equivalent firms.

In addition to adverse selection, the issuance of new debt is further complicated by moral hazard problems. Arrow (1962, p.153) argues that this problem is especially relevant for investment in R&D projects, given that "the output can never be predicted perfectly from the inputs." Pursuing this line of reasoning, Stiglitz and Weiss (1981) note that as interest rates rise, unmonitored borrowers have an incentive to use loans for projects that are not in the best interest of lenders. In particular, borrowers can invest *ex post* in riskier, higher-return projects that increase the probability of bankruptcy, but offer no offsetting gain to debtholders if success is achieved. This problem is accentuated as firms become more leveraged. It is for this reason that equity, not debt, is considered the natural

[9] The classic example of a market with asymmetric information and adverse selection problems is Ackerlof's (1970) used car market. But we find this example less convincing than the new-equity market for small, R&D-intensive companies. A potential buyer of a used car can, at relatively low cost, hire a mechanic to assess the car's true quality. In contrast, a potential investor might have to hire a team of scientists to make an accurate appraisal of the potential value of a firm's R&D projects.

[10] Acs and Audretsch (1990, p. 71) report that only a small fraction of new firms receive venture capital financing, suggesting that venture capital is not a quantitatively important method for overcoming information problems in equity markets.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

financial instrument for high-tech investment.[11] It should also be pointed out that the above problems are compounded by the lack of collateral value for most R&D investments.[12]

1.2 R&D and Physical Investment With Financing Constraints

We describe the investment problem of a small, high-tech firm by appealing to the model in Spence (1979). In his model, firm profits in the initial stage of the market are positive because of low industry capacity relative to demand. Each firm's rate of growth is constrained by access to internal finance. The solution in his model is that firms move out their expansion paths during the growth phase of the industry as rapidly as their internal finance permits, maintaining equality of marginal products of each type of investment.

In order to introduce R&D investment into the model, the production function is assumed to include not only a stock of capital but a stock of technology as well.[13] This follows the productivity literature, where it is common to assume that output is a homothetic function of technology and physical capital, and that the stock of technology is acquired through R&D expenditures (for a recent review of this literature, see Mairesse and Sassenou (1991)). The assumption of a homothetic function is supported by the empirical fact that the R&D-to-sales ratio is approximately constant over firm size in most industries (e.g., Griliches (1984)).

For reasons discussed in Section 1.1, we assume that firms face a binding financial constraint on investment expenditures. For the simplest case in which the firm obtains no external financing, such a constraint implies that the firm's total investment expenditures cannot exceed current cash flow. This stylized view of the financing constraint could be generalized to include debt as a multiple of internal equity as discussed in Spence (1979). However, this generalization turns out to not be necessary since the firms in our sample

[11]Long and Malitz (1985) provide formal empirical evidence that financial leverage is negatively correlated with R&D expenditures.

[12]Bester (1985) emphasizes that in debt markets, collateral can be used as both a signalling device to overcome adverse selection and as an incentive device to overcome moral hazard. However, these options are not likely to be available for small firms in high-tech industries because there is no collateral value to failed R&D and innovation-based investment projects.

[13]Including technology in the production function clearly accommodates process R&D. However, most R&D is for new product development. Griliches (1986, p.144) points out that the production function approach also accommodates new product R&D if output is replaced by sales. In our discussion of expansion paths, this would imply replacing the isoquant with an "isovalue" curve.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

obtain very little debt finance.

The existence of an internal finance constraint does not change the first order conditions determining the *relative* levels of the desired stocks of physical and technological capital (e.g., Henderson and Quandt (1971)). Rather, the constraint determines the *absolute* levels of R&D and physical investment. In the absence of adjustment costs, this allocation is determined by the parameters of the production function. If the production function is homothetic, then the expansion path is linear, and the optimal allocation of internal finance between R&D and physical investment is proportional to the (constant) shares of technology and physical capital in the production function. This fact allows a loose structural interpretation of the cash flow coefficients in our reduced-form regressions. We note that if the production function were not homothetic, or if there were adjustment costs, then expenditure shares would vary over time. In this case, the cash flow coefficients could be interpreted as a linear approximation of these shares over the time period covered by our panel.

1.3 Adjustment Costs

It is important to account for the probable existence of high adjustment costs for R&D when estimating the effect of internal finance on R&D. The failure to account for adjustment costs could bias our results for reasons similar to Griliches and Hausman's (1986) explanation of the puzzle that within-firm estimates of labor demand functions often yield output elasticities of less than one, implying increasing returns to scale. They argue that because of adjustment costs, labor is hired in anticipation of permanent output, with little adjustment made in response to transitory movements in output. Since a firm's R&D investment is predominantly a payment for a flow of services from its stock of highly trained scientists, engineers and other specialists, the Griliches and Hausman insight and approach is especially applicable to our problem.

Theoretical explanations and empirical evidence of high adjustment costs for R&D can be found throughout the economics literature.[14] Grabowski (1968) makes a strong case for

[14] Discussions of high adjustment costs for R&D are found outside the economics literature as well. For example, the literature on the management of technological innovation frequently recommends that temporary adjustments in R&D expenditures be avoided because of high adjustment costs (e.g., Twiss (1986)).

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

high adjustment costs for R&D and argues that "research workers, whose salaries constitute a sizable percentage of total expenditures, are not perfectly elastic in supply and cannot be alternatively fired and rehired in accordance with temporary changes in business conditions." There are a number of reasons why temporary hiring and firing of research workers is costly. For one, researchers require a great deal of firm-specific knowledge, and training new workers is expensive. Perhaps more importantly, fired specialists are able to transmit valuable knowledge to competitors who hire them. Pakes and Nitzan (1983) describe optimal labor contracts designed specifically to retain R&D workers to reduce appropriability problems. Levin et al. (1987) report that hiring a competitor's R&D personnel is viewed by many firms as an effective means of procuring technological capital compared to alternative channels of information spillover.

