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FIRM SIZE AND THE RETURNS TO R&D INVESTMENT IN HIGH-TECHNOLOGY INDUSTRIES

By

Teresa M. Doyle

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ABSTRACT

FIRM SIZE AND THE RETURNS TO R&D INVESTMENT
IN HIGH-TECHNOLOGY INDUSTRIES

By

Teresa M. Doyle

One of the recurring arguments in the policy discussions has been that domestic enterprises are too small to maintain technological leadership in an increasingly global marketplace. This argument is not new. Schumpeter (1942) postulated that there exists a positive relationship between firm size and technological progress, and that static economic efficiency should be foregone in order to achieve long-run technological progress. This study tests the Schumpeter hypothesis for five high-technology industries in which R&D investment is especially important: the computer, machinery, medical equipment, pharmaceutical and semiconductor industries.

The methodology used in this paper is a standard asset valuation framework in which the firm chooses an investment strategy to maximize its expected present discounted value. Returns to R&D, or technological success, is measured by the change in the market's valuation due to R&D investment over a five year period.

In testing the Schumpeter hypothesis, a continuous relationship between firm size and returns to R&D investment is first assumed. Results indicate that only in the computer and medical equipment industry is Schumpeter supported. The second part of the empirical analysis does not assume this continuous relationship and tests for a threshold effect between firm size and R&D profitability. I test for parameter stability of the estimated coefficients, and find that parameter stability can be rejected for all five industries. This implies that the coefficients are not stable over firm size. By using a maximum likelihood approach, points of structural instability are determined and the model is reestimated by creating firm size-dummy interaction terms. By allowing for endogenously determined thresholds, this methodology is able to determine the definition of large and small firm size. Results are consistent with the first part of the empirical analysis; only in the computer and medical equipment industry is Schumpeter supported. In the other three industries (machinery, pharmaceutical, and semiconductor) Schumpeter cannot be supported. These results suggest that Schumpeter's hypothesis needs to be qualified by closely analyzing industry conditions.

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INTRODUCTION

Innovation is central to economic growth. Yet, innovation is a complex matter, differing from one industry to another. Knowing that technological innovation can improve economic growth, governments try to encourage it. However, little is understood about how technological advance occurs or, more important, why some companies are better than others at turning it to their advantage. This study investigates an important aspect of the technological innovation process. Specifically, it examines whether firm size is a significant determinant of R&D profitability in high-technology industries.

The relationship between firm size and technological progress has, over the years, come to be known as the Schumpeter hypothesis. Although classical economists recognized that technical advance facilitated economic growth, they failed to develop an economic theory of technological progress.[1] Joseph Schumpeter was the first to derive an economic theory of technological progress. He noted that technology is not an exogenous phenomenon; technology is the result of innovation, and innovation is an endogenous activity (Schumpeter (1942)). An important theme of Schumpeter's theory

[1] For example, Adam Smith (1937) identified the two main ingredients that make technical advance an economic theory: to gain a competitive advantage and the requirement of investment. Smith, however, did not combine these points into a theory. Marx (1919) analogized an economic system to a biological entity that is ever changing compared with a chemical reaction that is tending toward an equilibrium. Marx appeared, however, to view technical advance as a change in the environment that capitalists reacted to instead of initiated (Kamien and Schwartz (1982)).

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is that there exists an incompatibility between perfect competition and entrepreneurial activity. When considering long-run technological progress, the former should be rejected. Schumpeter defended the current capitalist system with its large firms and oligopolistic markets.[2] While he conceded that perfect competition could theoretically assure efficient allocation of resources at a point in time, Schumpeter maintained that it would hinder long-run efficiency by stifling innovative activity:

> The large scale establishment or unit of control... has come to be the most powerful engine of...progress and in particular of the long-run expansion of total output not only in spite of, but to a considerable extent through...strategy which looks so restrictive when viewed in the individual case and from the individual point of time. In this respect, perfect competition is...inferior, and has no title to being set up as a model of ideal efficiency. (Schumpeter (1942), p. 106)

That is, Schumpeter believes that the process of creative destruction is more important than price competition. In introducing new products or processes a firm must be able to engage in monopolistic practices in order to secure profits from its investments. Although these profits will eventually be eroded by competition, they must last long enough to make innovation worthwhile. Society will benefit from technological progress, and the supranormal profits will enable the firm to continue to invest in R&D.[3] Schumpeter's assertions were vague, and it was left to others to fill in blanks and omitted steps.

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[2] Schumpeter's conjectures on the relationship between firm size and innovation wavered in his writings. For example, in Theory of Economic Development, Schumpeter argued that innovation typically arose from smaller firms. See Scherer (1992) for an overview of Schumpeter's writings.

[3] This hypothesis has two distinct elements. First, there exists a positive relationship between firm size and technological progress and second, a positive relationship between market power and technological progress. Schumpeter did not distinguish between the two hypotheses; he considered size and market power to be inextricably linked. (Baldwin and Scott(1987), Schumpeter(1939), and Scherer(1992))

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Galbraith (1952) extended Schumpeter's hypothesis and argued that because of the cost and uncertainty involved, R&D could only be undertaken by large firms:

> Most of the cheap and simple inventions have, to put it bluntly, been made. Not only is development now sophisticated and costly but it must be on a sufficient scale so that successes and failures will in some measure average out...Because development is costly, it follows that it can be carried on only by a firm that has the resources associated with considerable size. (Galbraith (1952), pp. 91-92).

The importance of technical advance as an economic theory was helped by Solow's (1957) study which found that 90% of the doubling of per capita output in the U.S. non-farm sector was the result of technical advance and only 10% was due to an increase in the capital-labor ratio.

Since Schumpeter, economists have been testing for a relationship between firm size and technological progress. To date, the overall results have been inconclusive (see Baldwin and Scott(1987), Kamien and Schwartz(1982), and Scherer(1992)). From the point of view of this study, these papers are deficient in four respects. First, the majority of the studies undertaken have utilized insufficient proxies for technological progress. Tests of the Schumpeter hypothesis have primarily focussed on whether inputs to the innovation process increase more than proportionately with firm size, using R&D expenditures or R&D employment as proxies for innovative inputs (Comanor (1967), Scherer (1984) and Bound et al.(1984)). However, R&D expenditures and employment are insufficient proxies of technological progress. Expenditures and employment are inputs in the innovation process; however it is a large step to conclude that innovative inputs equal outcomes of the innovative process (innovative outputs). Other studies have addressed this problem by testing the relationship between firm size and the number of patents

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patents registered, which is a measure of innovative output (see Bound et al.(1984) and Scherer(1965)). Unfortunately, simply adding the number of patents neglects qualitative differences among them; many patents reflect minor improvements and have little economic value, while others are extremely valuable (Griliches (1990)). Instead, this study examines the change in a company's market valuation due to investment in R&D over a five year period. It is argued that the stock market takes into account information about firms' expected future profitability, and therefore expected outcomes from R&D investment. This methodology avoids the problems of using innovative inputs and/or patents as a proxy for technological progress.

Second, the approach of pooling different industries takes a simplistic view of the Schumpeter hypothesis; technological opportunity and appropriability conditions are assumed to be identical across the industries. Technological opportunity refers to differences in the opportunities that industries face for research. Appropriability conditions refer to a firms ability to appropriate sufficient returns to make the innovation worthwhile. However, there is evidence that small and large firms' innovative activity responds to different technological and economic regimes (Acs and Audretsch (1987, 1988, 1991)). In order to test the Schumpeter hypothesis, five high-technology industries are analyzed: the computer, machinery, medical equipment, pharmaceutical, and semiconductor industries. These industries are similar in that technological opportunity is high in all five, but they differ in appropriability conditions. This paper tests for a relationship between firm size and R&D profitability and relates these results back to industry conditions.

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Third, previous studies use current R&D expenditures or employment data as a measurement of technological progress or innovation. Yet, innovative effort is not only the knowledge generated in any one period, but the accumulated stock of knowledge. This study employs panel data and is therefore able to test a hypothesis using an accumulated stock of R&D knowledge.

And fourth, it has been argued that Schumpeter's theory must be viewed as a threshold theory. That is, technological progress is not necessarily an increasing and continuous function of market power or business size (Markham (1965)). Most all of the previous studies use empirical methods in which they assume a continuous function and do not explicitly test for a threshold effect. This study uses empirical methodology in order to test for a threshold effect. First, a test of parameter stability is employed. If parameter stability is rejected, statistical analysis is able to determine the break point(s) for the size regimes, which allows "large" and "small" firm size to be statistically defined instead of assuming a priori what these size regimes are. Separating firms into different size regimes, a model is estimated to test whether firm size is a significant determinant to R&D profitability.

A. ADVANTAGES OF SMALL FIRMS VS. LARGE FIRMS

Three general arguments have been presented in support of Schumpeter's assertion of a positive relationship between firm size and technological progress. First, there are economies of scale in R&D expenditures, which implies that a larger R&D staff operates more efficiently than a small one. This may be due to researchers being more produc

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productive when they have more colleagues with whom to interact, or when a large research group allows for division of labor.

Second, an R&D program of a given size operates more efficiently in a larger firm. Mansfield et al.(1971) identified three critical probabilities associated with economically successful R&D projects, only one of which deals with technical success. The other two critical probabilities depend upon development and successful commercialization. This leaves room for other activities taking place in a firm to aid in turning successful research into an economically valuable product or process. For example, marketing and financial planning are better developed in large firms, which allows these firms to have an advantage over their smaller counterparts. Furthermore, Nelson (1959) argues that a large firm with an established name may be in a better position to exploit the development of innovation because it is easier for a large firm to enter into a new market compared to a firm without an established name. Another reason why large firms may have an advantage is due to diversification. Since it is impossible to predict the outcome of an R&D project, a given unit of R&D expenditures may or may not produce knowledge beneficial to particular project. If a firm is engaged in only one project, there is a higher risk involved in producing knowledge the firm is not able to use, compared with a firm engaged in a large number of projects. Thus, the more diversified a firm, the less risky is R&D, and the more a firm will gain, on average, from a given unit of R&D expenditures.[4] Third, economies of scale in the financial market exist. There may be capital market imperfections in which large firms have advantages in securing finance for R&D projects. This may be due to size of the firm being

[4]This argument assumes there is no market for knowledge per se.

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correlated with the availability and stability of internally generated funds.[5] Even with a perfect capital market, self-financing may be more desirable because borrowing requires disclosure of the very information that constitutes the innovation. Large firms are presumably better able to undertake internal financing than smaller firms.

Yet, the Schumpeter hypothesis of a positive relationship between firm size and technological progress is not without significant challenge. One of the most influential of the early studies is that of Jewkes, Sawers, and Stillerman (1969). They studied 61 significant inventions made in Great Britain and the United States from 1900-1950, and found that:

> More than one-half of the cases can be ranked as individual invention in the sense that much of the pioneering work was carried through by men who were working on their own behalf without the backing of research institutions and usually with limited resources and assistance or, where the inventors were employed in institutions, these institutions were, as in the case of universities, of such a kind that the individuals were autonomous, free to follow their own ideas without hindrance.[6] (p. 82)

In fact, they found that only 12 of the 61 inventions were attributed to large corporations.

There are many reasons why small firms may have an advantage in innovation. First, small firms may have a greater incentive to innovate when they can expect to capture substantial portions of the market by gaining first mover advantages.[7] Second, there may be disadvantages to size. Diseconomies of scale may occur if research

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[5]With the growth of venture-capital institutions, this has probably become less important.

[6]Jewkes, Sawers, and Stillerman (1969) did concede that development of an invention could be costly and could require the resources of a large firm.

[7] This is due to a smaller firm being able to capture a larger absolute amount of the quasi-rents due to cannibalization. See Arrow(1962), Scherer and Ross(1990), and Rosen(1991).

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decisions pass through layers of management. Different perceptions of risk may stifle ambitious innovation. For example, Rosen (1991) shows that large firms will invest in R&D projects which are safer and that supplement rather than replace current technology. Small firms tend to invest in riskier R&D projects. This may result in small firms earning a higher return on their R&D investment. Still, diseconomies of scale in R&D, rather than the economies mentioned earlier, could occur if a large number of people are involved in a project. Scientists and entrepreneurs may become less motivated in large firms as their ability to capture the benefits from their efforts diminishes.[8] Also, higher status and pay in a large firm often leads to management positions, instead of research (Scherer and Ross (1990)). In sum, theory does not predict an unambiguous relationship between firm size and technological progress. The relationship may vary by industry; it is left to empirical work to determine.

B. INDUSTRY CONDITIONS

Underlying factors in industries may explain advantages of firm size in innovation. These are usually classified into two broad groups: technological opportunity and appropriability conditions. Levin et al.(1987) investigate the extent to which appropriability conditions of both product and process patents differs across industries. They found that the effectiveness of patents in preventing duplication are limited. The major reason given for the limited effectiveness of patents is that competitors are able to

[8] There are numerous examples of new enterprises founded by discouraged scientists from large U.S. firms such as Hughes Aircraft, IBM, Sperry Rand(Unisys), Texas Instruments, and Western Electric. (See Scherer and Ross(1990))

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"invent around" patents. Yet, the survey data show other mechanisms, such as investments in complementary sales and service efforts, first mover advantages, and the ability to move down the learning curve to be quite effective in appropriating the returns from innovation.

The limited effectiveness of patents indicates that it is not enough that the research activity itself is successful; a firm must also be able to organize the other parts of the process efficiently and effectively for successful commercialization. That is, research must be combined with other aspects of the process, so-called complementary assets. These complementary assets could be considered services, such as after-sales support in the case of computers, or marketing in the case of medical equipment, in which dissemination of information about the equipment is essential. When these complementary assets are not present, competitors and/or imitators are likely to profit from the innovation--at times more than the firm that was first to innovate. In addition, large returns can be made from a modest technological advance if the company has the appropriate complementary assets.

Because of the high cost and uncertainty of research, and the importance of complementary assets, firms are most likely going to require access to capabilities which lie outside their organization in the process that starts with the concept of an idea and eventually might lead to the successful marketing of a new product. Examples include university research consortia, as well as horizontal and vertical linkages. Most important, especially for small firms, are the vertical linkages. That is, two or more firms may address particular aspects of the innovation process and therefore not undertake all of the steps in-house. Thus, firms need not perform all activities in-house for innovation to occur and to be successful.

Results suggest that these high-technology industries are not homogeneous and that firm size is a significant determinant to R&D profitability. But since industries are not homogeneous, the relationship between firm size and R&D profitability differs across industries. For example, the stock response to R&D investment in the medical equipment industry for firms with sales greater than $400 million is positive and significant, while it is not significantly different from zero for firms with sales less than $400 million. In the Industrial machinery industry, small firms are found to be those with less than $79 million in annual sales, while large firms are those with greater than $308 million in sales. Results suggest that the stock response to R&D investment in both small and large firms is greater than that for the average size firms.

These results aid us in understanding why previous studies of the Schumpeter hypothesis are inconclusive. Pooling industries ignores the fact that industries are heterogeneous; in some instances large firms are the "engines of technological progress", while in others, small firms appear to be more innovative.

This paper is organized in the following manner. The literature review is presented in Chapter I, while Chapter II includes definitions and descriptive statistics of industry conditions in the five high-technology industries studied. Chapter III presents the theoretical relationship between firm size and technological progress. Empirical results are discussed in Chapter IV, and conclusions and prospects for future research are offered in chapter V.

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I. REVIEW OF THE LITERATURE

Schumpeter argued that there exists a relationship between firm size and technological progress. However, it is difficult, if not impossible, to measure technological progress using an unambiguous, unidimensional scale. Even if a comprehensive list of all innovations were available, the contribution of an innovation to economically valuable knowledge is difficult to assess. Despite these difficulties, a variety of proxies for technological progress have been introduced. This chapter presents a review of the literature concerning the relationship between firm size and technological progress. I will first discuss the three major deficiencies in the literature: first, the majority of the studies utilize insufficient proxies for technological progress; second, many ignore industry conditions. And third, many of the studies do not test Schumpeter's original hypothesis. Throughout this section I discuss what conclusions we are able to draw from these studies and I will explain the advantages of my study and how it differs from previous work. Last, I discuss how this study expands on some recent literature which has analyzed the effectiveness of R&D expenditures.

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A. MEASUREMENT OF TECHNOLOGICAL PROGRESS

The majority of the studies concerned with the relationship between firm size and technological progress typically test whether technological progress increases more than proportionately with firm size. These studies proxy technological progress using a measure of innovative inputs or innovative outputs. For example, regression studies typically regress innovative inputs or outputs (X), on a measure of firm size (S): $\log(X_i) = a + b\log(S_i) + u_i$. The Schumpeter hypothesis would then be supported if $b>1$. Another method is to deflate innovational intensity by firm size: $(X/S)_i = a + bS_i + u_i$. In this case, the Schumpeter hypothesis is supported if $b>0$. Some of the more recent studies include quadratic terms in the regression equation. Yet, the proxies that the literature use are insufficient in measuring technological progress.

First, innovative inputs, such as R&D expenditures or personnel engaged in R&D are deficient to the extent that they indicate resources allocated toward enhancing technological progress, not their outcome (Kamien and Schwartz (1982)). Measuring inputs by the number of personnel employed in R&D assumes that they are the only source of innovation. It may be that someone directly involved in the production process, or someone in marketing initiates the new product or process. R&D employment and expenditure data are also subject to considerable error in reporting; firms are given considerable latitude in classifying activities used for financial reporting.[1]

[1]For example, Standard and Poor's Computstat data, which obtain data mainly from 10-K reports to the Securities and Exchange Commission, permit a more liberal definition of R&D expenditures than the National Science Foundation survey data. Cohen and Mowery(1984) find that Compustat data indicates firms conduct 12% more R&D, on average, than indicated by the FTC Line of Business data which uses the more restrictive

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Researchers have recognized this, and have employed measures of innovative outputs, such as patents and the number of significant innovations, as a measure of technological progress. Unfortunately, simply adding the number of patents neglects qualitative differences among them; many patents reflect minor improvements and have little economic value, while others are extremely valuable. For example, a survey of patent holders conducted in the 1960's at the Patent and Trademarks Foundation finds that the reported economic gain is highly dispersed. The mean economic value for patents that were reported to be in use and have a positive economic gain was $577,000 per patent. Yet, the reported standard deviation was $1.5 million, and the median economic value per patent was approximately $25,000. A separate analysis, which includes the above group of patents plus all patents that were not in use and had no economic gain or economic loss, finds that the mean economic value falls to approximately $112,000($473,000 in 1988 dollars).[2] Further, many important innovations are not patented, most often process innovations.[3]

The most difficult to obtain, but probably the best measure of technological progress is the number of significant innovations.[4] Yet, like patents, innovations are still

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NSF data.

[2]The National Science Foundation conducted two studies in the 1980's which attempted to evaluate the economic value of patents. In 1982, the Chemistry program of the NSF found the average economic value of a patent to be $500,000 (Cutler, 1984). An analysis of patents by engineering grantees found that the royalty potential was $73,000, but had a very large dispersion.

[3]See Griliches (1990) for a survey of patent statistics as economic indicators.

[4] Data on significant innovations have been assembled for selective industries such as the semiconductor (Tilton, 1971) and pharmaceutical industries (Pelzman (1973), Schwartzman (1976)). Data compiled by the U.S. Small Business Association identified

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an imperfect measure of technological progress in that all innovations do not contribute the same amount to technological progress and differ in economic value.

One of the earliest empirical studies relating firm size and innovational inputs utilized data for 387 Fortune 500 Companies in 1960. Hamberg (1964) found a positive but weak association between R&D expenditures and firm size, using employment as a proxy for firm size. Using the same data, but a slightly different model, Comanor(1967) found weak support for the Schumpeter hypothesis. Using a sample of 67 firms from 1957-1960, Mueller (1967) found that research intensity was negatively associated with firm size. More recently, Scherer (1984) found mild support for a Schumpeterian increasing returns hypothesis, using Line of Business data. Bound et al. (1984) utilize 1976 Compustat data; their results suggest that the elasticity of R&D expenditures with respect to sales is close to unity, but also significant nonlinearities in the relationship between sales and R&D expenditures. This implies that both large and small firms are more R&D intensive than average sized firms. Bound et al. suggest that their results conflict with earlier studies because of the inclusion of smaller firms. They point out that most of the previous work is based on Fortune 500 Companies, while their data set includes a large number of small publicly traded firms. In sum, these studies appear to be inconclusive as a group; they neither support nor refute the Schumpeter hypothesis. A number of studies looked directly at innovative outputs; they test the relationship between firm size and patent counts or the number of significant innovations, which are used as proxies.