Empirical evidence on adjustment costs is reported by Bernstein (1986) and Bernstein and Nadiri (1988, 1989). Bernstein and Nadiri (1989) estimate returns for R&D and physical investment as well as the marginal adjustment costs for these inputs for firms in four two-digit industries. The estimated marginal adjustment costs were higher for R&D in all four industries. In particular, the marginal adjustment cost for R&D was two to several times higher for two-digit SIC codes 28 and 35, two of the four industries in our panel.

The existence of high adjustment costs for R&D implies the following modification to our description of financially constrained firms. In order to minimize both the current and future adjustment costs, firms set the level of R&D expenditures in accordance with the "permanent" level of internal finance. When the firm believes that a change in the flow of internal funds is "transitory," it attempts to maintain the planned level of R&D expenditures by adjusting physical investment, or, if available, working capital. The econometric specification in Section 3.3 accommodates this description of firm behavior by postulating that current cash flow can be decomposed into a permanent component and a transitory component. Since high adjustment costs imply that R&D is relatively unresponsive to transitory movements, the full impact of the financing constraint is revealed by the relationship between R&D and permanent cash flow.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

1.4 Empirical Predictions

The existence of financial constraints and high costs of adjustment for R&D yields the following empirical predictions which we investigate in section 3. First, the division of internal finance among competing investments is determined by the parameters of the production function. If R&D and physical investment were the only components of total investment, then the cash flow coefficients would sum to one. In reality, of course, while R&D and physical investment are the principal components, there are other uses (sources) of funds such as working capital. Hence, the coefficients should sum to a number that is large but less than one. Second, if adjustment costs are important, R&D may not respond equally to transitory and permanent shocks to cash flow. Since the conventional within-firm estimator does not distinguish between transitory and permanent movements in cash flow, it may be a downward biased estimate of the effect of permanent movements. For this reason, we emphasize an instrumental variables procedure which is designed to control for both this bias and the existence of individual firm effects.

2 The Data and Summary Statistics

2.1 Construction of the Panel

The firm data for this study are taken from the May 1989 release of Standard and Poor's Compustat file. Compustat follows virtually every company listed on the American and the New York Stock Exchanges and the Over-the-Counter Markets. Out of the initial universe of 3035 manufacturing firms, we construct our panel using five selection criteria. A firm is included in our panel if (i) its primary location is domestic and it is not a subsidiary, (ii) the replacement value of its capital stock in 1983 is between $1 and $10 million, (iii) there are no missing values for essential variables from 1983 to 1987, (iv) there are no major mergers, acquisitions, or divestitures.[15], and (v) its industry is one of four identified as high tech: chemicals and drugs, machinery, electrical equipment and communications,

[15]Further details are described in an appendix available from the authors. This criterion excludes any firm for which the discrepancy between investment expenditures and the reported change in the gross book value of the capital stock net of retirements is greater than 15 percent.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

and instruments.[16] These four industries have the highest R&D-to-sales ratios in manufacturing, and collectively account for approximately one half of all R&D expenditures in manufacturing (see Scherer (1980, p.410)).

We examine the five-year time period 1983-1987 because using a longer period results in a sharp reduction in the number of small firms listed continuously in Compustat. The ten million dollar size cutoff is chosen to focus on small firms.[17] Domestic, non-subsidiary firms with historical data back to 1982 comprise approximately 61 percent of the Compustat universe of manufacturing firms. Of these, 56 percent are in high-tech industries, and of these, 37 percent have capital stocks of under $10 million at the start of our sample period. Deleting firms with major mergers and acquisitions leaves us with a final sample of 179 firms.[18]

Table 1 documents the beginning and ending average sizes of the firms in our panel. The average beginning value of the capital stock is $4.35 million, and the average number of employees is 237. On average, these firms accumulated capital at a very high average real rate of growth – over 12 percent annually over the five year period. The resulting average ending capital stock was 11.93 million and the average number of employees was 407. The standard deviation of the distribution of capital stocks grew from 2.5 in 1983 to 23.6 in 1987, reflecting a wide range of growth rates across firms. Very high growth rates are not uncommon in high-tech industries. For example, in the computer industry, a number of startups reached Fortune 500 size in just a few decades.[19]

The last row of Table 1 reports the ratio of R&D to R&D plus physical investment for our sample of high-tech firms. On average, these firms allocate as much funding to R&D as to physical investment. This ratio varies little across our four high-tech industries: the

---

[16]Griliches and Mairesse (1984) identified the two-digit SIC codes 28, 35, 36 and 38 as the science-based industries. A similar set of industries was identified by Bernstein and Nadiri (1988).

[17]Size cutoffs are always arbitrary, but ten million is a convenient cutoff because it is a focal point and because it closely corresponds to the 500-employee cutoff used in other studies of small firm behavior. Cutoffs ranging from five to twenty million yield the same pattern of findings reported in the next section.

[18]We examined the distribution of the data sample selected by the above criteria and identified eight distinct outliers, all of which had initial capital stocks of under $2 million. See the data appendix available from the authors for further details.

[19]The Wall Street Journal, Sept. 8, 1989, reports: "In the 32 years since a $70,000 capital investment launched Digital Equipment Corp, hundreds of electronics pioneers have started computer-hardware companies. More than a dozen of these startups have turned into Fortune 500 companies."

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

Table 1: Basic Statistics

Variable	Mean	Standard Deviation
Capital Stock, 1983	4.35	2.50
Capital Stock, 1987	11.93	23.61
Number of Employees, 1983	237	225
Number of Employees, 1987	407	1285
Sales, 1983	16.48	16.56
Sales, 1987	38.91	89.22
R&D/(R&D + Investment)	0.528	0.239

Note: All financial figures reported in millions of 1982 dollars.

ratio is 0.481 for pharmaceuticals, 0.530 for non-electrical equipment, 0.516 for electrical equipment, and 0.541 for scientific instruments. These ratios are approximately twice as high as the ratios for the balance of the manufacturing industries in Compustat.

We followed the standard practice in the investment literature of dividing each variable by the beginning-of-period replacement value of property, plant and equipment. This transformation from levels to ratios makes it possible to compare investment and R&D ratios over time and across firms. In a panel with firms that are growing over time as well as starting at different sizes, such a transformation yields trend-stationary series and controls for heterogeneity as well.[20]

2.2 Summary Statistics

Our key summary statistics appear in Table 2, which is divided into a section reporting investment and a section reporting sources of finance. These variables are scaled by the firm's capital stock. The first two columns of the table report the mean and the value at the 75th percentile for each variable. The last two columns of the table decompose the

[20]Since firms record accumulated capital stocks at book value, the replacement value of capital is constructed using a perpetual inventory method (for further details, see Salinger and Summers (1983)). The physical investment, R&D, and the change-in-sales variables correspond to the usual accounting definitions. Since firms treat R&D as an expense, we add R&D back into the usual accounting definition of cash flow. We note that if R&D is subject to classical measurement error, this construction would bias the least squares regressions of R&D on cash flow reported below; the instrumental variable estimates reported Section 3.3 eliminate this bias. A data appendix detailing the construction of the remaining variables (including Tobin's q) is available from the authors on request.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

Table 2: Summary Statistics

Variable	Mean	75th percentile	Variance Between-Firm	Variance Within-Firm
R&D	0.240	0.344	0.054	0.016
Physical Investment	0.257	0.280	0.078	0.128
Total Investment (R&D + Physical Investment)	0.497	0.624	0.195	0.194
Cash Flow	0.444	0.610	0.265	0.157
Net Long Term Debt Financing	0.035	0.023	0.027	0.124
Net Short Term Debt Financing	0.023	0.021	0.007	0.124
Net New Share Issues				
All observations	0.344	0.045	0.512	1.912
Excluding upper 5% tail	0.082	0.030	0.029	0.075
Dividends	0.008	0.000	0.000	0.000

Note: All variables first scaled by capital stock.

variance of each variable into its between-firm and its within-firm component. We adopt the terminology conventionally employed by panel data studies by using "between-firm" to refer to differences in firm-specific averages across firms, where the averages are computed over time; the term "within-firm" is then used to refer to deviations of variables from these firm-specific means.

Reading across the first two rows of Table 2, the means of the investment and the R&D ratios are almost the same; that is, on average, firms allocate as much resources to R&D as to physical investment. In addition, the relative shares are invariant across firm size, suggesting an approximately linear expansion path. As already noted, this is a very high level of R&D spending relative to physical investment compared to firms not in high-tech industries. In addition, the absolute size of the R&D and physical investment ratios is large, which is consistent with the high average growth rates observed in Table 1.

The variance decompositions of investment and R&D are given in the next two columns. The between-firm variances of these two ratios are of the same magnitude, with the variance of the investment ratio being somewhat greater than the variance of the R&D ratio. However, the within-firm variances are very different. The within-firm variance of physical

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

investment is nearly *ten times* greater than the within-firm variance of R&D. Moreover, for physical investment, the within-firm variance amounts to approximately two thirds of its total variance. In contrast, the within-firm variance of R&D is only 20 percent of its total variance. Hall and Hayashi (1989), among others, document a similar pattern in the variance decompositions of physical investment and R&D. This "smooth" behavior of R&D expenditures is consistent with the hypothesis that adjustment costs are high for R&D.

The second part of the table presents statistics on the financial behavior of the firms in our panel. Internal finance is obviously an important source of funds. The mean value of the cash flow ratio is only slightly less than the sum of the means of the investment and R&D ratios. Debt usage, on the other hand, is small; the sum of the mean values of both short term and long term new debt is barely ten percent of the mean of internal finance. This comparison is even more obvious when these ratios are compared at the 75th percentile. A striking result in the table is the fact that essentially none of the firms in our sample pay dividends, which is again consistent with the assumption that they face financing constraints.

The mean ratio of new share issues to capital is much larger than the mean ratio for debt. However, this number is misleading because of the effect of a few large outliers, as shown by the very low value of new share issues at the 75th percentile (the median is zero), and the very high total variance of this ratio. The high value of the mean results from a few very small firms (between $1 and $2 million in capital stock) making proportionately very large new share issues in the first year of our sample.[21] If the upper five percent tail of the distribution is excluded, the ratio declines to 0.082, as reported in the next row of the table.[22]

To summarize, the typical firm in our sample has the following profile. It pays no dividends, rarely issues new equity, and makes only modest use of debt finance. This financing pattern is consistent with the discussion on the role of internal finance in Section 1.1. In

[21]Two examples include Priam Corporation, which in 1983 had a capital stock of 2.4 million and a new share issue of 67.6 million, and Lymphomed, which had a capital stock of 1.4 million, and a new share issue of 13.8 million.

[22]Another way to measure the importance of internal finance relative to external finance is simply to add up the dollar values for *all* firms without scaling; over the time period 1984-1987, internal finance amounted to 3.3 billion, net new debt contributed 745 million and net new share issues amounted to 536 million, where all figures are computed in constant 1982 dollars.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

addition, internal finance is approximately equal to the sum of physical investment and R&D. All of this evidence supports our working hypothesis that the typical firm in our panel faces binding internal finance constraints.

3 Econometric Specification and Results

In this section, we first present the within-firm results and emphasize the potential importance of accounting for unobservable firm effects. We next present the between-firm results for reasons which we motivate below. Finally, we consider an econometric specification which explicitly allows for a differential response of R&D to the permanent and transitory components of cash flow.