Scherer (1965) used the number of patents issued to a firm in 1959 as a proxy for

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innovations introduced in 1982.

average inventive output 4 years earlier. His results indicate that smaller firms were responsible for a higher relative share of innovation: "If anything, the results show that firms below a half billion dollar sales mark generate more inventions relative to their size than do giant firms" (p. 1114). Using Line of Business and patent data, Scherer (1984) found that the majority of the industries reveal constant returns to scale in innovation. Bound et al.(1984) found support for both Scherer's earlier (1965) study and his 1984 study: the small firms have a larger ratio of patents per dollar of R&D expenditures than larger firms. Yet, after R&D expenditures reach $1 to $2 million, patents per dollar of R&D expenditures remain nearly constant except for the very large firms. This result supports Scherer's later study. One reason why we may find conflicting results from Bound et al. and Scherer (1984) is due to the data employed. Bound et al. utilizes a more comprehensive data set which includes many small publicly traded firms, while the Line of Business data include only larger firms.

Acs and Audretsch (1991) examine the relationship between firm size and the rate of technological change with a measure of innovative activity. Their data set includes 1,695 U.S. manufacturing firms for 1982. The authors find no evidence to support the hypothesis of increasing returns to innovative output.[5]

In sum, there is little support for the hypothesis that innovative outputs increase more than proportionately with firm size. In fact, evidence suggests that innovative outputs may be inversely related to firm size, which supports the hypothesis of diseconomies of scale. On the other hand, studies using innovative inputs as proxies for

[5] Acs and Audretsch (1989) compare the relationships between the number of patented inventions with their innovation data. They found that patented inventions provide "a fairly good, although not perfect, representation of innovative activity".

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technological progress appear to be mixed. Thus, taking into consideration all of these studies, results are inconclusive. If size is a significant determinant of technological progress, it is not overwhelmingly so. Yet, again, these studies are deficient because the proxies used for technological progress are inadequate.

This study, instead, examines the response of a company's stock value to R&D investment. The stock market takes into account all information about firms' expected future profitability, and therefore expected outcome from R&D investment. Thus, while still utilizing R&D expenditure data, R&D expenditures will be an independent variable, while the indicator of inventive output is the change in the stock market value of the firm. Thus, we avoid the problems associated with using patent data, in which economic value's are highly heterogeneous, as well as the assumption that innovative inputs are identical to technological progress.

B. ARE INDUSTRIES HOMOGENEOUS?

The second criticism of the existing literature is that the majority of the studies pool high and low technology firms and take no account of differences in industries. In fact, some studies which do recognize industry differences find that any support for the Schumpeter hypothesis disappears after industry effects are taken into account.

Nelson, Peck, and Kalachek (1967) noted that previous analyses which found a positive relationship between firm size and innovative inputs may have been misinterpreted. That is, in analyzing the entire economy larger firms were found to spend a higher proportion on R&D. Yet, Nelson et al. find that this was due in large part to the fact that certain industries, such as aircraft, electronics, and chemicals, were characterized by both greater than average R&D intensity and firm size. They found the relationship within individual industries to be much less pronounced. Soete (1979) utilized R&D data compiled by Business Week magazine for over 700 large corporations for 1975 and 1976. Overall, results suggested that R&D expenditures as a percentage of sales increase with firm size, being particularly high for the six largest firms. Yet, no clear pattern of an increasing or decreasing relationship emerged when he separated firms into 17 industry groups.[6] Unfortunately, his analysis on industries tests only for a linear relationship. Scherer (1984) combined Line of Business Data with a set of patent data. For each of 196 industries, he calculated elasticities of R&D with respect to firm size (sales). He found that the percentage of industries indicating constant returns to scale with respect to firm size and R&D spending and firm size and patenting to be 71.4% and 73.4%, respectively. The percentage of industries indicating decreasing returns with respect to patenting was slightly higher than those reporting increasing returns: 11.3% vs. 15.3%. On the other hand, the elasticity of R&D spending with respect to R&D spending revealed increasing returns for 20.4% of the industries, while decreasing returns occurred in 8.2% of the industries. Thus, in a majority of the industries size is not a significant factor for technological progress--industry differences are important. As Mansfield et al. notes (1971):

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[6]Soete found the scale coefficients to be significantly greater than one in the automotive, office equipment, and instrument industries, while the scale coefficient was significantly less than one in the textile industry. The aircraft, paper, machinery, fuel, rubber, drugs, electrical and chemical industries were all found to exhibit constant returns to scale.

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> In some industries, like steel, the biggest firms have carried out relatively few innovations; in other industries, like chemicals, the biggest firm seems to have performed very well.... This diversity is strikingly at odds with some of the simple generalizations found frequently in the literature.

Some recent studies have begun to investigate underlying factors in industries which may provide us with a greater understanding of why some industries are more innovative than others. These are usually classified into two broad groups. **Technological opportunity** refers to industries differing in the opportunities they face for research. That is, there are interindustry differences in production possibilities for transforming research into successful products and/or processes. **Appropriability conditions** refer to the firm's ability to appropriate sufficient returns to make the investment worthwhile. A patent allows perfect appropriability for a limited period in return for public disclosure, which guarantees diffusion of knowledge after the patent expires.

Levin, Cohen, and Mowery (1985) employ technological opportunity and appropriability survey data to test whether these variables are able to explain interindustry variation in R&D intensity.[7] Results indicate that the size of the firm is positively associated with business unit R&D intensity. Yet, when controlling for industry effects, the effect of size is insignificant. The industry characteristics perform best in the chemical industry, where the vectors of opportunity and appropriability variables are each

[7]The technological opportunity variables are intended to capture three dimensions: closeness to science, the importance of technical knowledge, and industry maturity. Appropriability conditions are measured with two indices: (1) the effectiveness of six mechanisms used by firms to capture and protect the competitive advantages of new processes and products, and (2) the range of imitation costs and time lags for major and minor, process and product, and patented and unpatented innovations.

jointly significant. In the electrical and machinery industries, the technological opportunity variables are found to be significant, while the appropriability variables are not. In the food industry, neither the appropriability nor the opportunity variables are statistically significant.

Using a unique approach in investigating technological opportunity, Jaffe (1986) constructs a technology based classification of technological opportunity. He utilizes the distribution of the firms' patents over different patent classes to characterize the technological position of the firm. The vector of technological opportunity dummies is statistically significant in explaining interfirm differences in patents, profits, and Tobin's q.[8] Yet, Jaffe also finds that conventional industry dummy variables perform equally well.

Levin et al.(1987) investigate the extent to which appropriability conditions of both product and process patents differs across industries, and thus could explain a portion of interindustry variation in patenting. They find that only five industries of a possible 130 lines of business regard product patents as highly effective. While twenty industries regard them as moderately effective. On the other hand, only three industries regard process patents as moderately effective. The major reason given for the limited effectiveness of patents is that competitors are able to "invent around" patents. Yet, the survey data show other mechanisms, such as investments in complementary sales and service efforts, first mover advantages, and/or the ability to move down the learning curve, to be quite effective in appropriating the returns from innovation. These studies indicate the

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[8]Tobin's q is defined as the market value of the firm divided by the replacement cost of the firm's tangible assets.

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importance of industry conditions in explaining technological progress.

Acs and Audretsch (1987, 1988) suggest that the innovation activity of large and small firms is affected by different technological environments. Their results suggest that large firms (more than 500 employees) tend to have the relative innovative advantage in industries which are capital intensive, concentrated, highly unionized, and produce a differentiated good. On the other hand, small firms (fewer than 500 employees) tend to have a relative advantage in industries which are highly innovative, utilize a large component of skilled labor, and have a relatively high proportion of large firms. Yet, Acs and Audretsch recognize that innovation counts do not measure the economic value of these innovations, and suggest that large firms may introduce innovations with higher market values.

In sum, the evidence indicates that the Schumpeter hypothesis relating innovation to size appears to be dependent on industry conditions. That is, evidence suggests that industries are not homogeneous. By combining firms into one group, conclusions about the relationship between firm size and innovative activity for the economy as a whole may be made. But this would not aid in determining why these results are found, since the assumption of homogeneous industries cannot be made. This study analyzes five high-technology industries: the computer, industrial machinery, medical equipment, pharmaceutical, and semiconductor industries. By analyzing the relationship between innovation and firm size for each industry separately, knowledge in the area of the relationship between firm size and technological progress can be made.

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C. CRITICISMS OF EMPIRICAL TESTING

There has been much discussion over Schumpeter's theory and what the empirical studies in the Schumpeterian tradition have actually tested. Markham (1965) was one of the first in expressing dissatisfaction with the empirical tests. He states that the original Schumpeterian hypothesis "does not imply that the measurable innovational effort of a firm as expressed, say, in terms of its R&D expenditures should be a continuous and increasing function of market power, business size, or, for that matter, retained earnings." (p. 324) Instead, Schumpeter's theory must be viewed "as a threshold theory; departure from perfect competition (or some form of monopoly) does not follow that twice this volume of departures, somehow measured, should lead to twice the volume of innovations."

Fisher and Temin (1973) argue that empirical research testing whether innovative inputs increase more than proportionately with firm size does not correspond to the original Schumpeter hypotheses. Fisher and Temin interpret Schumpeter as proposing increasing returns to scale in R&D with respect to both the size of the research establishment and the firm. They identify two relevant elasticities: the elasticity of research inputs with respect to the firm size and the elasticity of R&D output with respect to the firm. Fisher and Temin argue that empirical studies claiming to refute Schumpeter only show that the first elasticity is less than unity. To support Schumpeter, one must also show that the second elasticity is greater than one.[9]

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[9]Scherer (1973) criticized Fisher and Temin for not accurately representing empirical work that they attacked. Also, Rodriguez (1979) notes that in Fisher and Temin's model, increasing returns to scale is inconsistent with profit maximizing equilibrium.

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Kohn and Scott (1982) expand Fisher and Tieman's argument and develop conditions under which increasing returns to R&D inputs imply that the original Schumpeter hypothesis holds.[10] They also offer two definitions of the extent to which an industry may be considered "Schumpeterian". First, the greater the elasticity of (declining) marginal R&D cost with respect to the output of R&D, the more "Schumpeterian" the industry is in the cost sense. And second, the greater the marginal value added by R&D inputs with respect to the size of the firm, the more "Schumpeterian" the industry is in the productivity sense.[11]

In sum, the empirical methodology of testing the Schumpeter hypothesis has been challenged on the grounds that it is not testing Schumpeter's original hypothesis. Schumpeter argued that a large corporation appears to be especially conducive to organized innovative effort, but he never argued that there should be an increasing and continuous relationship between firm size and innovation.

This study will address these criticisms. First, I address Markham's criticism by testing for a threshold effect using various statistical techniques. I also model Schumpeter's hypothesis assuming a continuous function in order to compare results. Second, I address Kohn and Scott's criticism by utilizing a cost based test, which they

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[10]They demonstrate that it is possible to have increasing returns to R&D inputs and hence decreasing marginal R&D cost at equilibrium, provided that the marginal value added by R&D is falling more rapidly than its marginal cost.

[11] An essential methodological point is that empirical estimates of how "Schumpeterian" an industry is can be made by measuring the elasticity of R&D expenditures with respect to firm size at equilibrium, provided that the firms face similar R&D cost and productivity conditions. However, without uniform conditions, that is, a cross sectional analysis, results from a test of the relationship between firm size and R&D activity does not infer the Schumpeter hypothesis. (Baldwin and Scott (1987))

describe as similar to measuring R&D effectiveness. There are studies which measure R&D effectiveness, yet only two of these studies take into account firm size. This literature is discussed in the following section.

D. R&D AND FIRM PERFORMANCE

An alternative line of literature analyzes the effectiveness of R&D expenditures and patents on an indicator of firm performance, such as firm productivity or profitability. That is, instead of using R&D expenditures as a proxy for technological progress (that is, a dependent variable) R&D expenditures is included as an independent variable. Firm productivity or profitability is instead the dependent variable.

Numerous studies have estimated the return to R&D expenditures using a Solow residual model, focussing on productivity growth. For example, Clark and Griliches (1984) focus on productivity growth in the 1970's at the business level and find estimates of the rate of return to R&D investment to be almost 20%. In their model, they test for industry effects by including industry dummy variables. They conclude that estimation within industries has little effect on the results. Griliches and Mairesse (1984) analyze the relationship between output, employment, physical and R&D capital during the years 1966-1977. They find that in the cross sectional dimension, there is a strong relationship between firm productivity and the level of its R&D investments. Yet in the time dimension, this relationship comes close to vanishing. Griliches (1986), using NSF-R&D Census data from the 1970's, confirms the earlier studies in that R&D contributes positively to productivity growth. Griliches also finds that privately financed R&D has a signi

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a significantly larger effect on productivity than federally financed R&D, and that basic research appears to be more important as a productivity determinant than other types of R&D.

Yet, firm productivity is a measurement of process innovation only. This fails to take into account product innovation which is also an important component of technological advance. Process innovation considers upward shifts in the production function; product innovation considers the introduction of new production functions.[12]

R&D effectiveness can also be determined using accounting profits or a market value based measure of profitability. This allows consideration of both product and process innovation. For instance, Grabowski and Mueller (1978) suggest biases in previous structure-performance studies which utilize accounting profits. These studies ignore investment in intangible capital, such as R&D expenditures. The authors find that nearly half of the variance in unadjusted profit rates was due to improper accounting treatment of intangible capital. Ravenscraft and Scherer (1982) find that the long-run effect of a unit change in R&D expenditures leads to a change of $3.075 in gross profits.

Profits as an indicator of a firm's performance has come under much criticism (Fischer and McGowan, 1983). The firm's market value is an alternative measure of firm performance. Several studies have considered the value of R&D expenditures and patents using a market value approach. For example, Ben-Zion (1984) finds that a one dollar expenditure in R&D increases the firm's market value by 2.6 relative to the market's valuation of book value. Pakes (1984) investigates the dynamic relationships between the

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[12] In actuality, classification of product and process innovations depends on one's perspective. To some, a new computer is a product innovation; to others, a process innovation.

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number of successful patent applications of firm's investment in inventive activity (its R&D expenditures), and a measure of firm performance (its stock market value). He finds a significant correlation between the stock market rate of return and unexpected changes in both patent applications and R&D expenditures.[13] Pakes (1985) estimates that an "unexpected" patent leads to an increase in the firm's market value by $810,000, while an unexpected increase of $100 of R&D expenditures is associated with an increase in the firms value of $1,870. Connolly and Hirschey (1988) use a Bayesian approach in estimating the effect of unexpected patents and R&D expenditures on the firms market value. The data employed are mainly large firms; the sample includes 390 firms from the Fortune 500 from 1977. They find that each unexpected patent adds $5.33 million to excess valuation.[14] They also find that an extra dollar of R&D expenditure adds $3.60 to excess valuation. Taking a slightly different approach, Cockburn and Griliches (1988) measure the value of patents by examining the stock market's response to patent grants. They find that the estimated value of a patent is approximately $500,000. Yet, when R&D expenditures is included in the equation, this estimate is halved. They conclude that the stock market responds more strongly to changes in a firm's R&D spending than to changes in a firms stock of patents. Yet, none of these studies examine the relationship between firm size and the stock response to R&D investment. If firm size is an important determinant in the stock response to R&D, failure to include this results in specification bias.

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[13]Unexpected changes refers to changes that could not be predicted from the history of the variables included in the data set.

[14]Excess valuation is defined as the market value of common stock plus the book value of debt minus the book value of tangible assets, all normalized by sales.

Link (1981) recognized the association between firm size, innovative inputs, and firm performance, and tested whether a positive relationship between firm size and firm productivity exists. Concentrating on the chemical, machinery and trucking industries, Link found large firms earn a rate of return to R&D which is significantly greater than zero. However, he could not reject the hypothesis that the rate of return to R&D equals zero for small firms. Lichtenberg and Siegel (1991) extend Link's analysis by using detailed confidential longitudinal microdata. Dividing firms into three different size regimes, the authors find returns to company-funded R&D to be significantly higher for the largest firms compared with the smallest firms.

However, both Link and Lichtenberg and Siegel consider only process innovation. Process innovations are more likely to come from large established firms than are product innovations.[15] Therefore, it is not too surprising that the Schumpeterian hypothesis is supported. On the other hand, by analyzing the relationship between the market value of the firm and R&D inputs, the stock response to R&D investment in terms of both product and process innovation can be determined.

In sum, much of the empirical literature proposing to test the Schumpeter hypothesis considers whether innovative inputs increase more than proportionately with firm size. Yet, increasing returns to R&D inputs do not necessarily imply increasing returns to technological progress, which is the core of Schumpeter's theory. A test of the

[15] Large firms have greater incentives to develop internal process improvements. This is due to incentives to develop process improvements internally. Assuming that a new process reduces costs by a given percentage, the larger a firms output, the larger the total amount of savings. (Rosen (1991), Scherer and Ross(1990)).

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relationship between firm size and innovative outputs, such as patents, is deficient since the economic value of patents is highly heterogeneous. Furthermore, previous literature tests for a continuous relationship between firm size and technological progress, which is not what Schumpeter argued. An alternative approach in measuring technological progress analyzes the effectiveness of R&D expenditures on firm performance. This literature has not, however, considered whether firm size influences the marginal value of R&D output in terms of both product and process R&D. This study provides a unique method of testing the Schumpeter hypothesis. It determines the stock response to the firms market value for five high-technology industries, and tests whether this relationship is stable over an index of firm size. This approach both separates out industry effects and considers process and product innovation.

II. DESCRIPTION OF THE INDUSTRIES

This section presents a description of the five industries studied. In order to evaluate results from the Schumpeter hypothesis, an understanding of industry conditions is necessary. First, I present the definitions of the 4-digit SIC industries, and list the 10 largest firms in each of the industries. Second, I describe and compare industry conditions, specifically barriers to entry and appropriability conditions, which have been postulated to influence small and large firms' innovation rates(Acs and Audretsch (1987, 1988), Scherer and Ross(1990). Since appropriability and barriers to entry are not directly observable, I examine some of the measures which have been used as proxies.

A. INDUSTRY DEFINITIONS

The following section presents the definitions of the 4 digit SIC industries included in the study as defined by the 1987 Census of Manufactures along with the 10 largest firms in the industry in 1989.[1]

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[1] This information is obtained from Dun's Business Rankings (1991) which ranks businesses by sales volume within 4 digit SIC industry categories.

1. COMPUTER INDUSTRY

The Computer industry includes SIC 3570, 3571, 3575, 3577, and 3578. SIC 3570 is the general computer SIC classification code. Firms classified into this SIC are usually the larger firms which produce products in several sectors.[2] SIC 3571 is made up of establishments primarily engaged in manufacturing electronic computers. The 1987 Census of Manufactures defines electronic computers as machines which:

> (1) store the processing program or programs and the data immediately necessary for execution of the program; (2) can be freely programmed in accordance with the requirements of the user; (3) perform arithmetical computations specified by the user; and (4) execute, without human intervention, a processing program which requires them to modify their execution by logical decision during the processing run. Included in this industry are digital/analog computers.

SIC 3572 includes establishments which manufacture computer storage devices, while computer terminals is classified under 3575. SIC 3577 is defined as computer peripheral equipment, n.e.c. which includes products such as printers, plotters, and graphic displays. The Census of Manufactures defines calculating and accounting equipment, SIC 3578, as:

> establishments engaged in manufacturing point-of-sale devices, fund transfer devices, and other calculating and accounting machines, except electronic computers. Included are electronic calculating and accounting machines which must be paced by operator intervention, even when augmented by attachments. These machines may include program control or have input/output capabilities.

Last is office machines, n.e.c. (SIC 3579), which includes establishments producing such items as typewriters and word processing equipment.

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[2] The Census of Manufacturers does not provide data on this industry. However, the data used in this study classifies firms into this particular code.

TABLE 1: COMPUTER INDUSTRY:

10 Largest Firms, Ranked by Sales (1989)

	Firm	Annual Sales
1.	I.B.M.	$54.20 billion
2.	Unisys	$9.71 billion
3.	Digital Equipment	$9.38 billion
4.	N.C.R.	$5.64 billion
5.	Litton	$4.86 billion
6.	Apple	$4.07 billion
7.	Wang	$3.06 billion
8.	Pitney Bowes	$2.25 billion
9.	Harris	$2.06 billion
10.	Honeywell	$2.06 billion

2. MACHINERY INDUSTRY

Included in the machinery industry are SIC 3533, 3559, 3560, and 3561. Oil and gas field machinery (SIC 3533) includes those establishments primarily engaged in manufacturing machinery and equipment for use in oil and gas fields, or for drilling water wells, including portable drilling rigs. Special industry machinery, n.e.c., includes establishments producing equipment such as smelting and refining equipment, industrial sewing machines, and automotive maintenance machinery and equipment. SIC 3560 is the general machinery SIC classification code. Firms classified into this SIC are usually the larger firms which are most likely producing equipment in more than one product line.[3] Last is SIC 3561--pumps and pumping equipment--which include pumps for either general industrial, commercial, or household use, except fluid power pumps and motors.