3.1 Within-Firm Results

An important econometric issue not addressed in previous empirical studies of R&D and internal finance is the existence of individual firm effects. Controlling for unobservable firm effects is important for our study since the firm effect is likely to be positively correlated with both internal finance and R&D. The most obvious source of the correlation is that firms differ with respect to managerial abilities and that superior managers *both* generate higher cash flows and seek to expand their firms faster than inferior managers.[23] Failing to account for this firm effect can be viewed as a specification error which is likely to bias the estimate of the effect of internal finance on R&D.

We treat the firm-specific components of the respective error terms as fixed effects. Thus our baseline specification for the within-firm estimation is

$$RD_{it} = \beta_0 + \beta_{cf} CF_{it} + \alpha_i + v_t + e_{it}, \tag{1}$$

where α_i is the individual firm effect and v_t is the year effect. We use the standard method of sweeping out the fixed effects by transforming variables to deviations from their firm-specific means.[24] The error term e_{it} accommodates measurement error in the dependent

[23] See Mundlak (1978) and Hsiao (1986).

[24] See Hsiao (1986) for a detailed discussion of this approach.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

variable and the effect of unobserved explanatory variables assumed to be uncorrelated with internal finance and the firm and year effects. We do not view reverse causation as a problem in Equation 1 since there is a sizable gestation lag as well as an application lag between the outlay of an R&D dollar and the beginning of the associated revenue stream.[25] The physical investment equation is estimated using the same specification.

Our within-firm results are reported in Table 3. The top half of the table reports R&D regressions (A1 through A4) while the bottom half contains physical investment regressions (B1 through B4). Heteroskedasticity consistent standard errors are reported in parentheses (see White (1980)). Our baseline specifications A1 and B1 are based on the hypothesis that the firm's investment rate is determined by internal finance. The remainder of Table 3 examines the effect of including demand variables such as Tobin's q and the change in sales to control for the possible expectations role of cash flow. These variables have been used in past studies to investigate the physical investment behavior of mature firms. We include them here to check the robustness of our interpretation of the baseline specification.

For our baseline specification the cash flow coefficient is 0.197 for R&D and 0.482 for physical investment; these coefficients are precisely estimated. The implied elasticities (evaluated at the means in Table 2) are 0.355 and 0.833, respectively. The R^2 statistics for the R&D and physical investment regressions are 0.43 and 0.30, respectively. Thus, a fairly large percentage of the within-firm variation, particularly for R&D, is well explained by within-firm variation in internal finance alone. As already noted, we suspect that the lower estimated elasticity for cash flow for R&D may reflect the fact that firms "smooth" R&D expenditures because it is expensive to respond to *transitory* movements in cash flow. The extent to which the within-firm cash coefficient for R&D coefficient reflects this bias is the focus of subsections 3.2 and 3.3.

Specifications A2 and B2 add the change in sales to the baseline specification. This variable is presumably better than cash flow as a proxy for changes in product demand. Despite the high degree of correlation between cash flow and the change in sales, this regres-

[25] Pakes and Schankerman (1984, pp. 82-84) review the literature and report estimated gestation lags of at least one year; Ravenscraft and Scherer (1982) find even longer gestation lags, reporting mean lags between four and six years. See also the discussion in Griliches (1979, p. 101). Reverse causation problems are further mitigated by the use of instrumental variables in Section 3.3.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

Table 3: Within-Firm OLS Regressions

Equation	Independent Variables			df	R^2
	Cash Flow	Δ Sales	Tobin's q		
R&D Regressions					
A1	0.197	...	...	710	0.43
	(0.020)				
A2	0.173	0.012	...	709	0.46
	(0.022)	(0.009)			
A3	0.174	...	0.002	648	0.46
	(0.019)		(0.0007)		
A4	0.160	0.008	0.002	647	0.46
	(0.023)	(0.008)	(0.0006)		
Investment Regressions					
B1	0.482	...	...	710	0.30
	(0.053)				
B2	0.393	0.046	...	709	0.31
	(0.053)	(0.021)			
B3	0.490	...	-0.0005	648	0.30
	(0.056)		(0.0015)		
B4	0.402	0.049	-0.0014	647	0.31
	(0.055)	(0.021)	(0.0014)		

Note: Tobin's q is available for only 161 firms.
Note: Estimated with year and firm dummies (not reported).
Note: Heteroskedasticity consistent standard errors reported in parentheses

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

sor is not significant in the R&D regression.[26] However, the change in sales is significant in the physical investment regression, lowering the cash flow coefficient by approximately 20 percent.

In specifications A3 and B3, we include Tobin's q, which is tax adjusted following Salinger and Summers (1983).[27] Our results show that Tobin's q enters significantly for our R&D regression but not the physical investment regression.[28] The cash flow coefficient for R&D is reduced by just 10 percent. We considered alternative ways of entering Tobin's q in the regression. For example, we included leads of Tobin's q to capture the potential information role that current cash flow might be playing. This had no additional effect on the results reported in Table 3. Finally, specifications A4 and B4 include both Tobin's q and change-in-sales; in both cases, the reduction in the magnitude and the statistical significance of cash flow coefficient is still small.

The results in specifications A2-A4 and B2-B4 indicate that the explanatory power of cash flow is robust to the inclusion of demand variables. This evidence is suggestive, but it is still possible that sales and Tobin's q do not completely control for the expectations role played by cash flow. For this reason, we re-emphasize the summary statistics in Table 2 which reveal that the typical firm in the sample re-invests 100 percent of its earnings, yet obtains little external finance. When combined with this auxiliary evidence, the above regressions strongly suggest that cash flow is important as a source of finance rather than as a proxy for firms' investment opportunities.