TABLE 2: MACHINERY INDUSTRY:

10 Largest Firms, Ranked by Sales (1989)

	Firm	Annual Sales
1.	Dresser Industries	$3.11 billion
2.	Combustion Engineering	$3.04 billion
3.	Baker Hughes	$1.92 billion
4.	Babcock & Wilcox Co.	$1.70 billion
5.	Hughes Tool Co.	$1.15 billion
5.	Tilling Thomas Inc.	$1.15 billion
7.	Baker Hughes Prd.	$0.81 billion
7.	Tools Inc.	$0.81 billion
9.	Big Three Industries	$0.52 billion
10.	Cameron Iron Works Inc.	$0.50 billion

[3] Again, the Census of Manufacturers does not provide statistics on this SIC code.

3. MEDICAL EQUIPMENT INDUSTRY

Included in the medical equipment industry are SIC 3841, 3842, 3844, 3845, 3851, and 3861. Surgical and Medical Instruments (SIC 3541) is composed of establishments engaged in manufacturing medical, surgical, ophthalmic and veterinary instruments and apparatus. The Census of Manufactures defines SIC 3542, surgical appliances and supplies, as:

> made up of establishments primarily engaged in manufacturing orthopedic, prosthetic, and surgical appliances and supplies; arch supports and other foot appliances; fracture appliances, elastic hosiery, abdominal supporters, braces, and trusses; bandages; surgical gauze and dressings; sutures; adhesive tapes and medicated plasters; and personal safety appliances and equipment.

SIC 3844--X-Ray Apparatus and Tubes--is composed of firms which manufacture radiographic X-ray, fluoroscopic X-ray, and therapeutic X-ray apparatus and tubes for medical, industrial, research and control applications, or in manufacturing other irradiation equipment including gamma and beta-ray equipment. SIC 3845 is defined as electromedical equipment and SIC 3851 is ophthalmic goods such as ophthalmic frames, lenses, and sunglass lenses. SIC 3861, photographic equipment and supplies, is made up of establishments primarily engaged in manufacturing: (1) photographic apparatus, equipment, parts, attachments, and accessories, such as still and motion picture camera and projection apparatus; (2) photocopy and microfilm equipment; or (3) sensitized film, paper, cloth, and plates, and prepared photographic chemicals.

TABLE 3: MEDICAL EQUIPMENT INDUSTRY:

10 Largest Firms, Ranked by Annual Sales (1989)

	Firm	Annual Sales
1.	Eastman Kodak Co.	$13.30 billion
2.	Xerox	$10.30 billion
3.	Minnesota Mining & Mfg. Co.	$9.42 billion
4.	Johnson & Johnson	$8.01 billion
5.	Baxter Internatl.	$6.22 billion
6.	Polaroid Corp.	$1.76 billion
7.	Becton Dickinson	$1.58 billion
8.	Kendall Co.	$1.00 billion
9.	Nashua Corp.	$0.87 billion
10.	Bausch & Lomb	$0.84 billion

4. PHARMACEUTICAL INDUSTRY

The 1987 Census of Manufactures defines SIC 2834 as:

...made up of establishments primarily engaged in manufacturing, fabricating, or processing drugs in pharmaceutical preparations for human or veterinary use. The greater part of the products of these establishments are finished in the form intended for final consumption, such as ampoules, tablets, capsules, vials, ointments, medicinal powders, solutions, and suspensions. Products of this industry consist of two important lines, namely: (1) pharmaceutical preparations promoted primarily to the dental, medical or veterinary professions, and (2) pharmaceutical preparations promoted primarily to the public.

TABLE 4: PHARMACEUTICAL INDUSTRY:
10 Largest Firms, Ranked by Annual Sales (1989)

	Firm	Annual Sales
1.	American Home Products	$5.02 billion
2.	Pfizer	$4.91 billion
3.	Hoechst	$4.61 billion
4.	Abbott	$4.38 billion
5.	Smithkline Beckman Corp.	$4.32 billion
6.	American Cyanamid Co.	$4.16 billion
7.	Eli Lilly & Co.	$3.64 billion
8.	Warner-Lambert	$3.48 billion
9.	Schering-Plough Corp.	$2.69 billion
10.	Upjohn Co.	$2.52 billion

5. SEMICONDUCTOR INDUSTRY

The 1987 Census of Manufactures defines SIC 3674 as:

made up of establishments primarily engaged in manufacturing semiconductors and related solid-state devices. Important products of this industry are semiconductor diodes and stacks, including rectifiers, integrated microcircuits (semiconductor networks), transistors, solar cells, and light sensing and emitting semiconductors (solid state) devices.

TABLE 5: SEMICONDUCTOR INDUSTRY:

10 Largest Firms, Ranked by Annual Sales (1989)

	Firm	Annual Sales
1.	Texas Instruments Inc.	$5.59 billion
2.	National Semiconductor	$2.46 billion
3.	Intel	$1.90 billion
4.	Advanced MicroDevices	$1.00 billion
5.	Western Digital Corp.	$0.77 billion
6.	Micron Technology Inc.	$0.30 billion
7.	Uniden Corp. of America	$0.30 billion
8.	Micropolis	$0.29 billion
9.	Everex Systems Inc.	$0.27 billion
10.	LSI Logic Corp.	$0.26 billion

B. INDUSTRY CONDITIONS

This section presents descriptive statistics on variables which have been asserted to influence the innovation rates of large and small firms (Acs and Audretsch (1987, 1988), Scherer and Ross(1990), Kamien and Schwartz (1982)). The innovation rate is a measure of the number of innovations relative to firm size.[4] These statistics may provide information on why the Schumpeter hypothesis is supported or rejected once results are obtained.

As noted in the Introduction, an R&D program of a given size may operate more efficiently in a larger firm. In other words, scale economies in production may provide economies for R&D. One measure of scale economies in production is the capital intensity of an industry. The higher the capital intensity, the more likely large firms are able to take advantage of the economic gains from innovation. Similarly, the extent of product differentiation through advertising may grant advantages to large firms while inhibiting small firms innovation rates.[5] Therefore, the higher the capital intensity and/or advertising intensity of an industry, the more likely large firms will have an advantage in R&D. On the other hand, Acs and Audretsch have shown (1987, 1988) that smaller firms are relatively more innovative the higher the percentage of large firms comprising an industry.

One of the major tenants of the Schumpeter hypothesis is that market power and the potential for accruing economic rents is a necessary condition for innovation. A

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[4] The absolute number of innovations must be standardized by a measure of size in order to compare relative rates of innovation.

[5] The definition given by compustat for advertising expense is that "this item represents the cost of advertising media (radio, television, newspapers, periodicals, etc.) and promotional expenses". This can be compared with the average intensity for manufacturing. Scherer and Ross note that the median manufacturing industry devoted 0.66 percent of its sales revenue to advertising in 1977 (Federal Trade Commission, *Statistical Report: Annual Line of Business Report, 1977* (Washington: April, 1985). However, if total selling expenses are taken into account (cost of sales representatives, point of sales displays, coupons, samples, advertising allowances to retailers, and trade allowances as well as media advertising expenses), the median value increases to 7.75% of manufacturers' sales in 1977.

common measure of the extent of imperfect competition is the degree of concentration. While this study examines the relationship between firm size and technological progress, there is a considerable literature on the relationship between concentration and technological progress (see Baldwin and Scott (1987) and Kamien and Schwartz (1982) for an overview). The argument relating concentration to technological progress is similar to that of the advantages of large firms: Innovation can occur only in the presence of market power and "...only by a firm that has the resources which are associated with considerable size." (Galbraith) Therefore, if results indicate that large firms are more profitable in R&D in a particular industry, we can observe if there is a correlation between supporter of Schumpeter and concentration. Concentration measures have frequently been included in regression equations which test the Schumpeter hypothesis. Yet, once industry conditions are incorporated, these measures are often insignificant(see Kamien and Schwartz, Baldwin and Scott(1987)). However, the majority of the studies control for industry effects at the 2 digit level whereas this study disaggregates industries further than 2 digits.

As stated in the previous Chapter, underlying factors in industries may be able to explain interindustry differences in R&D investment and innovative performance. Yet, an important question remains to be answered: if firm size is a significant determinant of R&D profitability, is there a pattern between appropriability conditions and support for the Schumpeter hypothesis? For example, patent effectiveness might be extremely important for small firms, in part because other means of appropriation may not be feasible(Levin et al.(1987)). Table 6 shows the effectiveness of product and process patents as a means of capturing and protecting the competitive advantage of new processes or products. On a 7 point scale, the average for all industries is 3.5 for process patents and 4.3 for product patents. Appropriability conditions are below average in the computer industry and above average in the pharmaceutical industry, and approximately average for the other 3 industries. The mean scores infer that patents are not considered to be a very effective means in protecting the competitive advantages of new or improved precesses and products. In fact, in Levin et al. survey, they find that lead time, learning curves, and sales/service efforts were regarded as substantially more effective than patents in protecting product innovations.[6] And secrecy and the mechanisms listed above were more effective in protecting new processes, than were patents. These statistics, while useful, do not provide the entire picture of appropriability conditions.

[6] Unfortunately, the authors' only publish patent effectiveness broken down by industry, not the others.

TABLE 6: INDUSTRY DESCRIPTIVE STATISTICS

	Computer	Machinery	Medical Equipment	Pharma-ceutical	Semicond uctor
Advertising Intensity	1.9%	0.7%	4.1%	10.9%	0.7%
Capital Intensity	27.6%	42.5%	37.2%	34.9%	86.3%
CR4	43	16	43	26	40
HHI	793	146	854	318	597
Process Patents	3.3	3.2	3.2	4.9	3.2
Product Patents	3.4	4.4	4.7	6.5	4.5

Advertising Intensity is advertising expenditures divided by sales. These values are calculated from the Compustat Tapes, including all available observations (1982-1989).

Capital intensity is gross assets divided by value-of-shipments. Data are obtained from "The U.S. Dept. of Commerce, Bureau of the Census, *Annual Survey of Manufactures, 1982, Industry Profiles.*"

Concentration ratios: CR4 is the four firm concentration ratio, HHI is the Herfindahl-Hirschman Index. Data are obtained from "The U.S. Dept. of Commerce, Bureau of the Census, *Annual Survey of Manufactures, 1982, Concentration Ratios.*

Process/Product Patents: the effectiveness of patents as a means of capturing and protecting the competitive advantages of new or improved processes or products, based on a 7 point scale (1=not an effective means). These scores are obtained from Levin et al. (1987)).

III. THEORETICAL RELATIONSHIP BETWEEN FIRM SIZE AND TECHNOLOGICAL PROGRESS

"Innovation is the search for and the discovery, development, improvement, adoption and commercialization of new processes, products, and organizational structures and procedures. It involves uncertainty, risk taking, probing and reprobing, experimenting, and testing. It is an activity in which "dry holes" and "blind alleys" are the rule, not the exception." (Jorde and Teece (1992)). This chapter develops a theory for the relationship between firm size and innovation. First, models of the process of innovation are described, including a discussion of the differences between the serial models and the simultaneous model of innovation. Second, a framework for empirical analysis is developed. And last, an econometric model is established.

A. INNOVATION AS A PROCESS

Schumpeter did not specifically discuss the organizational aspects of the innovational process. Yet, in order to understand the role of firm size in innovation, it is crucial to consider the process aspect of innovative activities (see Kline and Rosenberg (1986), Teece (1989)). There have been a number of attempts to impose a conceptual order on the innovation process. However, just as inventions are typically very crude in their early stages, so are the general models of innovation (Teece (1986)). Three models of the innovation process are discussed: the traditional serial model, the chain-linked model, and the simultaneous model.

1. THE SERIAL MODEL

Traditional descriptions of the innovation process have focussed on the "serial model", which is also referred to as the linear model. In this model, the innovation process proceeds in steps from research to development to marketing. Only after completion of one stage is the process able to continue. A diagrammatic example of the serial approach is presented in Figure 1.

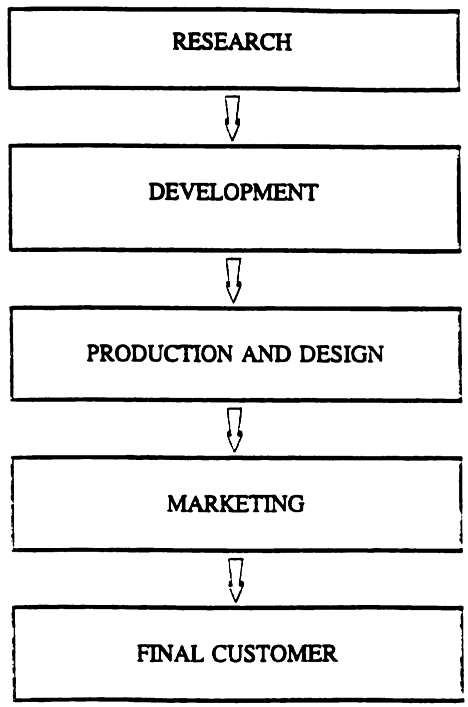

FIGURE 1: THE SERIAL MODEL

First, an idea is conceived, a project is formulated, and expenditures on basic research occur. This may or may not lead to successful research, and/or possibly a patentable product or process. However, if this stage is successful, further investment is needed in order to transform this basic research into a product or process, that is, the development stage. The next stage is production and design. Here, an acceptable design is formulated and the manufacturing process is implemented. Only after the successful completion of this stage does marketing of the innovation occur.

This model has been widely criticized for a number of reasons. First, there are no feedback mechanisms to and from the different areas of operation, or from users. However, feedback represents an important component of innovation. Rarely is the design and optimization of the innovation correct from the start. Jorde and Teece (1992) note another problem with the serial model in that "...it does not address the many small but cumulatively important incremental innovations that are at the heart of technological change in many industries, especially well-established industries like semiconductors, computers, and automobiles." And third, this model does not characterize process innovations as opposed to product innovations, which usually do not require marketing, or some other step of the process. Yet, the serial model may be a relevant characterization of the innovation process when large idiosyncratic fixed investment is required for commercialization. Some examples of innovation which follow the serial model include the NASA Mercury and Apollo programs, Department of Defense projects, the IBM 360, and the Xerox 9000 family of high speed copiers (Teece (1989)).

2. THE CHAIN-LINKED MODEL

One possible alternative to the linear model is the chain-linked model.[1] This model is depicted in Figure 2. In this model, the authors consider five alternative paths

[1]See Kline and Rosenberg (1986) for a detailed discussion.

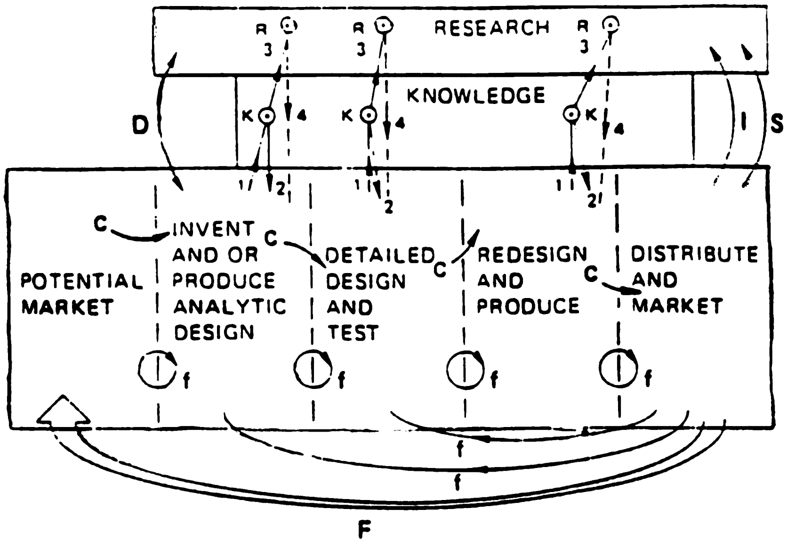

FIGURE 2: THE CHAIN-LINKED MODEL
Kline and Rosenberg (1986)

of the innovation process, instead of just one as in the serial model. The first, called the central-chain-of innovation (indicated by the arrows labeled "C"), proceeds from left to right: beginning with design, proceeding to development and production, and finally marketing. This path is similar to the traditional serial model, although it doesn't necessarily begin with research. The second path is an extension of the first and incorporates feedback mechanisms (marked by "f" and "F"). That is, at any step, the innovation cycle is able to feedback information to improve on previous stages. The third path addresses the small incremental innovations by modeling science alongside the development process (S). This stage recognizes that research encompasses the entire process, and may enter into the process at any particular point, or at all points of the process. For example, Kline and Rosenberg state that "When we confront a problem in technical innovation, we call first on known science, stored knowledge, and we do so in serial stages."[2] The link between research and problems in invention and design is the fourth course. This path is relevant when science produces radical innovations which create new industries (for example, semiconductors, lasers, and genetic engineering). And the last course is the feedback from products to science (arrow "I") in which innovation spurs innovation; the process becomes circular.[3]

In sum, there are three important differences to note when comparing the chain-linked model to the traditional serial model. First, there are five paths of activity instead of just one. Second, instead of research being pertinent only at the beginning of a project, this model realizes that research may encompass the entire process. And third, the importance of feedback is recognized in this model. R&D personnel must be closely connected to the end user and to the marketing personnel. In addition, development requires feedback from both marketing and research. Yet, just like the serial model, the chain-linked model assumes a particular sequence of activities, from research to design to production and then marketing.

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[2]Kline and Rosenberg (1986) illustrate this path with an example. In order to reduce pollution and improve mileage, you are interested in innovating an improved carburation-induction system for the spark ignition automobile engine. In order to accomplish this you must mix fuel and air at the molecule-to-molecule level, which conventional carburation systems fail to do. You first ask yourself whether you know of a current device that will do the job. If your answer is "no", you consult your colleagues and perhaps existing literature. If that does not yield a solution, you consult with experts in the field. Only if this is not fruitful do you initiate research.

[3]For example, "Without the microscope, one does not have the work of Pasteur, and without that work there is no modern medicine. Without the telescope, we would not have the work of Galileo, and without that work we would not have modern astronomy and cosmology, nor would space exploration with its various innovations have been possible." (Kline and Rosenberg, (1986) p. 293).

3. THE SIMULTANEOUS MODEL

In many cases innovation may not begin with research nor is it serial. In some instances time is of the essence and in order to succeed commercially the different stages must act simultaneously. Such a model is portrayed in Figure 3. It allows for the simultaneous work on all parts of the project at a given point in time, instead of progressing with the project only after one stage has been completed. The simultaneous model does not necessarily assume that all advantages accrue to the winner of a R&D or patent race, but it does recognize the importance of time. Because the different activities of the firm occur concurrently, marketing may be undertaken before development and design are finalized. Thus, close contact is necessary between the different activities for projects to be commercially successful.

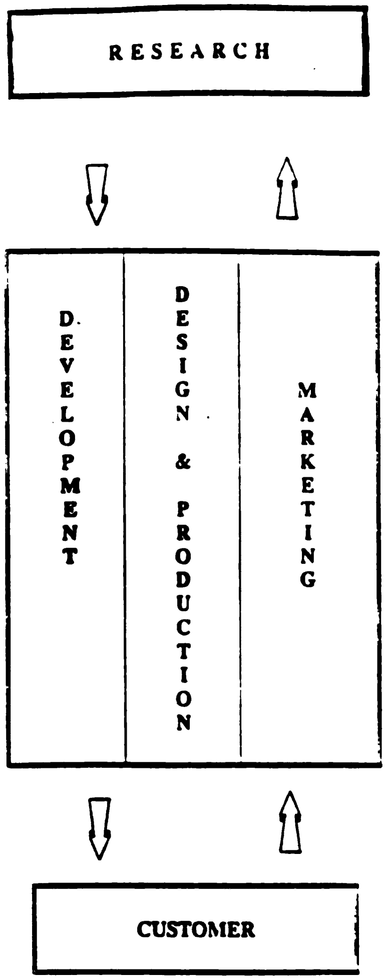

FIGURE 3: THE SIMULTANEOUS MODEL

In sum, the traditional serial model greatly oversimplifies the organizational challenges of innovation. A result of this is that the research aspect of the process is overestimated while other factors are not discussed. The chain-linked model and the simultaneous model point out that it is not enough for the research activity itself to be successful; a firm must also be able to organize the other parts of the process efficiently and effectively for successful commercialization. That is, research must be combined with other parts of the process, the so-called complementary assets. These complementary assets could be considered services, such as after-sales support in the case of computers, medical instruments or machinery, or marketing in the case of pharmaceuticals, in which dissemination of information about a new drug is essential. When these complementary assets are not present, competitors and/or imitators are likely to profit from the innovation--at times more than the firm that was first to innovate.[4] In addition, large returns can be made from a modest technological advance if the company has the appropriate complementary assets in place.[5]

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[4] The classic example of the importance of complementary assets is Electrical Musical Industries Ltd. (EMI) computerized axial tomography (CAT) scanner. Within six years of introduction in the U.S., the company had lost market leadership and by the eighth year it had dropped out of the CAT scanner business. The CAT scanner required a high level of training, support, and servicing because of its technological sophistication. EMI had none of these services and did not contract with another company to provide these services. Unfortunately for EMI, once the product was available it could be reverse engineered and copied quite easily.

[5] The classic example in this case is the IBM PC which was introduced in 1981. IBM used the new 16-bit microprocessor developed by Intel (the 8088) and a new operating system (DOS) which was developed for IBM by Microsoft. Apart from those new innovations, IBM used existing standards. The key to IBM's success was therefore not revolutionary innovation, but IBM's complementary assets: services and marketing. Another key was IBM's realization that in order for the PC to be successful, software was needed-in a short period of time. Instead of attempting to develop software itself, IBM made the operating system information publicly available and software firms proliferated.

4. LINKAGES

Up to now, all activities have been assumed to take place in-house. Yet, because of the high cost and uncertainty of research, innovation is most likely going to require access to capabilities which lie beyond the organization of a single firm. Examples include universities, as well as horizontal and vertical linkages.

University research has played an important role in the innovation process through numerous channels, including publications, research contracts and technical conferences.[6] The link to universities may be important in gaining access to graduate students, to attract faculty as partners in business ventures, and to encourage faculty to become familiar with their equipment. With the university-firm connection, firms may be more aware and attentive to changing conditions.

The great extent of horizontal linkages--research consortia--is a relatively new phenomenon. Because of successful foreign competition in the past two decades, cooperation among U.S. companies was advocated for the development of basic technologies was advocated. Yet until the antitrust laws were relaxed it was too risky for companies to enter into research agreements.[7] The escalation of R&D costs represents

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[6] However, there has been some debate on the commercial applicability and value of university technology. See Teece (1989).

[7] The National Cooperative Research Act was passed in 1984 which provides a "rule of reason" for evaluating the legality of each cooperative R&D venture on a case-by-case basis instead of declaring them "per se" illegal. This act also limits potential liability of these research consortia to actual damages compared with treble damages.

another reason why companies are forming R&D consortia.[8] By law, R&D consortia can only perform basic research and development up to a prototype stage and are prohibited from manufacturing and marketing products. Thus, the member companies are not cooperating with one another throughout the entire process.[9]

Horizontal linkages are beneficial to firms in that they can help firms to internalize part of the spillover effects to the consortium, because the firms receiving the benefits are likely to include a greater portion of firms which incurred the corresponding R&D costs. The effect of greater appropriability is, of course, to encourage greater investment in new technology. Markets tend to underinvest in new technology because those innovative firms which support R&D do not appropriate all the benefits of innovation--imitators are often more profitable than the innovating firm (See Levin et al.(1985)). Another argument for linkages is that they help reduce unnecessary duplication of research efforts, and may also assist in the definition of technical standards for systemic innovation (Teece (1986)).[10]

Most important, especially for small firms, are the vertical linkages. That is, two or more firms may address particular aspects of the innovation process and therefore not

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[8] For example, Oncogen is a three company research venture formed by Genetic Systems, Syntex, and Bristol-Meyers to develop diagnostic and therapeutic products for cancer treatment which would be too costly for one company to develop (see Davis(1985)).

[9] While many of these R&D consortia contain large firms, one research consortium (MCC) has formed an Associates Program through which smaller companies can gain access to the consortium's results. Also, the Midwest Technology Development Institute (MTDI) is a consortium which pools the resources of 10 midwestern states in order to make technology available to small business.

[10] Of course, the uncertainty of innovation often requires pursuing multiple technological paths.

undertake all of the steps in-house. For example, one firm's research may be patented and licensed to another firm for production and marketing. That is, research occurs in one firm, while the remaining stages occur in another firm. Or, research, development, production and design are all successful and take place within one firm. However, the firm does not have the marketing resources necessary so the product is licensed to another firm. Numerous other scenarios are possible. The point is that firms need not perform all activities in-house for innovation to occur and to be successful. In addition, contractual relationships can bring added credibility to the innovator, especially if the innovator is relatively unknown and the contractual partner is established and viable.[11] Teece (1986) discusses the factors that determine whether a contractual solution or integration is the optimal solution.

To summarize, the process nature of innovation is difficult to characterize because of its numerous dimensions. This study recognizes that organizational features of the firm are important, but does not seek to analyze all of them. Instead, it looks at one particular aspect: does the size of the firm affect R&D efficiency? That is, are small firms more profitable in turning research inputs into successful innovations or vice versa?

B. FRAMEWORK FOR EMPIRICAL ANALYSIS

The theoretical relationship between firm size and technological progress is analyzed by means of a profit maximization--market valuation model. It is argued that

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[11]For example, Cipher Data Products, Inc. contracted with IBM to develop a low-priced version of IBM's 3480 0.5 inch streaming cartridge drive, which became the industry standard.

the stock market takes into account information about firms' expected future profitability and therefore factors in expected outcome due to R&D investment. Accordingly, the effectiveness of R&D investment in high-tech firms is analyzed by evaluating the stock response to R&D inputs. The stock response measures the expected outcome of investment. If this response is significant, it indicates that these investments are deemed profitable by the market. If the stock response is not significantly different from zero, one can presume that the market does not value these investments and believes that it will not improve economic growth.

After briefly introducing the market valuation model, I discuss the firm's assets--both tangible and intangible--and incorporate these into the valuation model. A description of how risk factors into the model is then examined. And finally, the model is extended to allow for a test of whether firm size is a significant determinant of R&D efficiency.

1. THE FIRM'S MAXIMIZATION PROBLEM

The firm maximizes its value: $V=f(X_1, X_2 .... X_N)$ where V=the value of the firm and $X_1...X_N$ are the assets held by the firm. The value of the firm at time t is a function of the present value of the firm's future income streams:

$$V=\frac{INCOME_1}{(1+r)}+\frac{INCOME_2}{(1+r)^2}+\ldots\ldots\frac{INCOME_t}{(1+r)^t}=\sum_{t=1}^{T}\frac{INCOME}{(1+r)^t} \quad (1)$$

Where "r" is the discount rate and "Income" is the profit in each time period. Therefore, the firm's value at time t is a function of its future income streams, which in turn are a function of its assets: V = F {INCOME STREAMS (assets)}. The firm's assets can be separated into 2 broad categories: tangible assets and intangible assets (TA and IA, respectively):

$$V = f(\text{income streams (TA, IA)}) \qquad (2)$$

The firm invests in these assets to the point at which the marginal increase in firm valuation is equal to the marginal cost of investment.

2. TANGIBLE VS. INTANGIBLE ASSETS

The firm's tangible assets are its plant, property and equipment, which can be measured using standard accounting techniques. Intangible assets can be disaggregated into the firm's knowledge stock of capital and marketing stock of capital (KS, MS, respectively). For a high-technology firm, the extent of its knowledge capital is especially important.

$$V = f(\text{income streams (TA, KS, MS)}) \qquad (3)$$

where KS is the firm's knowledge stock and MS is the firm's marketing stock.

The firm's intangible assets are more difficult to measure than the firm's tangible assets. Since research is the primary component of a firm's intangible assets in high-technology industries, R&D investment can be a proxy for knowledge stock (See Griliches (1981), Connolly and Hirschey (1984, 1990), Hall(1993)). Advertising expenditures are also a form of intangible assets, which represent the degree of product differentiation.

Although R&D investment and tangible asset investment are based on similar considerations so that one could use the discounted present value of future income streams to evaluate the desirability of R&D investment, there is an important difference between these two types of investments: the future net income stream resulting from an R&D project is subject to more uncertainty than investment in plant and equipment. Tangible assets can often be sold, whereas it is difficult to put a price-tag on a stock of firm knowledge. One example of this is Texas Instruments' investment in the "magnetic bubble memory" technology. Texas Instruments (TI) invested in this technology for seven years, hoping that its efforts would lead to a revolutionary computer chip, and would capture a large share of the market held by ordinary electronic memory chips (DRAMS). Unfortunately for TI, the company's engineers underestimated the speed with which the older memory chip technology would evolve. DRAMS had become so cheap and capable by the time the new technology--magnetic bubbles--were ready for the market that the computer makers refused to switch technologies. By that time, TI had sunk tens of millions of dollars into the project. Although there is most likely a correlation between R&D investment and the net present value that can be attributed to R&D, this example illustrates that it is not guaranteed and is much more variable than that in tangible assets.

3. RISK AND THE VALUATION MODEL

A consideration which must be taken into account when analyzing market valuation models is uncertainty. By definition, innovation implies creating a new product or process, and this new product or process includes elements that we do not understand and are skeptical about in the beginning. A firm is uncertain how this new product will fare in the market, or whether R&D is successful even to make it to the market. That is, innovation implies uncertainty, or risk. Therefore, an understanding of risk, and how risk affects a firm's value is required.

Risk can be separated into two broad categories: systematic and unsystematic risk. Systematic (or nondiversifiable) risk refers to that portion of the variability of a security's return caused by factors affecting the market as a whole.[12] These sources affect all securities and cause the returns from all securities to vary more or less together. The second type of risk is unsystematic risk, and is risk that is unique to the firm. An example of this is variability in the firm's return that is due to its own management capabilities.[13] Another type of unsystematic risk, which is especially important in high technology firms, is R&D risk. R&D risk can be regarded as the risk of achieving success in all of the areas necessary to making a return on investment, for example, research, development, and marketing. Some of these sources of R&D risk are unique

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[12] Examples of systematic risk include: the change of the interest rate, changes in purchasing power (inflation), and changes in investor expectations about the overall performance of the economy.

[13] Other examples of unsystematic risk include such factors as management decisions, the availability of materials, foreign competition, and government regulation.

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to the industry, and one would expect risk to affect firms in one industry approximately the same way. For example, in the semiconductor industry, foreign competition reduced the returns to all U.S. companies. Yet, much of the R&D risk is specific to the firm and is considered to be unsystematic risk. The following section describes how firms are able to reduce risk through diversification.

4. DIVERSIFICATION

Firms are able to reduce risk through diversification. By diversifying into different product lines which have different risk-return characteristics, overall risk could be reduced because one product line may achieve high returns at the same time that the returns from another product line are low, and vice versa. The combined returns over time are therefore more stable and are subject to less uncertainty. Of course, the amount of risk reduction achieved depends on the degree of correlation between the returns of the individual product lines. The risk of failure is another determinant of the variability of returns, important especially in high-technology firms. Failure can be defined as an investment which generates a negative rate of return. The risk of failure explains the desire of many companies to diversify.

In addition to reducing risk by diversifying across product lines, a firm can also reduce risk by investing in different projects within the same product line. A well known example is oil and gas exploration.[14] Oil and gas exploration is very similar in its

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[14] As an example, assume that the firm knows that any wildcat well that they drill will cost approximately $2 million and have only a 10% chance of success. Successful wells will result in profits of $24 million. In this case, the expected return of the firm

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riskiness to the high-tech industries considered in this study, except that high-technology companies complicate the analysis due to the number of steps involved. In other words, successful research doesn't necessarily mean a successful product, as in oil exploration; there are many more steps involved.

5. RISK AND THE REQUIRED RATE OF RETURN

Risk is important because it affects the required return on investment: the higher the uncertainty of returns, the higher the required return for investors. To understand this, risk and the expected return for a firm are analyzed. This is then translated into a required return for investors, and this required return is incorporated into equation 1, the market valuation model.

I begin by generalizing the valuation model to include uncertainty of returns. The expected return for a firm depends upon the weighted average of the expected return for all of the firms product lines. Let the expected return for a firm at time t be:

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would be 30% (Expected Return=24(.10)-2(.9)=$0.6m). If a firm drilled only one well, there would be a 90% chance that the firm would fail, and the total project risk would be very high. Unsuccessful wells will result in no profits, and the entire investment will be a loss, or failure. However, if one firm drilled 100 wildcat wells, the risk of failure from all wells would be very low($.1^{100}$). In order for the firm to break-even, only 7.7% of the wells need be successful. This return is achieved with very little risk relative to that facing a firm drilling a single well(Moyer, McGuigan, and Kretlow (1992)).

As this example illustrates, the risk of drilling any individual well can be diversified away very effectively by expanding production. An analogy of this example for high-tech firms is that one firm can focus on more than one product line or can focus on alternative research paths to achieve a breakthrough in R&D. This is one example of how firm size can affect risk and therefore return on investment.

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$$E(R_{i,t}) = \sum_{i=1}^{N} \sum_{t=1}^{T} W_{i,t} R_{i,t} \quad (4)$$

where $W_{i,t}$ is the expected return for firm i at time t, $R_{i,t}$ is the expected return from an individual product line: $\Sigma W_i = 1$ and $0 \leq W_i \leq 1$.

The expected return is translated into a required rate of return for investors by using a conventional approach--the risk adjusted discount rate model. Let the required return from any one investment j, denoted k_j, be equal to the following:

$$k_j = r_f + \Theta_j \quad (5)$$

where r_f is the risk free rate and Θ_j is the risk premium required by investors.

A common method in determining the risk premium is by measuring the systematic risk: Beta(β). Usually betas are computed for firms; therefore equation 5 is extended to focus on the overall required return for the firm. Beta is a measure of the volatility of a firm's returns relative to the returns of a broad-based market portfolio. It is defined as the ratio of the covariance of returns for firm j and the market portfolio to the variance of returns for the market. A Beta (β) = 1.0 indicates that the firm is of average systematic risk (that is, the same risk characteristics as the market as a whole). A β greater than 1.0 indicates that a firm has greater than average systematic risk; likewise, a β less than 1.0 indicates that the returns to the firm have less than average systematic risk.

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The beta coefficient is a function of the firm's standard deviation of returns (σ_i), the markets standard deviation (σ_m), and the i[th] firm's correlation with the markets return ($\rho_{i,m}$) each measured over a particular sample period:

$$\beta_i = \frac{Cov(r_i, r_m)}{\sigma_m^2} = \rho_{i,m}\frac{\sigma_i}{\sigma_m} \tag{6}$$

By diversifying, either across product lines or by expanding the number of projects within a product line, the firm's returns will be less variable, and therefore a firm's β will be lower.

A firm's beta can be determined by estimating the following regression equation:

$$r_{i,t} = \alpha_i + \beta_i r_{m,t} + \epsilon_{i,t} \tag{7}$$

Where $r_{i,t}$ represents the return for the i^{th} firm in the t^{th} period. This is usually determined by calculating the return for the firm over a one month period. The analogous one-period return from a stock index (usually Standard and Poor's) is denoted by $r_{m,t}$. The regression intercept is indicated by α_i. β_i is the beta systematic risk index for the i^{th} firm estimated over a particular sample period. It is customary to use 60 monthly data points to calculate betas (Kolb and Rodriguez (1992)). Last, $\varepsilon_{i,t}$ is an unexplained residual for the i^{th} firm during the t^{th} time period: $E(\varepsilon_{i,t})=0$. Given β, it is now possible to compute the risk premium, Θ, that is applicable to the firm. Rearranging equation 5 I obtain:

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$$\Theta = k^* - r_f \qquad (8)$$

where Θ is the risk premium for the firm, k^* is the investor's required return, and r_f is the risk-free rate of return.

Next, let k_m be the expected rate of return on the overall market portfolio and r_f be the expected risk free rate. Then the average market risk premium is equal to:[15]

$$\Theta_m = k_m - r_f \qquad (9)$$

Using the firm's beta, the investor's required return can now be determined. For a project with average risk (β equal to 1.0), the risk premium should be equal to the market risk premium. If a firm's beta is 2.0, this implies that the firm's return is twice as risky as the market average, so its risk premium should be twice the market risk premium.

$$\Theta = \beta(k_m - r_f) \qquad (10)$$

Rearranging equation 8, the required return is:

$$k^* = r_f + \Theta_f \qquad (11)$$

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[15] Based on historic stock market data over the time period 1926-1989, the average market risk premium has been 8.6%. (Moyer, McGuigan, and Kretlow (1992)).

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$$k^* = r_f + \beta_f(k_m - r_f) \tag{12}$$

Thus, the required return is a function of the risk-free rate and the market return which are the same for all firms, and the firm's beta, which is a measure of the volatility of a firm's returns as compared with the market. This is the point at which diversification becomes important. Recall that the more stable the returns, perhaps due to a large number of investments or product lines, the lower the firm's beta will be. This implies that the required return (k*) is lower.

Incorporating this into equation 1 (the firm's net present value), and substituting k*, the required return on investment, for the interest rate (r):

$$V = \frac{INCOME_1}{(1+k*)} + \frac{INCOME_2}{(1+k*)^2} + \ldots\ldots \frac{INCOME_T}{(1+k*)^T} = \sum_{t=1}^{T} \frac{INCOME}{(1+k*)^t} \tag{13}$$

The implication of the above equation is that the higher the perceived risk of the firm by the market, the higher the required rate of return (indicated by k*), and the lower the firm's net present value, all other things equal.

MODEL

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C. MODEL

In this section, an empirical model is formulated from the market valuation model in order to test the Schumpeter hypothesis. It differs in three key assumptions from the studies reviewed in Chapter II. First, instead of focusing on whether innovational inputs increase more than proportionately with firm size, the outcome of these inputs is analyzed. This is done by examining the response of a company's stock value to R&D expenditures over a five year period. It is argued that the stock market takes into account information about firms' expected future profitability and therefore factors in expected outcome due to R&D investment. Using this method, the problems associated with using both R&D inputs and outputs (patent data) do not occur. Second, instead of pooling both low and high-technology firms, industry conditions are given recognition by focusing separately on five key high-tech industries: the computer, machinery, medical equipment, pharmaceutical, and semiconductor industries. And third, various statistical methods are employed in order to test for the effect of firm size. This is done, first, by employing a relatively simple functional form which assumes a continuous relationship between firm size and technological progress. Second, I specifically test for the precise definition of small and large firm size; that is, a continuous relationship is not assumed to exist.

1. EMPIRICAL FORMULATION AND MEASUREMENT ISSUES

I begin by generalizing equation 3 in order to take risk into account:

$$V = f(\text{income streams } (TA, KS, MS, Risk)) \tag{14}$$

where V is the market valuation of the firm, TA is the tangible assets, KS is the knowledge stock, and MS is the marketing stock.

R&D investment is used as a proxy for knowledge capital and advertising expenditures for marketing capital. As stated in the previous section, the firm's beta is commonly used as a measure of systematic risk.

Yet, the true functional form of the relationship between firm valuation and tangible and intangible assets is unknown. One possible method of analyzing the relationship between firm valuation and tangible and intangible asset investment is by means of applying a Taylor expansion to an unknown functional form:

$$V_{i,t} = \alpha_{i,t} + \gamma_1 TA_{i,t} + \gamma_2 RD_{i,t} + \gamma_3 ADV_{i,t} + \gamma_4 Risk_{i,t} + \epsilon_{i,t} \tag{15}$$

where V, TA, RD, and ADV are defined above. A firm's beta is used as a proxy for risk.

The coefficients (γ_1, γ_2, and γ_3) measure the effect of a change in the different types of capital held by the firm. The coefficients on the different types of capital represent the investors' perceived effectiveness of the firm for turning different types of capital investment into future income streams. The coefficient on "Risk" (γ_4) represents the effect of risk on market valuation. This framework will be used in this study to analyze whether R&D efficiency differs across firm size.

Measuring the effectiveness of different types of capital at a given point in time has potential problems. First, stocks of knowledge are being measured; however, the amount of the knowledge capital held by the firm prior to a given point in time is unobservable, and therefore the total amount held at any particular time is therefore also unobservable.[16] Second, the firm's knowledge base affects firm value (due to expected future income streams), but the value of the firm may also affect the firm's stock of knowledge (a higher firm valuation may increase R&D investment, all other things held constant).

One method of mitigating these problems is by first differencing. First differencing can eliminate the importance of the unobservable levels of intangible capital held by the firm by only considering the change during the relevant time period. In addition, first differencing diminishes the importance of the endogenous setting of capital levels.

Entering beta directly into the model would require computing the firms' betas at the beginning and end of the time period in order to calculate the change during that time period. Empirical investigations by Baesel (1974), Blume (1971), and Roenfeldt et al. (1978) examine the stationarity of betas over time. These studies all conclude that the stability increases as the length of the estimation period increases--betas are relatively

[16] For example, this data set spans from 1982-1989. There is no way to measure the firm's stock of knowledge capital before 1982. Since the knowledge stock is unobservable before 1982, it must also be unobservable after 1982.

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stable for periods of 4 or more years.[17] For this reason, I assume that firms have the same value of beta at the beginning and end of the time period (five years). This means that, when first differencing, the beta (risk variable) drops out of the equation.[18]

If beta is a relevant variable and it is omitted, then the regression equation is misspecified.[19] In this case, R&D expenditures may be correlated with beta since outcomes due to R&D investment are subject to great uncertainty. Yet, it is relative expenditures, not absolute expenditures, that would suggest a higher beta. Therefore, we may expect R&D intensity (R&D expenditures as a percentage of firm size) to be correlated with beta. This may be important if R&D intensity varies over size classes, because the coefficients on R&D which measure the perceived effectiveness of R&D

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[17] A test of beta stationarity usually entails ranking firms by their beta coefficient and grouping them into quintiles. To evaluate the influence of the length of the subsequent estimation period on the stability of beta coefficients, betas are estimated for various lengths of subsequent periods. Transition matrices are established based on the firms ranking in the initial period and its ranking in subsequent periods (see Roenfeldt et al. (1978)).