3.2 Between-Firm Results

We have two reasons for presenting between-firm results, in spite of the potential importance of controlling for unobservable firm effects. One reason is that over *three fourths* of the

[26]The correlation between cash flow and the change in sales is 0.68.

[27]The data required to construct Tobin's q are available for only 161 firms.

[28]Hayashi and Inoue (1989) have pointed out that when there are multiple quasi-fixed factors, it is necessary to assume the existence of a capital aggregator and then to redefine Tobin's q in terms of this aggregate. In their framework, Tobin's q is a weighted average of shadow prices of the components of the aggregate measure of quasi-fixed factors. Since we wish to consider the determinants of these factor demands separately, neither the traditional nor this augmented version of Tobin's q is strictly applicable. Nevertheless, we construct a traditional measure of Tobin's q and include it in some specifications for sake of comparison to previous studies.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

variance of the R&D ratio is in the cross-sectional dimension.[29] More importantly, the between-firm results are of interest because the transitory component of cash flow tends to average out over time. Hence, these estimates provide evidence on the extent to which the within-firm estimates are biased downward due to the unresponsiveness of R&D to the transitory component of cash flow.

The standard approach to obtaining the between-firm result is to regress the firm-specific means of the dependent variable on the firm-specific means of the independent variables. For our panel, this amounts to regressing the 1983-1987 firm average of R&D on the 1983-1987 firm average of cash flow. To permit direct comparisons with our within-firm results, Table 4 reports the similar specifications.

The results for our baseline regressions (C1 and D1) appear in Table 4 below. The between-firm estimate of the cash flow coefficient are 0.328 for R&D and 0.306 for physical investment. These results are consistent with our summary statistics that show that our firms, on average, allocate roughly equal amounts to R&D and physical investment. The increase in the R&D coefficient and the nearly offsetting decline in the physical investment coefficient is consistent with the view that firms smooth R&D expenditures to transitory shocks in cash flow at the expense of physical investment. The remaining specifications in Table 4 consider the robustness of the baseline specification. The inclusion of observable firm characteristics such as average sales and average q may also help control for fixed firm effects. As is true with the within-firm specifications, the coefficient on Tobin's q is significant, and has some effect on the cash flow coefficient for R&D, but the effect of cash flow is still large and statistically significant. These results are robust to a number of alternative specifications which we do not report.[30]

---

[29] Griliches and Mairesse (1984, p.345), facing a similar situation, also present both the within-firm and the between-firm results, noting that to not do so can lead to discarding most of the variance in the sample.

[30] Our main concern was the possibility of reverse causation from R&D to cash flow caused by regressing five-year averages on five-year averages. To address this issue, we re-estimated the between-firm regression on the last three years of the panel, using the first two years of cash flow as instruments. For our baseline specification, the cash flow coefficient for R&D rose by 25 percent, while the coefficient for physical investment fell by 13 percent. In both cases, the coefficients were highly significant.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

Table 4: Between-Firm OLS Regressions

Equation	Independent Variables: Cash Flow	Sales	Tobin's q	df	R^2
R&D Regressions					
C1	0.328	...	...	174	0.53
	(0.024)				
C2	0.301	0.009	...	173	0.52
	(0.034)	(0.010)			
C3	0.253	...	0.004	155	0.54
	(0.038)		(0.0016)		
C4	0.232	0.007	0.004	154	0.54
	(0.041)	(0.010)	(0.0016)		
Investment Regressions					
D1	0.306	...	...	174	0.31
	(0.048)				
D2	0.278	0.010	...	173	0.30
	(0.067)	(0.014)			
D3	0.282	...	0.001	155	0.31
	(0.060)		(0.0019)		
D4	0.260	0.008	0.001	154	0.31
	(0.076)	(0.014)	(0.0019)		

Note: Tobin's q is available for only 161 firms.
Note: Estimated with industry dummies (not reported).
Note: Heteroskedasticity consistent standard errors reported in parentheses.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

3.3 Instrumental-Variable Results

We now consider an econometric specification which explicitly recognizes and controls for the downward bias induced by high adjustment costs for R&D. In particular, assume that observed cash flow, CF_{it}, consists of a permanent component, CF_{it}^*, plus a transitory component, w_{it}. If R&D expenditures respond primarily to the permanent component of cash, then the specification in Equation 1 becomes

$$RD_{it} = \beta_0 + \beta_{cf} CF_{it}^* + \alpha_i + v_t + e_{it}, \tag{2}$$

where $CF_{it} = CF_{it}^* + w_{it}$. We can rewrite this model in terms of observable cash flows as

$$RD_{it} = \beta_0 + \beta_{cf} CF_{it} + \alpha_i + v_t + e_{it} - \beta_{cf} w_{it}. \tag{3}$$

Since the w_{it} component of the composite error term in Equation 3 is negatively correlated with observed cash flow, the within-firm and first-differenced estimates of β_{cf} are downward biased.[31] Griliches and Hausman (1986) describe a Hausman test for the existence of this bias that compares the within-firm and first-differenced estimates of Equation 3. They show that under most conditions, the existence of the transitory component will bias the first-differenced estimate more than the within-firm estimate. In Row 1 of Table 5, Columns 1 and 2 report the within-firm and first-differenced estimates of Equation 3 for the full, five-year panel. For R&D, the point estimates of the cash flow coefficient are 0.197 (as reported in Table 3) and 0.133, respectively. Given the precision of these estimates, it is obvious that the first-differenced estimate is significantly lower. In addition, we also computed the "long-differenced" estimates and found that the cash flow coefficient was monotonically increasing in the length of the difference operator.[32] As shown by Griliches and Hausman (1986), these findings provide additional evidence that R&D is unresponsive to the transitory component in cash flow, and hence that both the within-firm and first-differenced estimates understate the effect of cash flow on R&D.[33]

[31] Note that this specification is formally identical to the classical errors-in-variables problem.