[18]Even if firm betas were to be calculated, Harrington (1983) states that "betas vary greatly, even when they are calculated on the basis of historical returns." She also notes that the longer the time period in which beta is calculated, the better the forecast accuracy. Since investors are assumed to take all information into account when determining portfolios, one assumes that they analyze the most accurate beta available. Since the most accurate beta is one which utilizes a longer time horizon (as stated previously, usually 5 years), this, by definition, assumes that beta is constant over that period of time. This is not to say that beta <u>is</u> constant over a five year period; in fact, it is most likely that the change in beta is not equal to zero. This assumption implies that beta's are not expected to change drastically over this period.

[19] The implication of this is that biased and inconsistent estimates of the coefficients are obtained if there is a correlation between the omitted variable and the independent variables. If the variables are uncorrelated, the estimator will be unbiased, however, the variance of the coefficient will be biased (overstated). As such, the hypothesis that a coefficient is significantly different from zero may be rejected when that coefficient is significant.

expenditures may also include the effect of risk. I find no evidence that R&D intensity varies across size classes.

The proxy for risk--beta--is a measure of systematic risk. Alternatively, unsystematic risk can be taken into account by deflating firms' market value by a market index, which is discussed in detail in Appendix 1. This allows for the separation of increases in market value due to overall increases in the general level of the market compared with increases due to tangible and intangible asset investment.

To sum up, while risk does play a major role in market valuation, this effect can be factored out by assuming that unsystematic risk for a firm is constant over a 5 year period. In addition, industry conditions are taken into account by estimating coefficients for each industry separately. And unsystematic risk is taken into account by deflating the firm's valuation by a market index (see Appendix 1).

Beginning with equation 15 and first differencing:

$$V_{i,t} - V_{i,t-5} = \alpha + \gamma_1 \left(Assets_{i,t} - Assets_{i,t-5}\right) + \gamma_2 \sum_{t=T-5}^{t=T} RD_{i,t} + \gamma_3 \sum_{t=T-5}^{t=T} ADV_i \tag{16}$$

where:

$V_{i,t}-V_{i,t-5}$: the change in the market value of the firm over a five year period.

$Assets_{i,t}-Assets_{i,t-5}$: the change in the value of the firm's tangible assets.

ΣRD: sum of R&D expenditures over a five year period.

ΣADV: the sum of advertising expenditures over a five year period.

The model above characterizes the profitability of different types of capital investment on market valuation, but it does not indicate the relationship between firm size and capital effectiveness--specifically R&D profitability. Again, the true functional form of this relationship is unknown. I present two possible methods of modelling this relationship. The first is a relatively simple approach which involves including sales-intangible asset interaction terms. The second approach statistically tests for points of structural change.

2. FIRM SIZE - INTANGIBLE ASSET INTERACTION TERMS

A relatively simple way of testing the Schumpeter hypothesis is by applying a Taylor expansion to an unknown functional form:

SPECIFICATION 1:

$$V_{i;t}-V_{i;t-5}=\alpha_{i;t}+\gamma_1(ASSETS_{i,t}-ASSETS_{i;t-5})+\gamma_2\sum_{t=T-5}^{t=T}RD_{i,t}+ \gamma_3(Sales*\sum_{t=T-5}^{t=T}RD)_{i,t}+\gamma_4(Sales^2*\sum_{t=T-5}^{t=T}RD)_{i,t}+\gamma_5\sum_{t=T-5}^{t=T}ADV_{i,t}+ \gamma_6(Sales*\sum_{t=T-5}^{t=T}ADV)_{i,t}+\gamma_7(Sales^2*\sum_{t=T-5}^{t=T}ADV)_{i,t}+\epsilon_{i;t}$$

where:

$V_{i;t}-V_{i;t-5}$: the change in the market value of the firm over a five year period. $V_{i;t}-V_{i;t-5}$ is deflated by the change in a market index over the relevant time period. This controls both for systematic risk and general trends in the stock market (see Appendix 1).

$Assets_{i,t}$-$Assets_{i,t-5}$: the change in the value of the firm's tangible assets over a five year period.

ΣRD: sum of R&D expenditures over a five year period.

Sales*ΣRD: a firm size-R&D interaction term. Sales is a proxy for firm size.

$Sales^2$*ΣRD: controls for non-linearities in the relationship between firm size and the rate of return to R&D.

ΣADV: the sum of advertising expenditures over a five year period.

Sales*ΣADV: a firm size-advertising interaction term. Sales is a proxy for firm size.

$Sales^2$*ΣADV: controls for non-linearities in the relationship between firm size and the rate of return to advertising.

Size enters into the relationship between firm size and the stock response to R&D investment by means of the sales-R&D and $sales^2$-R&D interaction terms. The coefficient γ_1 represents the return to tangible assets. The Schumpeter hypothesis will be tested by means of evaluating the coefficients on the Sales-R&D interaction terms.

Including the sales-squared term forces the relationship between firm size and the stock response to R&D to be quadratic. There is evidence that there exist non-linearities in the relationship between firm size and R&D expenditures and patents (Scherer (1984), and Bound et al.(1984)). By including the squared term, I am able to test for this non-linear relationship. This specification is a variant of those used by previous studies which regress innovative inputs or outputs on a measure of firm size (see Chapter I). Note that

this specification assumes a continuous function.[20] Yet, it may be the case that the relationship between firm size and R&D profitability is not continuous. In other words, there may be a particular firm size such that the stock response to a firm with sales greater than that amount is significantly greater than (or less than) the stock response to R&D for a firm with sales less than that particular firm size--in other words, a threshold effect. In addition, this specification in not able to determine the definition of large and small firm size.

3. PARAMETER STABILITY

Ideally, one would like to first statistically determine whether there exist different size regimes. If this is found to be the case, one can then test for differences in R&D profitability by separating firms into these different size groups. In order to arrive at Specification 2, I relax the assumption of a continuous quadratic relationship. I first specifically test for points of structural change.

One method of testing for parameter stability is to perform the CUSUM and CUSUM of Squares statistical test (Brown, Durbin, Evans (1975)).[21] However, this test

[20] An alternative "simple" specification would be to divide firms into 2 or 3 equal size groupings. One could create dummy size-R&D (and Advertising) interaction variables. A t-test is then able to determine whether the stock response in large firms is significantly different from that in small firms. Yet, this specification a priori assumes a definition of large and small firms. Only by chance would one choose the "true" break points.

[21] An alternative test of the stability of the regression coefficients is "Chow's Predictive Test" (Kmenta (1986)), which is based on the F-statistic. However, this test is similar to Specification 3 (see Appendix 4), which assumes particular break points. This may lead to the rejection of the null hypothesis of different size regimes when more than one regime actually exists.

does not provide information on the point(s) at which parameter instability occurs, or which variable(s) cause the instability. In the case in which parameter stability is rejected, appropriate break points can then be determined by applying Quandt's (1958) log likelihood ratio test. Finally, the Schumpeter hypothesis can be tested by creating dummy size-interaction terms for n-1 of the n different size groups as determined by the log likelihood ratio test. For example:

SPECIFICATION 2:

$$\begin{aligned} V_{i,t} - V_{i,t-5} &= \alpha_{i,t} + DS_{i,t} + DL_{i,t} + \gamma_1 (Assets_{i,t} - Assets_{i,t-5}) + \\ & DS*\gamma_2 (Assets_{i,t} - Assets_{i,t-5}) + DL*\gamma_3 (Assets_{i,t} - Assets_{i,t-5}) + \\ & \gamma_4 \sum_{t=T-5}^{t=T} RD_{i,t} + \gamma_5 DS* \sum_{t=T-5}^{t=T} RD_{i,t} + \gamma_6 DL* \sum_{t=T-5}^{t=T} RD_{i,t} + \\ & \gamma_7 \sum_{t=T-5}^{t=T} ADV_{i,t} + \gamma_8 DS* \sum_{t=T-5}^{t=T} ADV_{i,t} + \gamma_9 DL* \sum_{t=T-5}^{t=T} ADV_{i,t} + \epsilon_{i,t} \end{aligned} \qquad (18)$$

where:

$V_{i,t}$-$V_{i,t-5}$: the change in the market value of the firm over a five year period. $V_{i,t}$-$V_{i,t-5}$ is deflated by the change in a market index over the relevant time period. This allows us to control for general trends in the stock market. See Appendix 1.

$Assets_{i,t}$-$Assets_{i,t-5}$: the change in the value of the firms tangible assets over a five year period.

An alternative test of parameter stability, which is also based on recursive residuals, is proposed by Harvey and Collier (Harvey (1981)).

The switching regressions model determines appropriate break points, but does not specifically test for parameter stability.

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ΣRD: sum of R&D expenditures over a five year period.

ΣADV: the sum of advertising expenditures over a five year period.

DS*ΣRD(and DS*ΣADV): Dummy interaction variables. DS=1 if annual sales are less than a specified value, which is different for each industry.

DL*ΣRD(and DL*ΣADV): Dummy interaction variables. DL=1 if annual sales are greater than a specified value, which is different for each industry.

Note that two break points (or three size regimes) are assumed to exist in the above specification (equation 18). This need not be the case--one break point, two break points, etc. may be found to exist.

For medium size firms, the stock response to R&D is γ_4. The stock response to R&D for small firms is the sum of the coefficients "$\gamma_4 + \gamma_5$"--the coefficients on $\Sigma RD_{i;t}$ + DS*$\Sigma RD_{i,t}$. For large firms, the stock response to R&D is the sum of the coefficients on $\Sigma RD_{i,t}$ + DL*$\Sigma RD_{i,t}$--$\gamma_4 + \gamma_6$. The standard error for the stock response to R&D in small firms is determined by:

$$Standard error(\hat{\gamma}_4+\hat{\gamma}_5)=\sqrt{s_4^2+s_5^2+2Cov(\hat{\gamma}_4,\hat{\gamma}_5)} \quad (19)$$

where s_4 is the standard error for the coefficient γ_4, and s_5 is the standard error for the coefficient γ_5. Similarly, the standard error for the stock response in large firms can be computed by substituting s_6 for s_5, and Cov(γ_4,γ_6) for Cov(γ_4,γ_5). A t-test can then be used to determine whether the stock response to R&D in large firms is significantly different that in small f

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4. PARAMETER TESTS:

The Schumpeter hypothesis of a positive relationship between firm size and R&D profitability is tested by means of analyzing the effect of firm size on R&D profitability.

a. SPECIFICATION 1

The effect of firm size on R&D profitability is tested by means of analyzing the mixed partial derivative (denoted Z) of the change in market valuation with respect to both firm size (sales) and the stock of R&D capital (ΣRD):

$$Z = \frac{\delta^2 (V_{i,t} - V_{i,t-5})}{\delta Sales \delta \Sigma RD} = \gamma_3 + 2\gamma_4 Sales \qquad (20)$$

Z signifies the effect of a one dollar increase in the stock of R&D holding sales constant; or the effect of a one dollar increase in sales holding the stock of R&D constant. It is used to show how this effect changes as firm size changes. In order to do this, interpretation of the signs on the independent variables--γ_3 and γ_4--is necessary. The sign on γ_3 indicates whether the change in valuation ($V_{i,t}$-$V_{i,t-5}$) as R&D increases is increasing or decreasing ($\gamma_3>0$ and $\gamma_3<0$, respectively) as firm size increases. The rate of change of this increase or decrease is represented by γ_4. If $\gamma_4<0$, this implies that the change in market valuation with respect to R&D is changing at a decreasing rate. On the other hand, $\gamma_4>0$ indicates that the change in market valuation with respect to R&D is changing at an increasing rate. If Z changes sign from positive to negative ($\gamma_3>0$ and $\gamma_4<0$), this means that the effect of firm size on R&D profitability changes from being a positive effect to a negative effect. Z could change from a negative effect to a positive effect ($\gamma_3<0$ and $\gamma_4>0$) as well. In testing the Schumpeter hypothesis, I evaluate how Z changes as firm size changes and whether Z is significantly different from zero. In order to evaluate the significance of Z, the standard error of Z--denoted S--is computed:

$$S=[Var(\gamma_3)+4*Sales^2*Var(\gamma_4)+4*Sales*Cov(\gamma_3,\gamma_4)]^{\frac{1}{2}} \quad (21)$$

Next, 95% confidence intervals are determined for Z ($Z\pm 2S$). This information is used in testing the Schumpeter hypothesis. If the upper confidence bound always lies above the zero axis, while the lower confidence bound always lies below the zero axis then Schumpeter is not supported regardless of the signs of γ_3 and γ_4. This scenario indicates that the effect of size on R&D profitability is not significantly different from zero. In order for size to have a significant effect, the lower and upper confidence bounds must either both lie above or below the zero axis for a range of firm size (not necessarily the entire range). Next I describe the four combinations of signs on γ_3 and γ_4 and explain the conditions in which Schumpeter is supported.

1. $\gamma_3>0$ and $\gamma_4>0$. This implies that as firm size increases the change in market valuation as R&D changes is increasing ($\gamma_3>0$) at an increasing rate ($\gamma_4>0$), see Figure 4. In Figure 4, both the upper and lower confidence bounds lie above the zero axis for the entire range of firm size, which indicates that the effect of size on R&D profitability is

increasing at an increasing rate (and is significantly different from zero).[22] Therefore, Schumpeter is supported.

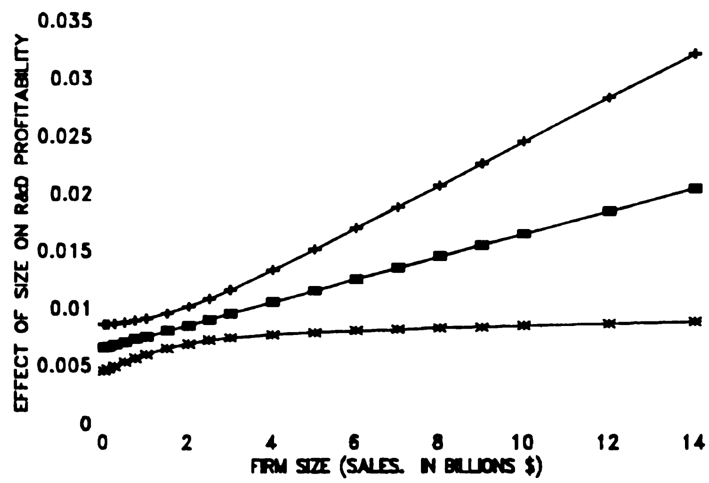

FIGURE 4: $\gamma_3>0$, $\gamma_4>0$; SCHUMPETER SUPPORTED

2. $\gamma_3>0$, $\gamma_4<0$. The effect of size on R&D profitability is increasing ($\gamma_3>0$), but at a decreasing rate ($\gamma_4<0$). If Z changes sign from positive to negative, then this would imply a threshold effect of firm size with respect to R&D profitability. Whether or not Schumpeter is supported depends upon the confidence bounds. For example, in Figure 5, for firms with sales less than the size corresponding to point X (approximately $7 billion in annual sales), size has a positive and significant effect on R&D profitability; as firm size increases, R&D profitability increases, albeit at a decreasing rate. However, for firms with sales greater than $7 billion, size does not have a significant effect on R&D profitability since the confidence bounds straddle the zero axis. Point Y corresponds to the firm size at which the effect of size on R&D profitability changes from a positive effect to a negative effect (in other

[22]Instead, if the lower confidence bound is below the zero axis while the upper confidence interval above, then Schumpeter would not be supported--size does not have a significant effect on R&D profitability. In other words, the rate of change in market valuation with respect to the sum of R&D expenditures and firm size does not significantly change as firm size increases.

words, as size increases R&D profitability now decreases). Figure 5 portrays a case in which the Schumpeter hypothesis is supported. R&D profitability increases as size increases, but after a certain point, size is not a significant determinant of R&D profitability. In other words, there exists a threshold effect of firm size with respect to R&D profitability (point X).

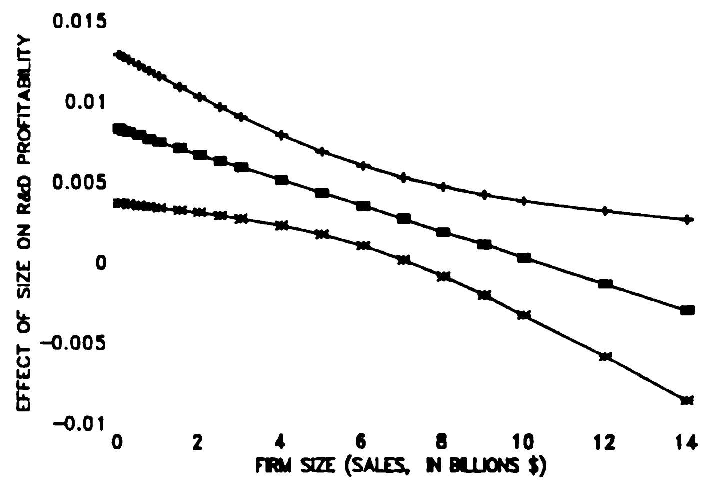

FIGURE 5: $\gamma_3>0$, $\gamma_4<0$; SCHUMPETER SUPPORTED

Of course, Schumpeter is also supported if the upper and lower confidence bounds both lie above the zero axis, which is similar to Figure 4 with the difference that the slope is now negative. This implies that the effect of size on R&D profitability is increasing as firm size increases (at a decreasing rate) and that this effect is significant. And since Z does not change sign, no threshold effect exists.

Yet, it is possible that the Schumpeter may not be supported when $\gamma_3>0$ and $\gamma_4<0$ (see Figure 6). The primary difference between Figures 5 and 6 is that the upper confidence bound in Figure 6 lies below the zero axis over a range of firm size. The interpretation of Figure 6 is similar to that of Figure 5. For firms with sales less than point X, R&D profitability is increasing at a decreasing rate, and this effect is nificantly different

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significantly different from zero. Between points X and Y(corresponding to approximately $9 billion to $12 billion in sales), the effect of size on R&D profitability is not significantly different from zero[23]. For firms with annual sales greater than Y (approximately $12 billion in annual sales), the effect of firm size on R&D profitability is negative and significantly different from zero. Therefore, Schumpeter is not supported in Figure 6 since size is found to have a negative and significant effect on R&D profitability.

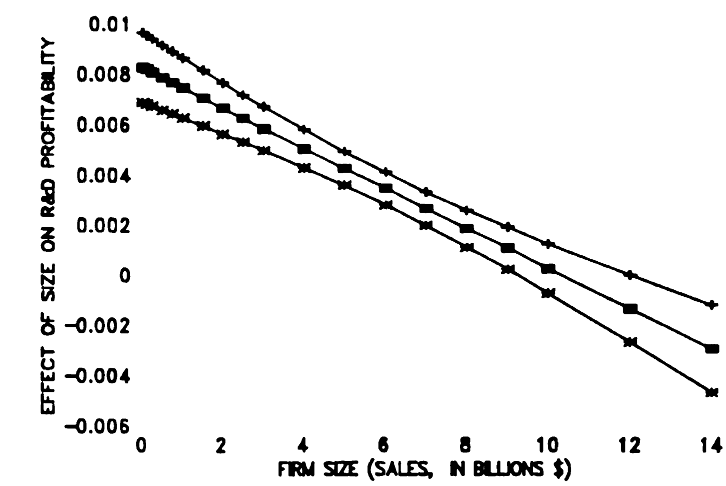

FIGURE 6: $\gamma_3>0$, $\gamma_4<0$; SCHUMPETER NOT SUPPORTED

3. $\gamma_3<0$ and $\gamma_4>0$. The effect of size on R&D profitability is decreasing at an increasing rate (see Figures 7 and 8). The Schumpeter hypothesis is supported only if the upper and lower confidence bounds lie above the zero axis for a range of firm size (Figure 7). In other words, Z changes sign and the effect of size on R&D profitability is positive and significantly different from zero. In reference to Figure 7, size has a negative and significant effect on R&D profitability for firms with annual sales less than the firm size associated with point X (approximately $4 billion in annual sales). At point

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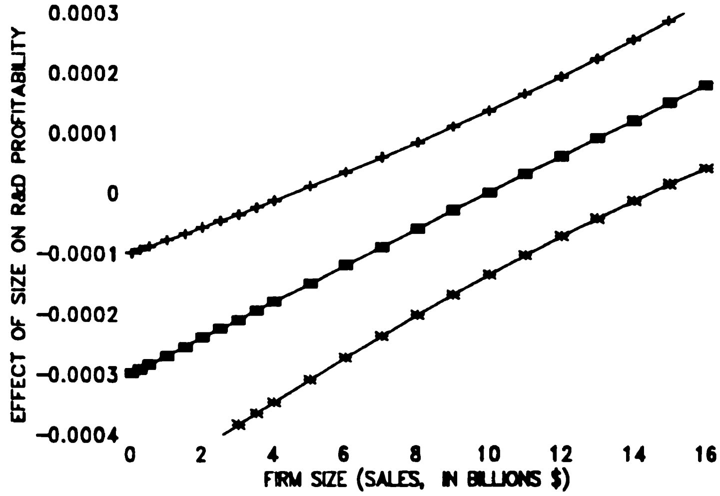

FIGURE 7: $\gamma_3<0$, $\gamma_4>0$; SCHUMPETER NOT SUPPORTED, SCENARIO A.