[32] For R&D, the second, third and fourth differenced coefficient estimates were 0.197, 0.211 and 0.233, respectively.

[33] The first-differenced estimate for physical investment is also lower, although the proportional decline is

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

Table 5: Instrumental Variable Regressions

	Specification				
	5-year sample		3-year sample		
	1. Within (OLS)	2. F.D. (OLS)	3. F.D. (OLS)	4. F.D. (GMM) i.n.i.d. Error	5. F.D. (GMM) MA(1) Error
R&D Regression					
1. β_{cf}	0.197	0.133	0.085	0.362	0.344
	(0.020)	(0.021)	(0.024)	(0.049)	(0.086)
2. $d.f.$	710	711	355	355	355
3. Instruments	n.a.	n.a.	n.a.	CF_{-2}	CF_{-3}
4. $H(d.f.)$	n.a.	n.a.	n.a.	0.78(2)	0.14(2)
5. Prob. Value	n.a.	n.a.	n.a.	0.677	0.932
Investment Regression					
6. β_{cf}	0.482	0.395	0.250	0.476	0.461
	(0.053)	(0.053)	(0.065)	(0.091)	(0.208)
7. $d.f.$	710	711	355	355	355
8. Instruments	n.a.	n.a.	n.a.	CF_{-2}	CF_{-3}
9. $H(d.f.)$	n.a.	n.a.	n.a.	1.97(2)	1.71(2)
10. Prob. Value	n.a.	n.a.	n.a.	0.369	0.426

Note: Estimated with year dummies (not reported).

Note: Heteroskedasticity consistent standard errors in parentheses.

Note: Instrument set expands with time to include all valid lags in the panel.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

In order to obtain consistent estimates of the cash-flow coefficient in Equation 2, we follow the research strategy suggested by Griliches and Hausman (1986, p.114). First, firm effects are removed by first differencing so that Equation 3 becomes

$$RD_{it} - RD_{it-1} = \beta_{cf}(CF_{it} - CF_{it-1}) + (e_{it} - e_{it-1} + \beta_{cf}w_{it} - \beta_{cf}w_{it-1}), \qquad (4)$$

where year dummies have been suppressed for clarity. Next, consistent estimates of β_{cf} in Equation 4 are obtained using instrumental variables.[34] The natural instruments are lags of cash flow, which are highly correlated with the first difference of current cash flow, but uncorrelated with the composite error term under the assumption that the transitory component w_{it} is independently distributed. In this case, all lags of cash flow dated $t-2$ and earlier are valid instruments. This specification appears in Column 4 of Table 5. In order to allow for the possibility of serial correlation in the transitory component of cash flow, we consider an alternative specification in which this component follows an MA(1) process. In this case, lags of cash flow dated $t-3$ and earlier are uncorrelated with w_{it-1}, and are therefore valid instruments. This specification appears in Column 5.

The results in Columns 4 and 5 are computed using the generalized method of moments (GMM) estimator developed by Hansen (1982) and White (1982). This estimator is efficient and allows for conditional heteroskedasticity in the errors.[35] For comparison, Column 3 re-

much smaller.

[34] We note that the use of lags of cash flow as instruments also provides some additional assurance against the possibility of reverse causation from current R&D to current cash flow.

[35] The estimator applied to Equation 4 is

$$\hat{\beta} = [W'Z\hat{\Omega}^{-1}Z'W]^{-1}W'Z\hat{\Omega}^{-1}Z'Y,$$

where Y is the vector of the dependent variable, W is the matrix of explanatory variables (including year dummies) and Z is the matrix of instrumental variables; which includes all available lags of valid instruments in the panel. The rows of Y and W are first stacked by cross section, and then each cross section is stacked by time period. The matrix of instrumental variables is block diagonal, where each block is the matrix of instrumental variables corresponding to the respective time period (See Holtz-Eakin, Newey and Rosen (1988) for further details). A consistent estimate of the element rs of (Ω/N) is given by

$$(\hat{\Omega}/N)_{rs} = \sum_{i=1}^{N}(\hat{e}_{ir}\hat{e}_{is}Z'_{ir}Z_{is})/N,$$

for all r, s, where the $\hat{e_{it}}$ are consistent estimates of the residuals obtained using a first-stage, instrumental variable estimate of β. This procedure is valid when $E(\hat{e}_{ir}\hat{e}_{js}) = 0$ for all i, j, r, s such that $i \neq j$, that is, when the error term is assumed to be independent over cross sectional units. Hence, this procedure admits

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

estimates the OLS specification in Column 2 for the shorter panel required for implementing the GMM estimator.

The instrumental variables estimator in Column 4 is 0.362, which is nearly twice the within-firm estimate, but very close to the between-firm estimator. Using the summary statistics in Table 2, this coefficient implies a cash flow elasticity for R&D of 0.670. Thus, the results in Table 5 indicate that the within-firm results underestimate the effect of cash flow on R&D, but that the between-firm results do not. For physical investment, the estimated coefficient and implied elasticity are 0.476 and 0.822, respectively. In contrast to the R&D results, these estimates are very close to the within-firm estimates, implying that physical investment is relatively more responsive to transitory movements in cash flow.

The results in Columns 4 and 5 are essentially identical, which suggests that the transitory component is well represented by an independent process. Additional evidence in support of the specification and the validity of the instruments is provided by Hansen's (1982) chi-squared test of the model's overidentifying restrictions. These test statistics and their p-values appear in Rows 4, 5, 9, and 10 of Table 5. This test easily accepts the specification for both R&D and physical investment.

The instrumental variables results reconcile the difference in magnitude between the within-firm and between-firm estimates. Collectively, these results indicate that firms smooth R&D in response to transitory movements in cash flow because of high adjustment costs. For physical investment, adjustment costs do not appear to be as important. Alternatively, adjustment costs may be important, but this downward bias is roughly offset by the fact that the higher adjustment costs for R&D induce firms to smooth R&D at the expense of physical investment.

4 Conclusion

Contrary to previous studies, we find a substantial effect of internal finance on R&D expenditures for the firms in our panel. This result is robust to a variety of estimators and control variables, however the estimated magnitude is sensitive to the econometric specification. In

---

arbitrary autocorrelation in e_{it}.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

particular, we argue that the conventional within-firm estimator for R&D is downward biased if, because of adjustment costs, firms do not respond to transitory movements in cash flow. We correct for this problem by following the research strategy outlined by Griliches and Hausman (1986), and obtain cash flow elasticities for R&D and physical investment of 0.670 and 0.822, respectively. These results are consistent with the view that the principal determinant of investment for small, high-tech firms is internal finance.

We suspect that in addition to the "adjustment cost" bias noted above, an important reason why previous studies found no effect is that they examined large firms that were unlikely to face significant internal finance constraints. This is because large firms may have better access to external finance, and typically generate cash flows in excess of investment needs. For these reasons, our study examines small, high-tech firms. Having done so, it is important to point out that "small" firms are very important in U.S. manufacturing. Acs and Audretsch (1988, 1990) demonstrate this point with a set of findings for firms with less than 500 employees, which is close to our size cutoff of 10 million in capital stock.[36] They report that firms in this size range accounted for 94.2 percent of all firms, 21.4 percent of sales, and 28.9 percent of employment in manufacturing in 1982. Firms with less than 100 employees accounted for 12.1 percent of sales and 16.5 percent of employment. Of more importance for assessing the results of our study, Acs and Audretsch (1988) find that firms with less than 500 employees accounted for approximately 40 percent of all innovations in manufacturing in 1982.

We end by mentioning a few avenues for future research. It would be interesting to estimate the *ex post* return to R&D for firms of the type we have studied. Several studies have found high private rates of return to R&D.[37] While appropriability problems can explain high public rates of return, we suggest that financial constraints may explain the puzzle of high private rates of return. Another avenue is to reconsider the internal finance effects on R&D for larger firms using panel data techniques. The difficulty in designing and interpreting the results of such a study is that most large firms are not likely to face binding finance constraints. We have run exploratory regressions for a panel of Compustat

[36] In particular, for our sample of firms, the mean level of employees is 237 in 1983 and 407 in 1987.

[37] See for example Griliches (1986) , Jaffe (1986) and Bernstein and Nadiri (1988).

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

firms covering the same time period and the same high-tech industries. We find that while estimated cash flow coefficients decline quite dramatically for large firms, they do remain statistically significant.[38]

[38]For example, for firms with capital stocks between $10 and $100 million, the cash flow coefficient estimated in first differences was approximately 0.08, slightly more than one-half the size of the coefficient reported in Table 5. For firms over 100 million in assets, the cash flow coefficient was approximately 0.04, but still significant. While these estimates are only exploratory, they suggest that *some* large firms may also face financing constraints for R&D.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

References

Acs, Zoltan J. and David B. Audretsch (1990), *Innovation and Small Firms.* Cambridge: The MIT Press.

Acs, Zoltan J. and David B. Audretsch (1988), "Innovation in Large and Small Firms: An Empirical Analysis" *American Economic Review* **78**, 678-690.

Akerlof, George A. (1970), "The Market for 'Lemons': Quality Uncertainty and the Market Mechanism" *Quarterly Journal of Economics* **84**, 488-500.

Arrow, Kenneth J. (1962), "Economic Welfare and the Allocation of Resources for Invention" in R. R. Nelson, (ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors.* Princeton: Princeton University Press, 609-625.

Bernanke, Ben and Mark Gertler (1989), "Agency Costs, Net Worth and Business Fluctuations" *American Economic Review* **79**, 14-31.

Bernstein, Jeffrey I. (1986), *Research and Development, Tax Incentives, and the Structure of Production and Financing.* Toronto: University of Toronto Press.

Bernstein, Jeffrey I. and M. Ishaq Nadiri (1988), "Financing and Investment in Plant and Equipment and Research and Development" in M. H. Preston and R. E. Quandt, (ed.), *Prices, Competition, and Equilibrium.* New York: Phillip Allan, 233-248.

Bernstein, Jeffrey I. and M. Ishaq Nadiri (1989), "Rates of Return on Physical and R&D Capital and Structure of the Production Process: Cross Section and Time Series Evidence" in B. Raj, (ed.), *Advances in Econometrics and Modelling.* Dordrecht: Klewer Academic Publishing, 169-185.

Bester, Helmet (1985), "Screening vs. Rationing in Credit Markets with Imperfect Information" *American Economic Review* **75**, 850-855.

Calomiris, Charles W. and R. Glenn Hubbard (1990), "Firm Heterogeneity, Internal Finance, and Credit Rationing" *Economic Journal* **100**, March, 90-104.

Devereux, Michael and Fabio Schiantarelli (1989), "Investment, Financial Factors and Cash Flow: Evidence from U.K. Panel Data" mimeo.

Elliot, J. W. (1971), "Funds Flow vs. Expectational Theories of Research and Development Expenditures in the Firm" *Southern Economic Journal* **37**, 409-422.

Fazzari, Stephen M. and Michael J. Athey (1987), "Asymmeteric Information, Financing Constraints, and Investment" *Review of Economic Studies* **69**, 481-487.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

Fazzari, Steven, R. Glenn Hubbard and Bruce C. Petersen (1988), "Financing Constraints and Corporate Investment" *Brookings Papers on Economic Activity* **1**, 141-195.

Gertler, Mark (1988), "Financial Structure and Aggregate Economic Activity: An Overview" *Journal of Money, Banking and Credit* **20**, 559-596.