Y (approximately $9 billion in annual sales), the effect of size on R&D profitability changes from being negative to positive. However, the effect of size on R&D profitability is not significant between points X and Z. Only when firms are larger than the firm size associated with point Y (the point at which the lower confidence bound crosses the horizontal axis) is this effect both positive and significant. In Figure 7, there exists a threshold effect to the positive influence of size on R&D profitability. Since size has both a positive and a negative effect, Schumpeter is not supported. Now suppose that the lower confidence bound does not cross the zero axis (see Figure 8). This scenario also implies a threshold effect; size has a negative and significant effect on R&D profitability up to point X, then the effect of size on R&D profitability is not significantly different from zero. The effect of size on R&D profitability changes from negative to positive at point Y, however, it is not significantly different from zero. Since, as firm size increases, R&D profitability

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4. $\gamma_3<0$ and $\gamma_4<0$. This combination of signs implies that the Schumpeter hypothesis is not supported--regardless of the position of the confidence bounds. Yet, the confidence bounds provide an explanation why Schumpeter is not supported. For example, in Figure 9, for firms with annual sales less than point X (approximately $1 billion in annual sales), the effect of size on R&D profitability is not significantly different from zero. However, for firms with annual sales greater than X but less than Y (the point at which the upper confidence bound crosses the zero axis for the second time), as size increases R&D profitability decreases. Therefore, Schumpeter is not supported.

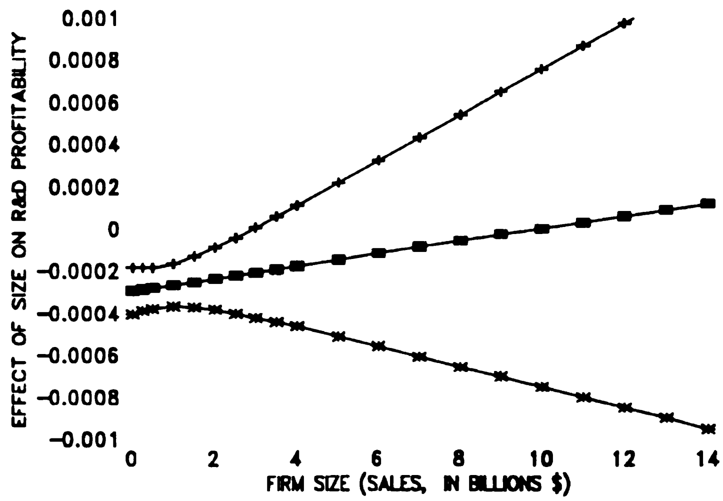

FIGURE 8: $\gamma_3<0$, $\gamma_4>0$; SCHUMPETER NOT SUPPORTED, SCENARIO B.

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[24] An alternative scenario is if the upper confidence bound lies above the zero axis and the lower confidence bound below. This implies that the effect of size on R&D profitability is not significantly different from zero, and therefore Schumpeter is not supported.

If the upper confidence bound always lies below the zero axis, the Schumpeter is not supported because size has a negative effect on R&D profitability. And if the upper confidence bound lies above the zero axis, Schumpeter is again not supported; size has no significant effect on R&D profitability.

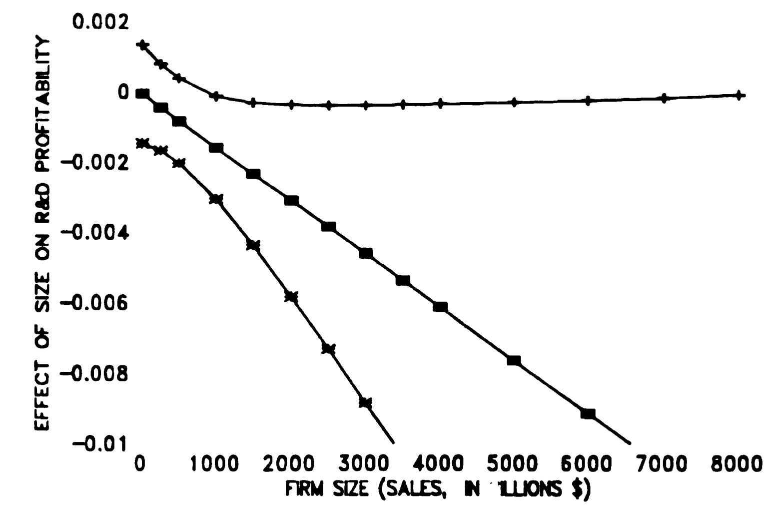

FIGURE 9: $\gamma_3<0$, $\gamma_4<0$;
SCHUMPETER NOT SUPPORTED

b. **SPECIFICATION 2:**

In this specification, size enters into the regression equation through dummy interaction terms (refer to equation 18). A t-test can be used to determine whether the stock response to R&D in large firms is significantly different from that in small firms. The Schumpeter hypothesis is supported if the stock response to R&D in the largest size class is significantly greater than the smaller size class(es). For example, if

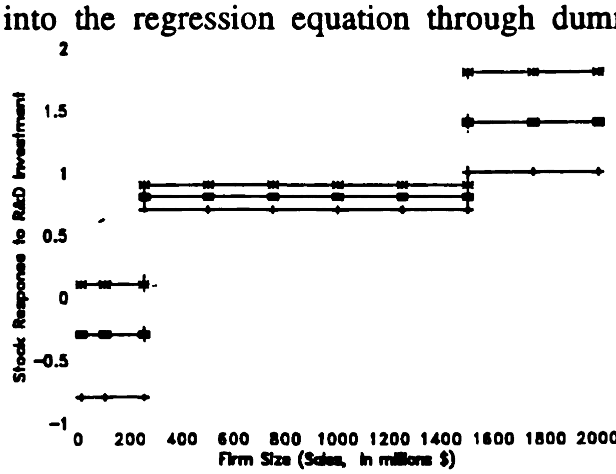

FIGURE 10: SPECIFICATION 2,
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Quandt's log likelihood ratio test indicates the existence of 3 size regimes, then the Schumpeter hypothesis would be supported if $\gamma_4+\gamma_6$ is significantly greater than $\gamma_4+\gamma_5$, and $\gamma_4+\gamma_6$ is significantly greater than γ_4(in other words, γ_6 is positive and significantly different from zero). If two size regimes are found to exist in an industry (γ_6DL*ΣRD would fall out of equation 18), then Schumpeter's hypothesis would be supported if $\gamma_4+\gamma_5$ is significantly less than γ_4 (that is, γ_5 is negative and significantly different from zero). This can be shown graphically by plotting the stock response to R&D investment on the vertical axis and firm size on the horizontal axis. Confidence bounds are plotted as well so that we can test for significance. For example, Schumpeter is supported in Figure 10 since the stock response to R&D is higher in larger firms than in both the medium and smaller size classes.

However, if size does not confer an advantage to R&D profitability, then either the CUSUM or CUSUM of Squares test cannot reject parameter stability or the CUSUM or CUSUM of Squares test rejects parameter stability, but the different size regimes that exist are not due to the stock response to R&D investment. In the case of the latter, this implies that the stock response to R&D investment in large firms is not significantly different from that in medium or small (or both) size regimes. That is, γ_5 and γ_6 are not jointly significant. The parameter instability may be due to the long-term profitability of advertising investment.

Alternatively, the Schumpeter hypothesis may not be supported because the long term profitability of R&D investment in small firms is greater than that in large firms. In this case both parameter stability would be rejected and the stock response to R&D in the largest size class would not be significantly greater than the smaller size class(es). For ample, if Quandt's log

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example, if Quandt's log likelihood ratio test determines that three size regimes exist, then small firms are more profitable in R&D if $\gamma_4+\gamma_5$ is significantly greater then $\gamma_4+\gamma_6$. If medium size firms are more profitable in R&D then large firms, then γ_4 is significantly greater than $\gamma_4+\gamma_6$. In other words, γ_6 is negative and significant. If two size regimes exist ($\gamma_6 DL^*\Sigma RD$ would fall out of equation 18), then small firms would be more profitable in R&D if $\gamma_4+\gamma_5$ is significantly greater than γ_4. That is, γ_5 is positive and significantly different from zero. An example of this scenario is shown in Figure 11.

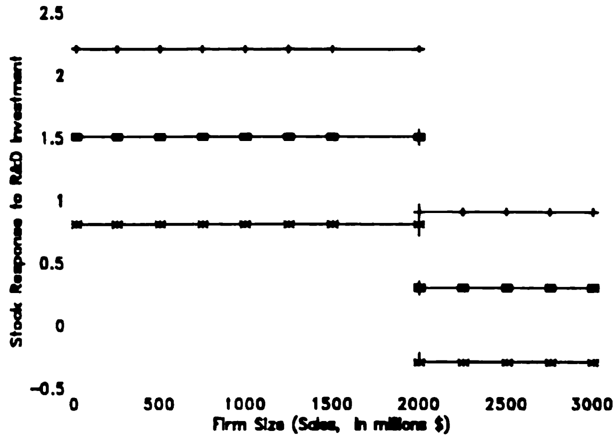

FIGURE 11: SPECIFICATION 2, SCHUMPETER NOT SUPPORTED

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Table 7

IV. RESULTS

This chapter begins with a description of the data. Next, I present regression results from specification 1 (firm size-intangible asset interaction terms). Third, I test for parameter stability using the CUSUM and CUSUM of Squares statistical test. If structural stability is rejected, I determine points of structural change and estimate specification 2, or a variant thereof.

A. DATA:

Estimation was performed on annual data from 1982-1989. Data were obtained from three Standard and Poor's Compustat data tapes: Industrial, Over the Counter, and Full Coverage. The Industrial file includes many large firms listed on the American and New York stock exchanges. The Over the Counter (OTC) tape includes companies traded over the counter, with inclusion criterion being that these firms must command significant investor interest. The Full Coverage tape includes companies traded on regional exchanges, wholly owned subsidiaries, and privately held companies. The firms are divided into five industries according to their Standard Industrial Classification (SIC). Table 7 presents a listing of the industries and the SIC code(s) for each industry. For

TABLE 7: INDUST

INDUSTRY
Computer
Industrial Machinery
Medical Equipment
Pharmaceutical
Semiconductor

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TABLE 7: INDUSTRIES USED IN ESTIMATION	
INDUSTRY	SIC CODE(S)
Computer	3570-3572 3575-3579
Industrial Machinery	3533, 3559, 3560, 3561
Medical Equipment	3841, 3842, 3844, 3845, 3851, 3861
Pharmaceutical	2834
Semiconductor	3674

each of the five sectors, Table 8 presents summary statistics: the mean and median R&D expenditures, advertising expenditures and market value, and the minimum, median, mean, and maximum firm size and R&D intensity (R&D expenditures/Sales). Comparing the mean and median firm size in each of the five industries, note that the distribution of firm size is skewed to the left. For example, in the computer industry the mean firm size is $2.9 billion, while the median is $131.5 million; in the semiconductor industry the mean is $607.6 million, while the median is only $121.1 million. The average R&D intensity for all sectors pooled is 9.4%. The lowest mean of R&D intensity occurs in the machinery industry (5.8%), while the highest mean occurs in the pharmaceutical industry (12.4%).

Information was obtained on a firm's market value, tangible assets, sales, R&D expenditures, and advertising expenditures. The criterion used in including observations is that all observations must report sales, assets at time t and time t-5, market value at time t and time t-5, and R&D expenditures over a five year period. Table 9 presents the total observations listed in the respective industries between 1987 and 1989 which report

R&D Expenditure
Mean:
Median:
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Mean:
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Market Va
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Median:
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TABLE 8
SUMMARY STATISTICS, IN MILLIONS $

	Comp	Mach	Medi	Phar	Semi	All
R&D Expenditures						
Mean:	$224.3	$26.0	$46.5	$222.7	$60.7	$65.9
Median:	8.9	7.2	1.8	144.0	9.9	8.6
Advertising expenditures						
Mean:	23.3	9.5	27.7	176.5	5.0	28.5
Median:	1.3	2.4	0.5	49.1	1.9	2.2
Market Value						
Mean:	1435.9	597.8	759.6	6351.6	821.5	1400.2
Median:	97.2	108.3	45.1	2448.5	100.1	117.0
Firm Size						
Minimum:	0.4	4.9	0.2	2.3	1.7	0.2
Median:	131.5	129.7	42.8	1153.2	121.1	118.1
Mean:	2877.6	715.4	176.0	2367.1	607.6	863.4
Maximum:	14000.0	7100.0	1810.0	9700.0	6500.0	23000
R&D Intensity						
Minimum:	0.6%	0.5%	0.7%	0.6%	0.3%	0.3%
Median:	7.7%	4.2%	5.6%	9.3%	8.5%	8.3%
Mean:	9.1%	5.8%	7.4%	12.4%	9.8%	9.4%
Maximum:	110.1%	17.9%	90.3%	42.1%	24.8%	110.0%

Comp: Computer Industry; Mach: Machinery Industry; Medi: Medical Equipment Industry; Phar: Pharmaceutical Industry; Semi: Semiconductor Industry; Firm Size: Annual Sales; R&D Intensity: R&D Expenditures/Sales

sales, the total number of observations included in the sample, and the number of observations reporting each of the statistics above. When comparing the number of one year statistics available (market value, assets, and R&D expenditures) with the number of 5 year statistics available ($V_{i,t}$-$V_{i,t-5}$, $Assets_{i,t}$-$Assets_{i,t-5}$, and ΣRD) it appears as if many observations are excluded because statistics are not available five years prior. This criterion is more likely to exclude relatively more smaller firms compared to larger firms. Table 10 presents the percentage of observations included in the sample with less than $1 million, $10 million, and $100 million in annual sales, R&D expenditures and firm size, before and after the filter process. From this table I find that the 5 year criterion does indeed exclude many so-called "small" firms, regardless of how small is defined. However, the data set still includes a relatively large percentage of small firms (less than $100 million in annual sales).[1]

[1] Many previous studies only included Fortune 500 firms.

TABLE 9: NU

Number of observations reporting:
Sales
Market Value
V_{it}-$V_{i,t-5}$
Assets
$Assets_{it}$-$Assets_{i,t-5}$
R&D
ΣRD
After Filter

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TABLE 9: NUMBER OF OBSERVATIONS REPORTING VARIOUS STATISTICS

Number of observations reporting:	Comp	Mach	Medi	Phar	Semi
Sales	595	246	299	202	145
Market Value	396	170	249	206	137
$V_{i,t}-V_{i,t-5}$	176	105	132	112	103
Assets	604	248	255	229	147
$Assets_{i,t}-Assets_{i,t-5}$	348	178	141	152	114
R&D	586	173	217	189	136
ΣRD	327	109	139	102	95
After Filter	165	74	132	79	92

$V_{i,t}-V_{i,t-5}$ is the change in market valuation over a 5 year period.

$Assets_{i,t}-Assets_{i,t-5}$ is the change in tangible assets over a five year period. R&D is R&D expenditures, ΣRD is the sum of R&D expenditures over a five year period. After filter is the number of observations included in the sample.

TABLE 10: SUMM

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Before Filter	
% < $1 million	[illegible]
% < $10 million	2
% < $100 million	7
Avg. R&D exp.	$7
Avg. R&D exp. over 5 years	$3
Mean annual sales	$28
Median annual sales	$
After Filte	
% < $1 million	
% < $10 million	
% < $100 million	
Avg. R&D exp.	
Avg. R&D exp. over 5 years.	
Mean Sales	
Median Sales	

% < X million is

annual sales.

TABLE 10: SUMMARY STATISTICS BEFORE AND AFTER FILTER

	Computer	Machinery	Medical Equipment	Pharma-ceutical	Semicon-ductor
Before Filter					
% < $1 million	4.55%	4.40%	5.69%	10.4%	2.07%
% < $10 million	21.34%	21.25%	36.45%	31.19%	16.55%
% < $100 million	70.81%	66.37%	90.10%	66.32%	69.01%
Avg. R&D exp.	$79.04	$20.06	$33.14	$108.72	$43.18
Avg. R&D exp. over 5 years	$379.04	$176.22	$206.41	$744.93	$282.23
Mean annual sales	$2877.61	$715.42	$556.85	$1168.92	$400.65
Median annual sales	$38.48	$27.87	$18.27	$69.07	$53.79
After Filter					
% < $1 million	1.87%	0.0%	0.71%	0.0%	0.0%
% < $10 million	11.87%	2.70%	17.42%	3.81%	10.87%
% < $100 million	39.43%	78.33%	77.62%	17.71%	47.89%
Avg. R&D exp.	$224.29	$26.03	$46.52	$222.66	$60.66
Avg. R&D exp. over 5 years.	$461.48	$147.86	$206.41	$920.88	$291.39
Mean Sales	$1300.00	$23.37	$176.79	$2367.11	$607.63
Median Sales	$131.47	$129.70	$42.78	$1153.20	$121.09

% < X million is the percentage of firms in the sample with less than $X million in annual sales.

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Assets: Book value

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$$A\hat{D}V_{i,t} = \alpha_{i,t}$$

A large number of firms do not report advertising expenditures for one year, or for a number of years. Instead of excluding these firms, an instrumental variable approach is used in order to predict advertising expenditures on the basis of a firm's sales, tangible assets, and R&D expenditure. First, I run regressions including only those firms that report positive advertising expenditures, for each industry separately. One such specification suggests that advertising expenditures are a function of firm sales, assets, and R&D expenditures:

$$A\hat{D}V_{i,t}=\alpha_{i,t}+\beta_1 Sales_{i,t}+\beta_2 Assets_{i,t}+\beta_3 RD_{i,t}+\epsilon_{i,t} \qquad (22)$$

ADV: Advertising expenditures of firm i at time t.

Assets: Book value of firm i's tangible assets at time t.

Sales: Sales revenue of firm i at time t.

R&D: R&D expenditures of firm i at time t.

Next, I compute a firm's predicted advertising expenditures based on the above estimated coefficients for those firms that do not report expenditures. I also tried the following additional specifications:

$$A\hat{D}V_{i,t}=\alpha_{i,t}+\beta_1 Sales_{i,t}+\beta_2 (Sales)^2{}_{i,t}+\beta_3 RD_{i,t}+\epsilon_{i,t} \qquad (23)$$

$$A\hat{D}V_{i,t}=\alpha_{i,t}+\beta_1 Assets_{i,t}+\beta_2 (Assets)^2{}_{i,t}+\beta_3 RD_{i,t}+\epsilon_{i,t} \qquad (24)$$

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Results do not differ significantly when employing the alternative specifications listed above. Further, when using the instrumental variable technique, estimated coefficients are similar to those obtained when I assume that if advertising expenditures are not reported, it is equal to zero.

As stated previously, I exclude those firms which do not report R&D expenditures. The primary reason for excluding these firms instead of assuming expenditures to be zero is due both to SEC reporting requirements and the manner in which Compustat handles company responses. The SEC requires disclosure of R&D expenditures when it is "material", exceeds 1% of sales, or a policy of deferral or amortization of R&D expenses is pursued. It is difficult, therefore, to distinguish between the responses "not available", "zero", "not significant", or "missing". For example, Bound et al. (1984) state:

> If accountants and their companies conclude that R&D expenditures were 'not material' (possibly zero but not necessarily), they sometimes say this in the 10-K report, in which Compustat records 'zero' or 'not significant'. Yet, a company may say nothing about R&D, in which case Compustat records 'not available'. It is also likely that companies reported as 'not available' include some which are 'randomly' missing, that is, a company performs 'material' R&D, but for some reason Compustat could not get the number for that year.

All firms included in this sample report positive R&D expenditures. I find that the majority of the firms that do not report R&D expenditures also do not report either sales, assets, or market value. If I assume that the missing observations are not available simply because of data reporting problems, then the least squares estimators will be unbiased and consistent, but there will be a loss of efficiency. If the missing observations are correlated with R&D failure, then the OLS estimates will be biased (overstated).

However, there is no a priori reason why this may be the case due to the SEC reporting requirements which were previously discussed.

B. ESTIMATION RESULTS: FIRM SIZE-INTANGIBLE ASSET INTERACTION TERMS

The null hypothesis of constant coefficients for the five industries is rejected at the 5% significance level, therefore a separate regression is estimated for each industry. This result suggests that even in this narrowly defined group of high-technology industries, constant coefficients cannot be assumed across industries. I use three different specifications in testing for constant coefficients. First is a basic model, which includes only the change in tangible assets, sum of R&D expenditures and sum of advertising expenditures over a five year period. Second is a model similar to specification 1; it includes firm size-intangible asset interaction terms. And third, I divide firms into three equal size groups, create dummy interaction terms, and test whether the stock response to R&D in the largest size category is significantly greater than the stock response in the smallest size category. This specification is similar to Specification 2. However, it assumes a priori a definition of large and small firm size, whereas Specification 2 statistically tests for break points. For details and results, see Appendix 2.

In addition, this data set includes three time periods so that each firm potentially has three observations within each industry (1982-1987; 1983-1988; 1984-1989). The null hypothesis of constant coefficients for the three time periods could not be rejected at the 5% significance level for all industries except the computer industry.[2] Yet, when the model is estimated separately for each time period in the computer industry, the coefficients are similar in sign and in magnitude to that when the data is pooled. Since more observations are available when combining time periods, I pool the data for all industries.

I performed some general specification tests that rejected the null hypothesis of homoskedasticity at the 5% level of significance.[3] All regression results presented have been corrected for heteroskedasticity using weighted least squares.[4] See Appendix 3 for a description of the technique used.

In this section I discuss results for each of the five industries studied. Results for this specification (equation 18) are presented at the end of this section in Tables 11 and 12 and Figures 12 - 17. The figures presented show the effect of size on R&D profitability, which is the cross partial derivative of the change in market valuation with respect to firm size and the R&D capital stock. The cross partial is shown on the vertical

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[2]

Computer:	F=6.05	$F_c(12,122)=2.34$
Machinery:	F=0.31	$F_c(12,37)=2.99$
Medical Equip.:	F=0.72	$F_c(8,87)=2.66$
Pharmaceutical:	F=1.15	$F_c(8,55)=2.82$
Semiconductor:	F=1.77	$F_c(8,68)=2.82$

[3]See Kmenta(1986), pg. 295.

[4] In some industries results differed depending on whether the sales squared term was or was not included (see Appendix 3).

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axis, while firm size is on the horizontal axis. In addition, Appendix 4 reports results for an alternative specification: dummy size-interaction terms.[5]

1. COMPUTER INDUSTRY

R&D profitability is increasing at a decreasing rate for firms with sales less than $31 billion (the point at which Z changes sign); see Figure 12. This means than R&D profitability increases as firm size increases, albeit at a decreasing rate. However, the effect of size on R&D profitability is significant only when annual sales are less than $6 billion (that is, when both the upper and lower confidence bounds are above the zero axis). For firms with sales between $6 billion and $54 billion, the effect of size is not significant since the confidence bounds straddle the zero axis. However, when sales are greater than $54 billion, the effect of size on R&D profitability is negative and significant--implying that as size increases, R&D profitability decreases.[6]

There are relatively few firms with annual sales greater than $20 billion, and these firms may be influencing results. When firms with annual sales greater than $20 billion

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[5] This alternative specification (dummy size-interaction terms) entails dividing firms into three equal size groups and then creating dummy size-R&D (and advertising) interaction variables. A t-test is then able to determine whether the stock response to R&D in large firms is significantly different from that in small firms. This specification is similar to Specification 2 (the parameter stability specification), however; there is one important difference. That difference is that this specification a priori assumes a definition of large and small firms; only by chance would one "choose" the true break points. This alternative specification, while simple, may lead one to reject the hypothesis that there exist different size regimes when, in fact, size regimes do exist. For details and results, see Appendix 4.

[6] This applies to only one firm: International Business Machines (IBM).

are excluded from the sample, R&D profitability increases at an increasing rate as firm size increases ($\gamma_3>0$ and $\gamma_4>0$); see Figure 13. However, size is a significant determinant to R&D profitability only when sales are between \$2 billion and \$4.5 billion. Since size has a positive and significant effect on R&D profitability for a range of firm size, Schumpeter is supported.

2. MACHINERY INDUSTRY

Size has a negative effect on R&D profitability, as indicated by the vertical intercept; see Figure 14. At a firm size of approximately \$2.7 billion in annual sales, this effect changes from a negative to a positive effect. This means that, for firms with annual sales less than \$2.7 billion, as size increases R&D profitability decreases, at an increasing rate($\gamma_4>0$). R&D profitability attains a minimum at \$2.7 billion, then R&D profitability increases as size increases. However, since the value of the upper confidence bound is greater than zero while the value of the lower confidence bound is less than zero, the effect of size on R&D profitability is not significantly different from zero and Schumpeter is not supported.

3. MEDICAL EQUIPMENT INDUSTRY

The effect of size on R&D profitability is positive up to a threshold point of \$800 million in annual sales (see Figure 15). This is shown by the positive vertical intercept and by both the value of the upper and lower confidence bounds greater than zero. The effect of siz

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effect of size on R&D profitability does turn negative at $900 million in annual sales (the point at which Z changes sign). However, since the value of the upper confidence bound is greater than zero while the value of the lower confidence bound is less than zero, size is not a significant determinant of R&D profitability. In short, R&D profitability increases as firm size increases, but only up to a point. Since size has a positive effect, Schumpeter is supported.

4. PHARMACEUTICAL INDUSTRY

Since the vertical intercept (γ_3) is positive and the slope (γ_4) is negative, this implies that as firm size increases, R&D profitability is increasing at a decreasing rate(see Figure 16). Z changes sign at a firm size of approximately $3.25 billion in annual sales which implies that the effect of size on R&D profitability becomes negative--as firm size increases, R&D profitability now decreases. Since the value of the upper confidence bound is greater than zero while the value of the lower confidence bound is less than zero, size is not a significant determinant of R&D profitability for firms with sales less than $4.8 billion. However, size has a negative and significant effect when firm size is between $4.8 billion and $6.3 billion (when the value of the upper confidence bound is less than zero). Size, again, does not have a significant effect on R&D profitability for firms larger than $6.3 billion. Since size has either a negative or insignificant effect on R&D profitability, Schumpeter is not supported.

5. S

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5. SEMICONDUCTOR INDUSTRY

Results from Specification 1 indicate that the effect of size on R&D profitability is negative(γ_3<0), see Figure 17. At a firm size of approximately $3 billion in annual sales this effect becomes positive (this is the point at which Z changes sign). This means that as size increases R&D profitability decreases for firms with less than $3 billion in sales, but increases for larger firms. However, since the value of the upper confidence bound is greater than zero while the lower bound is less than zero over the entire range of firm size, Schumpeter is not supported since the effect of size is not significantly different from zero.

In sum, the results from specification 1 indicate that in some industries, firm size is a significant determinant of the stock response to R&D investment. However, industries are not homogeneous; the influence of firm size varies across the 5 industries studied. In only one industry, however, is the Schumpeter hypothesis supported (two if the computer industry excluding firms with annual sales greater than $20 billion is included). One possible reason for the lack of support is the assumption of a continuous effect. It may be the case that the relationship between firm size and R&D profitability is not continuous, but is instead discontinuous. Therefore, I will try an alternative form which tests for stability in the parameters and is able to test take a discontinuous functional form into consideration.

TABLE 11: THE S
SALE

constant
$Assets_{i,t}$-$Assets_{i,t-5}$
ΣRD
Sales*ΣRD
$Sales^2$*ΣRD
ΣADV
Sales*ΣADV
$Sales^2$*ΣADV
N
R^2
F
df

Standard errors giv

*Significant at the

Variable Definitio

$Assets_{i,t}$-$Assets_{i,t-5}$:

ΣRD/ΣADV:Sum

Sales*ΣRD/ΣAD

$Sales^2$*ΣRD/ΣAD

TABLE 11: THE STOCK RESPONSE TO R&D INVESTMENT SALES-R&D INTERACTION TERMS

	Computer	Computer[1]	Machinery
constant	75.93**	83.78	-19.02**
	((0.66)	(126.24)	(4.33)
$Assets_{i,t}$-$Assets_{i,t-5}$	1.42**	1.54**	0.85
	(0.08)	(0.08)	(0.15)
ΣRD	-0.48	-0.53	1.26**
	(0.29)	(0.57)	(0.24)
Sales*ΣRD	0.3E-3	0.6E-3**	-0.5E-2*
	(0.1E-3)	(0.3E-3)	(0.03)
$Sales^2$*ΣRD	-0.5E-8	-0.5E-7*	0.1E-5*
	(0.2E-8)	(0.3E-7)	(0.9E-6)
ΣADV	-1.67	0.28	-0.34
	(1.27)	(2.05)	(1.27)
Sales*ΣADV	-0.1E-2	-0.2E-2	0.02**
	(0.9E-3)	(0.2E-2)	(0.8E-3)
$Sales^2$*ΣADV	0.2E-7	0.2E-6**	-0.5E-5*
	(0.2E-7)	(0.1E-6)	(0.3E-5)
N	164	158	73
$\bar{R}^2$	.76	.78	.69
F	75.57	82.63	23.60
df	7,157	7,152	7,66

Standard errors given in parentheses.

*Significant at the 10% level **Significant at the 5% level

Variable Definitions:

$Assets_{i,t}$-$Assets_{i,t-5}$: Change in the book value of tangible assets over a five year period.

ΣRD/ΣADV:Sum of R&D/advertising expenditures over a 5 year period.

Sales*ΣRD/ΣADV: Sales-R&D/advertising expenditure interaction terms.

$Sales^2$*ΣRD/ΣADV: $Sales^2$-R&D/advertising expenditure interaction terms.

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Variable

Assets

ΣRD/ΣA

Sales*ΣR

Sales²*Σ

TABLE 11, CONTINUED

	Medical Equipment	Pharmaceutical	Semiconductor
constant	-0.64 (3.86)	69.80** (34.99)	-24.67** (8.8)
$Assets_{i,t}$-$Assets_{i,t-5}$	1.07** (0.24)	0.50** (0.04)	0.83** (0.14)
ΣRD	-0.91 (0.60)	2.14** (0.70)	0.31 (0.47)
Sales*ΣRD	0.8E-2** (0.2E-2)	0.6E-3 (0.6E-3)	-0.8E-3 (0.8E-3)
$Sales^2$*ΣRD	-0.4E-5** (0.1E-5)	-0.8E-7 (0.7E-7)	0.1E-6 (0.1E-6)
ΣADV	-1.29 (1.16)	-1.65 (1.27)	6.09* (3.80)
Sales*ΣADV	-0.5E-2 (0.4E-2)	0.2E-3 (0.7E-3)	0.3E-2 (0.7E-2)
$Sales^2$*ΣADV	0.5E-5* (0.3E-5)	0.1E-7 (0.7E-7)	-0.5E-6 (0.1E-5)
N	111	79	79
R^2	.75	.90	.31
F	47.51	88.6	6.09
df	7,103	7,71	7,71

Standard errors given in parentheses.

*Significant at the 10% level **Significant at the 5% level

Variable Definitions:

$Assets_{i,t}$-$Assets_{i,t-5}$: Change in the book value of tangible assets over a five year period.

ΣRD/ΣADV:Sum of R&D/advertising expenditures over a 5 year period.

Sales*ΣRD/ΣADV: Sales-R&D/advertising expenditure interaction terms.

$Sales^2$*ΣRD/ΣADV: $Sales^2$-R&D/advertising expenditure interaction terms.

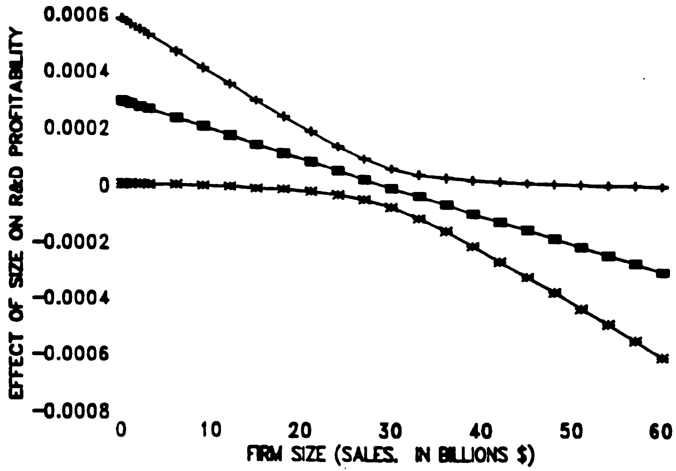

FIGURE 12: THE EFFECT OF SIZE ON R&D PROFITABILITY, COMPUTER INDUSTRY

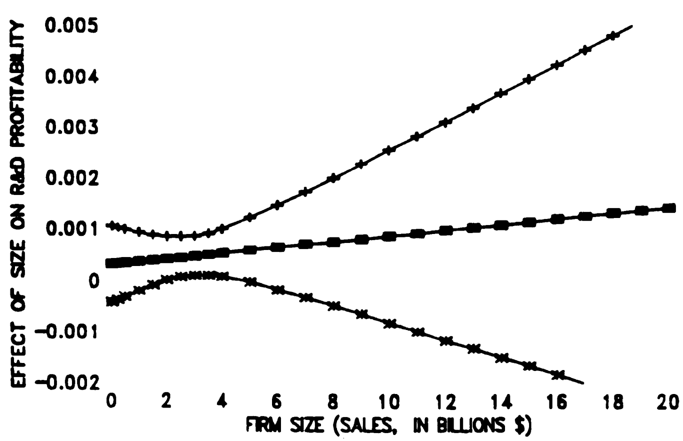

FIGURE 13: THE EFFECT OF SIZE ON R&D PROFITABILITY, COMPUTER INDUSTRY (EXCLUDING FIRMS WITH ANNUAL SALES >$20 BILLION)

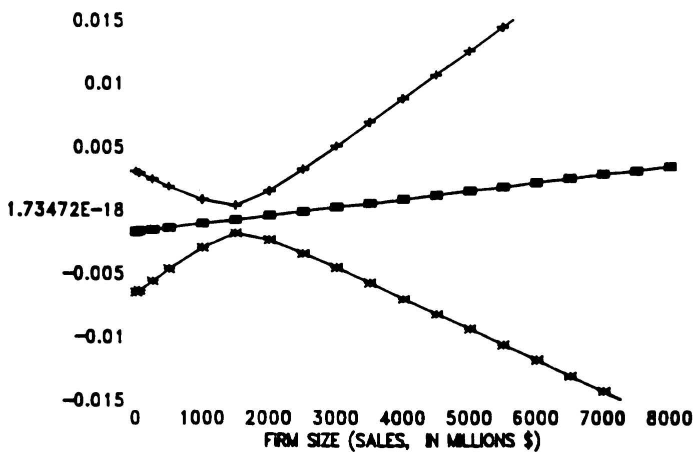

FIGURE 14: THE EFFECT OF SIZE ON R&D PROFITABILITY, MACHINERY INDUSTRY

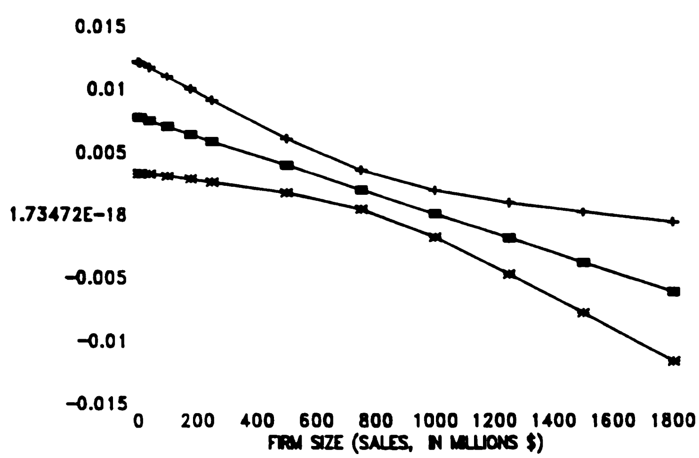

FIGURE 15: THE EFFECT OF SIZE ON R&D PROFITABILITY, MEDICAL EQUIPMENT INDUSTRY

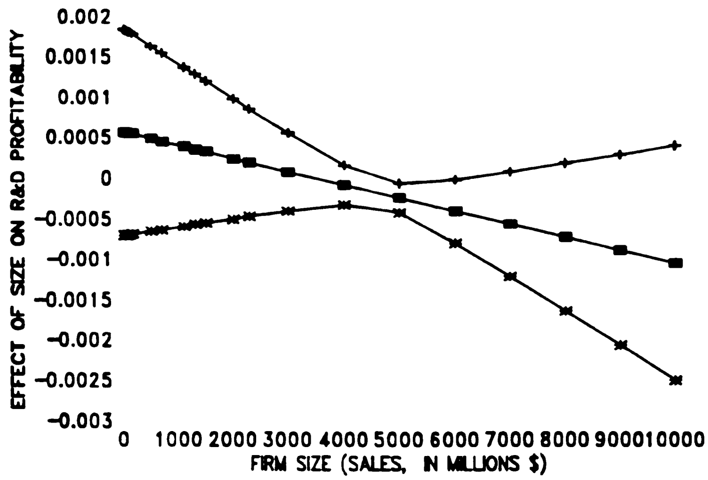

FIGURE 16: THE EFFECT OF SIZE ON R&D PROFITABILITY, PHARMACEUTICAL INDUSTRY

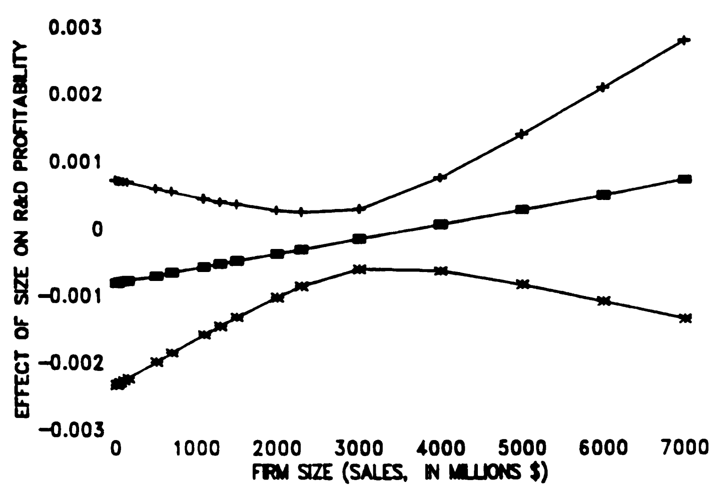

FIGURE 17: THE EFFECT OF SIZE ON R&D PROFITABILITY, SEMICONDUCTOR INDUSTRY

C. PARAMETER STABILITY

Results reported above need to be qualified in regard to the limitations imposed by assuming that the stock response to R&D investment is continuous over a ranking of firm size. In addition, specification 1 does not specifically test for a statistical definition of large and small firm size.

Ideally, one would like first to determine statistically whether there exist different size regimes. If this is the case, one can then test for differences in R&D profitability by separating firms into these different size groups. This allows a determination of firm size regimes from the data without assuming a priori knowledge of these regimes.

1. THE CUSUM AND CUSUM OF SQUARES TEST

Is the relationship between the change in firms' market value and tangible and intangible asset investment stable over firm size? The definition of stability refers to the estimated coefficients of the explanatory variables, and whether they remain constant over a ranking of firm size. Since the regression model assumes constancy of the regression coefficients for all sample observations, the model will be misspecified if these coefficients are not stable, and the model does not correct for this instability of the parameters. The relatively simple procedures for testing model stability are the F-test or dummy variables. However, these tests require prior knowledge of the point at which the change in the estimated coefficients is presumed to occur, knowledge which may not be obtainable. Another relatively simple method of detecting observations which diverge

from the model specification is an examination of residuals. However, a plot of OLS residuals, or a plot of their squares against the ordered variable[6] is not a sensitive indicator of small or gradual changes in the parameters (Brown et al. (1975)).

The CUSUM and CUSUM of Squares statistical tests developed by Brown, Durbin, and Evans (1975) can be used to test parameter stability over an index of firm size. These procedures and the procedures used to test for the points of structural change are preferred over F-tests or dummy variables because they do not require a priori knowledge of the point in which the function shifts. These statistical tests have usually been applied to time series data. However, they can be used to test for model stability in any data set that can be ranked (see Link (1981)). The null hypothesis (H_o) that all of the regression coefficients are stable over an index of firm size will be tested against the alternative (H_A) of parameter instability:

$$H_o: \quad \begin{array}{c} \gamma_1^1 = \gamma_1^2 = \ldots \gamma_1^N \\ \gamma_2^1 = \gamma_2^2 = \ldots \gamma_2^N \\ \gamma_3^1 = \gamma_3^2 = \ldots \gamma_3^N \\ \ldots \\ \ldots \end{array} \tag{25}$$

where the superscript refers to the observation number and the subscript refers to the coefficient in the regression equation.

[7] The ordered variable could be time in days, months or years in time-series studies. In this study, the ordered variable is sales, a proxy for firm size.