Grabowski, Henry G. (1968), "The Determinants of Industrial Research and Development: A Study of the Chemical, Drug and Petroleum Industries" *Journal of Political Economy* **76**, 292-306.

Griliches, Zvi (1979), "Issues in Assessing the Contribution of Research and Development to Productivity Growth" *Bell Journal of Economics* **10**, Spring, 92-116.

Griliches, Zvi, (ed.) (1984), *R&D, Patents, and Productivity.* Chicago: University of Chicago Press.

Griliches, Zvi (1986), "Productivity, R&D, and Basic Research at the Firm Level in the 1970's" *American Economic Review* **76**, 141-154.

Griliches, Zvi and Jerry A. Hausman (1986), "Errors in Variables in Panel Data" *Journal of Econometrics* **31**, 93-118.

Griliches, Zvi and Jacques Mairesse (1984), "Productivity and R&D at the Firm Level" in Zvi Griliches, (ed.), *R&D, Patents and Productivity.* The University of Chicago Press, 339-374.

Hall, Bronwyn and Fumio Hayashi (1989), "Research and Development as an Investment" NBER Working Paper #2973, Cambridge: National Bureau of Economic Research.

Hansen, Lars (1982), "Large Sample Properties of Generalized Method of Moments Estimators" *Econometrica* **50**, 1029-1054.

Hayashi, Fumio and Tohru Inoue (1989), "Implementing the Q Theory of Investment in Micro Data: Japanese Manufacturing 1977-1985" Osaka University.

Hoshi, Takeo, Anil Kashyap, and David Scharfstein (1991), "Corporate Structure, Liquidity and Investment" *Quarterly Journal of Economics* **106**, 33-60.

Henderson, James M. and Richard E. Quandt (1971), *Microeconomic Theory.* New York: McGraw-Hill.

Holtz-Eakin, Douglas, Whitney Newey and Harvey S. Rosen (1988), "Estimating Vector Autoregressions with Panel Data" *Econometrica* **56**, 1371-1395.

Hsiao, Cheng (1986), *Analysis of Panel Data.* Cambridge: Cambridge University Press.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

Hubbard, R. Glenn and Anil Kashyap (1990), "Internal Net Worth and the Investment Process: An Application to U.S. Agriculture" mimeo, Columbia University.

Jaffe, Adam B. (1986), "Technological Opportunity and Spillovers of R&D" *American Economic Review* 76, 984-1001.

Kamien, Morton I. and Nancy L. Schwartz (1978), "Self-Financing of an R&D Project" *American Economic Review* 68, 252-261.

Kamien, Morton I. and Nancy L. Schwartz (1982), *Market Structure and Innovation.* Cambridge: Cambridge University Press.

Levin, Richard C., Alvin K. Klevorick, Richard R. Nelson, and Sidney G. Winter (1987), "Appropriating the Returns from Industrial Research and Development" *Brookings Papers on Economic Activity* 3, 783-831.

Long and Malitz (1985), "Investment Patterns and Financial Leverage" in B. M. Friedman, (ed.), *Corporate Capital Structures in the U.S.* Chicago: University of Chicago Press, 325-351.

Mairesse, Jacques and Mohamed Sassenou (1991), "R&D and Productivity: A Survey of Econometric Studies at the Firm Level" NBER Working Paper #3666, Cambridge: National Bureau of Economic Research.

Meyer, John R. and Edwin Kuh (1957), *The Investment Decision: An Empirical Study.* Boston: Harvard University Press.

Mueller, Dennis C. (1967), "The Firm's Decision Process: An Econometric Investigation" *Quarterly Journal of Economics* 81, 58-87.

Mundlak, Yair (1978), "On the Pooling of Time Series and Cross Section Data" *Econometrica* 46, 69-85.

Myers, Stewart C. and Nicholas S. Majluf (1984), "Corporate Financing and Investment Decisions When Firms have Information that Investors Do Not" *Journal of Financial Economics* 13, 187-221.

Pakes, Ariel and Shmuel Nitzan (1983), "Optimum Contracts for Research Personnel, Research Employment, and the Establishment of "Rival" Enterprises" *Journal of Labor Economics* 1, 345-365.

Pakes, Ariel and Mark Schankerman (1984), "An Exploration into the Determinants of Research Intensity" in Zvi Griliches, (ed.), *R&D, Patents and Productivity.* The University of Chicago Press, 209-232.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis

Ravenscraft, David and F. M. Scherer (1982), "The Lag Structure of Returns to Research and Development" *Applied Economics* 14, 603-620.

Salinger, Michael A. and Lawrence H. Summers (1983), "Tax Reform and Corporate Investment: A Microeconomic Simulation Study" in Martin S. Feldstein, (ed.), *Behavioral Simulation Methods in Tax Policy Analysis.* University of Chicago Press, 247-287.

Scherer, F. M. (1965), "Firm Size, Market Structure, Opportunity, and the Output of Patented Inventions" *American Economic Review* 55, 1097-1125.

Scherer, F. M. (1980), *Industrial Market Structure and Economic Performance.* Boston: Houghton Mifflin Company.

Schumpeter, Joseph A. (1942), *Capitalism, Socialism, and Democracy.* New York: Harper and Row.

Spence, Michael A. (1979), "Investment Strategy and Growth in a New Market" *Bell Journal of Economics* 10, 1-19.

Stiglitz, Joseph E. and Andrew Weiss (1981), "Credit Rationing in Markets with Imperfect Information" *American Economic Review* 71, 393-410.

Twiss, Brian (1986), *Managing Technological Innovation.* New York: Longman.

White, Halbert (1980), "A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heterskedasticity" *Econometrica* 48, 817-838.

White, Halbert (1982), "Instrumental Variables Regression with Independent Observations" *Econometrica* 50, 483-500.

Digitized for FRASER
http://fraser.stlouisfed.org/
Federal Reserve Bank of St. Louis