The procedure is as follows. First, the observations must be ranked in some manner. Because I am testing for parameter stability across firm size, the observations are sorted from the smallest firm size to largest. Next, a series of regressions are run in which the number of observations increases from k+1 to N, where k is the number of regressors and N is the total number of observations. The CUSUM and CUSUM of Squares require the calculations of one-period prediction residuals which are obtained by applying the regression computed with r-1 observations in order to predict the r^{th} observation using k explanatory variables. Let e_r be the forecast error: $e_r = y_r - x_r'\gamma_{r-1}$, where γ_{r-1} is the least squares coefficient vector computed using all observations up to (but not including) $y_r x_r$. For each regression the forecast error is calculated and normalized by its standard deviation:

$$w_r = \frac{y_r - x_r'\hat{\gamma}_{r-1}}{\hat{\sigma}} = \frac{y_r - x_r'\hat{\gamma}_{r-1}}{\sqrt{1 + x_r'(X_r'X_{r-1})^{-1}x_r}} \qquad r = k+1, \ldots N \tag{26}$$

where $X'_{r-1} = [X_1, \ldots X_{r-1}]$

The variable $w_{k+1}, \ldots w_N$ is a sequence of approximately normal variables such that $E(w_r) = 0$ (Brown et al. (1975)). The set of scaled residuals are independent and distributed $N(0,\sigma^2)$. The CUSUM test is based on the cumulative sum of these recursive residuals:

$$W_r = \sum_{r=k+1}^{r=N} \frac{w_r}{\hat{\sigma}^2} \qquad r = k+1, \ldots N \tag{27}$$

The significance of the departure of the sample path of W_r from its mean value line ($E(W_r) = 0$) is tested. If the structure of the equation changes over a ranking of firm size, this will result in a shift of the residuals when compared with a model assuming constant coefficients. If a structural shift occurs, a disproportionate number of recursive residuals would tend to have the same sign; this implies that the population errors are no longer centered at zero. In other words, if γ_r is constant up to observation $r=r_o$ and different from then on, W_r will have a mean zero up to r_o and nonzero mean from then on. If the CUSUM of residuals fall outside the confidence bounds, then H_o is rejected. These confidence bounds lie symmetrically above and below the line W_r such that the probability of crossing one or both lines is α, the significance level. Upper and lower confidence bounds are given by:

$$\pm \frac{a\sqrt{N-k} + 2a(r-k)}{\sqrt{N-k}} \qquad (28)$$

where N is the total number of observations in the sample, k is the number of regressors and a = 0.948 at the 5% significance level (Harvey, p. 152). Two graphical examples of the CUSUM test are shown in Figures 18 and 19. The values on the horizontal axis correspond to the observation number (not firm size). The values on the vertical axis correspond to the value of W_r--the cumulative sum of recursive residuals. Figure 18 portrays an example in which structural stability cannot be rejected by the CUSUM test.

On the other hand, in Figure 19 parameter stability is rejected; the test statistic lies outside its confidence bound (observation 13).

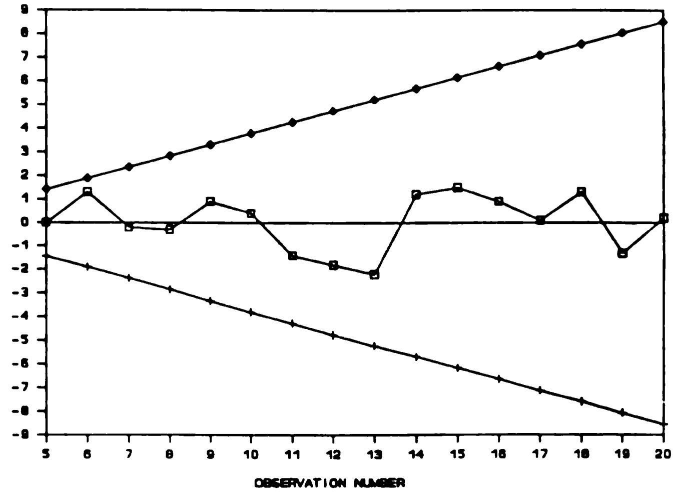

FIGURE 18: CUSUM TEST--PARAMETER STABILITY

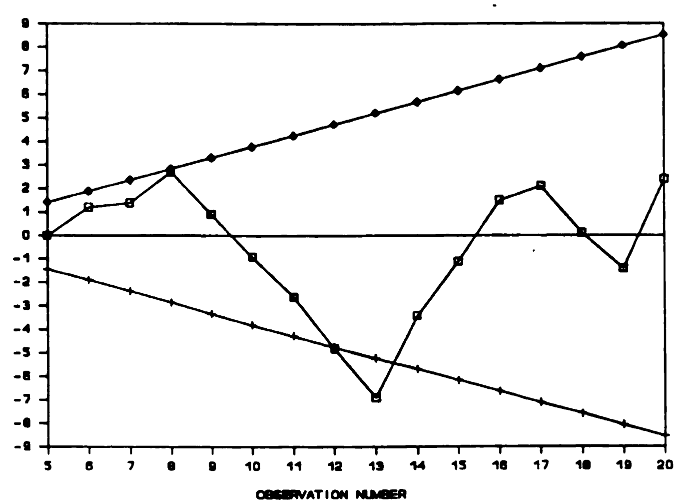

FIGURE 19: CUSUM TEST--PARAMETER STABILITY REJECTED

The CUSUM of squares test is based on the normalized cumulative sum of squared residuals from a recursive estimation model. The difference between the CUSUM and CUSUM of squares tests is that the CUSUM of Squares is stronger and more reliable than the CUSUM test (Link (1981) and Garbade(1977)). In addition, the CUSUM test is aimed at detecting mainly systematic and gradual movements in the coefficients, while the CUSUM of squares test detects mainly haphazard types of movements. In other words, the CUSUM of Squares test is better at detecting parameter instability if the relationship between firm size and the stock response to R&D is not continuous. The term haphazard refers to a discontinuous function. Although it is possible that both the CUSUM and CUSUM of Squares tests reject parameter stability. The two tests are independent and it is possible for one test to reject the null hypothesis while the other does not (for examples, see Brown, Durbin, and Evans (1975), and Stern, Baum and Greene (1979)).

The CUSUM of Squares test statistic (S_r) equals the value of the cumulative sum of w_r^2 up to observation r, divided by the cumulated sum of w_r^2 over the entire period:

$$S_r = \frac{\sum_{r=k+1}^{r} w_r^2}{\sum_{r=K+1}^{r=N} w_r^2} \qquad r=k+1,\ldots N \tag{29}$$

S_r follows a Beta distribution with mean: (r-k)/(N-k). The value of S_r will lie between zero and one: $S_r=0$ if $r<k+1$; $S_r=1$ if $r=N$. If the regression coefficients are constant,

S_r will lie along its mean value line within confidence limits $\pm c_o + (r-k)/(N-k)$.[7] Significance tests are performed by drawing the pair of lines which lie parallel to the mean-value line. If S_r crosses either of these significance lines, the null hypothesis of the constancy of the regression coefficients can be rejected. Again, the values on the horizontal axis correspond to the observation number. The values on the vertical axis correspond to the value of S_r. Figure 20 portrays an example of the CUSUM of Squares test which cannot reject the null hypothesis of parameter stability. While in Figure 21, parameter stability is rejected.

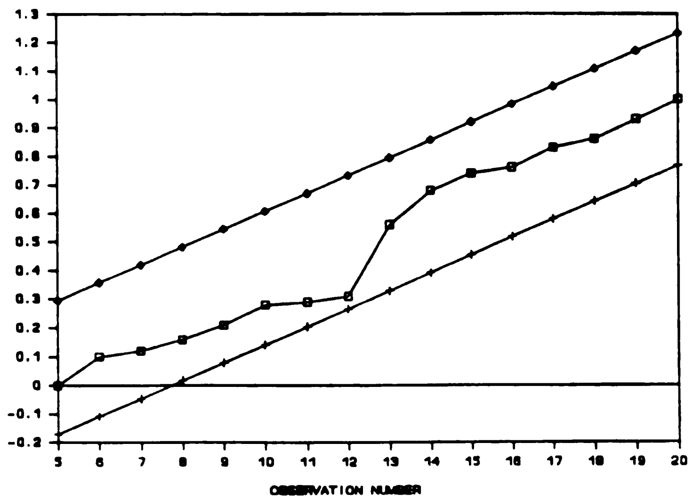

FIGURE 20: CUSUM OF SQUARES TEST--PARAMETER STABILITY

[8] The statistic c_0 is distributed as Pyke's modified Kolmogorov-Smirnov statistic (Brown et al. (1975), Harvey (1981)).

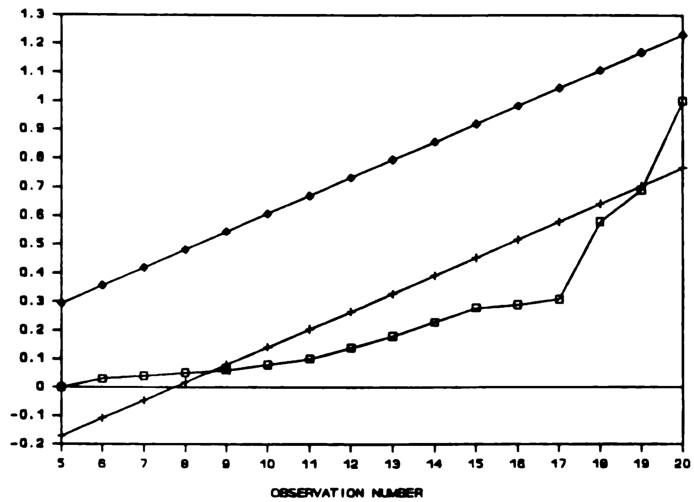

FIGURE 21: CUSUM OF SQUARES TEST: PARAMETER STABILITY REJECTED

There are two points to note about these tests. First, it can be said that the underlying structure made a significant shift at the point in which the observation fell outside the confidence bound and thus we can reject the null hypothesis of stability. This does not mean, however, that the shift occurred at this specific observation, only that the structure is then emerging as a significant change. The "true" point of structural change may have occurred before or after the observation which first crossed the confidence bound (Brown et al. (1975)). Quandt's log likelihood ratio test, which is described below, tests for the point at which the regression relationship changed abruptly. This test is used if the CUSUM of Squares test rejects parameter stability. If the CUSUM test rejects parameter stability, then interaction terms (Specification 1) will be better able to detect the true relationship. Second, if either the CUSUM and CUSUM of Squares reject parameter stability, it does not necessarily imply that parameter instability is due to differences in R&D profitability across firm size. These tests are not able to determine which parameters are or are not stable. All parameters must be examined to determine the explanatory variable(s) whose coefficients are unstable.

2. QUANDT'S LOG LIKELIHOOD RATIO TEST

If the CUSUM or CUSUM of squares test rejects the hypothesis of constant coefficients, then in order to determine the appropriate break point(s), Quandt's Log Likelihood Ratio technique is employed (Quandt (1958)). This technique is a standard likelihood ratio statistic for deciding between the two hypothesis H_0 and H_A, where H_0 is parameter stability. The likelihood ratio is defined as:

$$\lambda_r = \frac{L(\omega)}{L(\eta)} \tag{30}$$

Where $L(\omega)$ is the unrestricted maximum of the likelihood function over the entire parameter space ω, and $L(\eta)$ is the maximum of the likelihood function over the subspace $\eta \subset \omega$, which is restricted by the hypothesis.

The procedure is as follows. First, order the observations and divide the data into two mutually exclusive groups, beginning with group 1 including k+1 observations and N-(k+1) observations in group 2. Next, estimate the model for the two groups separately and calculate the likelihood value, which can be calculated by:

$$\lambda_r = -N\log\sqrt{2\pi} - n_1\log\hat{\sigma}_1 - n_2\log\hat{\sigma}_2 - \frac{N}{2} \tag{31}$$

Where N is the total number of observations in the sample and $n_1(n_2)$ is the number of observations in group 1(2). σ_1 (σ_2) is the standard error of the regression for group 1(2). Third, move the point of division between the two groups one unit to the right. For example, group one will now contain k+2 observations, and group 2, N-(k+2) observations. Again, calculate the likelihood value. This procedure is continued until group 1 contains N-(k+1) observations and group 2 contains k+1 observations. The points of the likelihood function are then plotted. The point at which the switch from one relationship to another occurs is then the observation number at r at which λ_r attains its maximum. From this information, the firm size at which structural change occurs can be determined.[9] The values on the vertical axis correspond to the values of the likelihood, while the values on the horizontal axis correspond to the firm size which divides the firm into the two regimes.

Yet, these points of maxima only indicate possible points of structural change. A sufficient test for structural change at a given point is given by Quandt (1960), in which the null hypothesis is that the regression equation obeys separate regimes. The test statistic is as follows:

$$\Phi = \frac{\hat{\sigma}_1^{n_1}\hat{\sigma}_2^{n_2}}{\hat{\sigma}_N} \qquad (32)$$

where σ is the estimated standard error of the regression, subscripts 1 and 2 denote the two different groups, N is the total number of observations, and n_1 /n_2 are the number of

[9] In some industries I found a point of structural change which was not at a global maximum.

observations in each group.[10] Under the null hypothesis, -2ln Φ is distributed χ^2, with the appropriate degrees of freedom.[11] If significant, then these points will be used in defining large and small firm sizes.

In sum, in order to account for qualifications of the results obtained in section B above, the following procedure is applied. First the CUSUM and CUSUM of Squares tests are performed in order to test for parameter stability across a ranking of firm size. If either the CUSUM or CUSUM of Squares test rejects parameter stability, Quandt's Log Likelihood Ratio test is performed in order to determine the point at which the structural change occurs. Quandt's (1960) test is used to corroborate these points. After determining appropriate break points, dummy size-interaction variables are constructed.[12] Finally, specification 2 is estimated, and the results obtained will allow for testing of the Schumpeter hypothesis.

3. ESTIMATION RESULTS, PARAMETER STABILITY

I will now present the results from the CUSUM, CUSUM of Squares, and Quandt's statistical tests, and final regression results for each of the industries.

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[10]Link (1981) has generalized this test statistic to include more than two regimes.

[11]Some reservations on the validity of this test are expressed by Quandt (1960).

[12] This specification is similar to that in Appendix 4, except that the distinction between large and small firms has been statistically determined.

a. COMPUTER INDUSTRY

The CUSUM test cannot reject the hypothesis of constant coefficients, however, the CUSUM of squares does(see Figures 22 and 23). Results from Quandt's log likelihood ratio test suggest that there exist possible points of structural change at both $180 million and $1900 million in annual sales(see Figure 24).[13] Dummy interaction variables are constructed using these break points and specification 2 is estimated (see Tables 12 and 13). Estimation results indicate that the stock response to R&D in both firms with sales less than $180 million and sales greater than $1.9 billion is not positive and significant, whereas, on average, the stock response to R&D is positive and significant.[14] This is portrayed graphically in Figure 25. Firm size is on the horizontal axis while the stock response to R&D is on the vertical axis. The value of the stock response is the middle line while the confidence bounds (stock response$\pm$2s) are the upper and lower lines. These results conform with evidence of industry conditions in which a few large firms experienced unusually high growth throughout the 1980s.[15] The negative and significant, or insignificant coefficient on R&D for large firms indicates that these firms' R&D programs were not perceived profitable by investors.

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[13] Both points are statistically significant when Quandt's (1960) test is employed: $-2\ln\phi=517.17$, $\chi^2_c(.01)=86.92$.

[14] The stock response to R&D for firms with sales less than $180 million is -3.04(s=4.35), while it is -0.36(s=0.26) in large firms.

[15] For example, in 1982, IBM had annual sales of $26.2 billion and by 1989 sales had doubled to $54.2 billion. Digital Equipment's sales increased over 300% and Wang's sales increased approximately 460% from 1982 to 1989.

These results can be reconciled with those from specification 1 by noting that the stock response to R&D increases, then decreases. Because specification 1 assumes that the function is continuous, it found that the most profitable firm size (in R&D) was less than $6 billion. Specification 2 statistically determines size regimes, and the least profitable firm size in R&D was determined to be greater than $1.9 billion. In sum, because the stock response to R&D in large firms is significantly lower than that in medium size firms, the Schumpeter hypothesis is not supported. As in Specification 1 however, the very large firms may be influencing these results. Quandt's log likelihood was not able to determine this point of structural change because there are too few observations for firms with sales greater than $20 billion to be included in the regresssion equation. Therefore, firms with annual sales greater than $20 billion are excluded from the sample. Quandt's log likelihood ratio test suggests three possible points of structural change: $180 million, $390 million, and $1.9 billion. Two of these break points are significant: $390 million and $1.9 billion. Dummy interaction variables are again constructed using these break points and Specification 2 is estimated. Results are given in Tables 12a and 13a and portrayed graphically in Figure 26.

These results indicate that the stock response to R&D investment is now positive and significant for large firms, indicating that these firms' R&D programs are perceived profitable by investors. Although large firms are more profitable than smaller firms in R&D, their stock response to tangible assets is not significantly different from zero. Also, the intercept term for the large firms is now negative and significant. This indicates that it was only the largest firms that grew so rapidly during the 1980s. One possible explanation for the insignificant coefficient on the R&D term for small firms is that,

because of low barriers to entry (relatively easy entry), small firms had to first "prove themselves" to the market. Once these firms grew to approximately $1.9 billion in sales, then investors realized that they would survive and valued their knowledge stock accordingly.

In sum, these results suggest that there are a few outliers in the computer industry which influence the results. The firms with sales greater than $20 billion grew rapidly during the 1980s, but their R&D programs were not profitable. On the other hand, the R&D programs of the firms with sales between $1.9 billion and $20 billion were perceived profitable by investors. Once these very large firms are excluded from the sample, I find support for the Schumpeter hypothesis. Large firms are more profitable in R&D than their smaller counterparts.

b. MACHINERY INDUSTRY

The CUSUM and CUSUM of squares tests both reject parameter stability.(see Figures 27 and 28). Test results from Quandt's log likelihood ratio test, which is presented graphically in Figure 29, indicate that there exist two points of structural change: $79 million and $308 million in annual sales.[16] Results suggest that both small firms (less than $79 million in sales) and large firms (greater than $308 million in sales) are more profitable in R&D than the "average" size firms; see Tables 14 and 15 and Figure 30. For small firms, the stock response to R&D ranges from 0.84 to 1.10(s=.34-

[16] χ_2=38.45, $\chi^2_{critical}$=86.92. The null hypothesis of structural change cannot be rejected.

.42), while it is 1.28(s=0.50) in large firms.[17] The stock response to advertising expenditures is not significantly different from zero for all of the size classes.[18]

Specification 1 does reveal a positive and effect of size on R&D profitability for larger firms. However, this effect is not significantly different from zero. Again, this highlights the problems with specification 1 in that it assumes that the function is continuous.

In short, R&D profitability is not significantly different in large firms compared with smaller firms. However, in both small and large firms, the stock response to R&D investment is greater than that in medium sized firms. Therefore, the Schumpeter hypothesis is not supported.

c. MEDICAL EQUIPMENT INDUSTRY

Parameter stability is rejected at the 5% significance level (see Figures 31 and 32). Results from Quandt's log likelihood ratio test indicate that there exists a structural change at $400 million in annual sales (Figure 33).[19] I separate firms into 2 separate regimes and estimate a variation of equation 19. Results indicate that the stock response to R&D is positive and significant in firms with sales greater than $400 million, while it

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[17] The hypothesis that the stock response to R&D in small firms is equal to that in large firms can not be rejected(s=.63).

[18] In addition, the constant term for the size classes differs. In small firms it is negative and significant, in medium size firms it is positive and significant, while in large firms it is not significantly different from zero.

[19] This point is statistically significant at the 5% level: $-2\ln \phi=718.93$, $\chi^2_c(.01)=86.92$. Therefore the null hypothesis of no structural change is rejected.

is not significantly different from zero for smaller firms; see Tables 16 and 17 and Figure 34. The stock response to advertising is not significantly different from zero for both small and large firms. In addition to the positive and significant coefficients on R&D, the constant term for large firms is also positive and significant, whereas in small firms it is not significantly different from zero. This indicates that there may be scale economies in which large firms have an advantage relative to smaller firms. On the other hand, the stock response to tangible asset investment is positive and significant for small firms, but not significantly different from zero for larger firms. Thus, in larger firms, the firm's stock of knowledge is more important than tangible assets. On the other hand, investors value these tangible asset investments in smaller firms.

Results here corroborate previous results, only now a statistical definition of large and small firms is determined. Both Specification 1 and Specification 2 find that there exists a threshold point to which size has a positive and significant effect on R&D profitability. In short, both specifications find support for the Schumpeter hypothesis.

d. PHARMACEUTICAL INDUSTRY

Both the CUSUM and CUSUM of squares test reject the hypothesis of parameter stability at the 5% significance level (see Figures 35 and 36). The results of Quandt's log likelihood ratio test indicate that there exist three possible points of structural change: $125 million, $200 million, and $700 million in annual sales (see Figure 37). Yet, Quandt's (1960) test indicates that only one of these points is statistically significant:

\$700 million in annual sales.[20] Firms are therefore separated into only 2 size categories: sales $\leq$ \$700 million and sales > \$700 million, and specification 2 is estimated. The estimation results are presented in Tables 18 and 19 and shown graphically in Figure 38. The results indicate that firms smaller than \$700 million in annual sales have a significantly higher stock response to R&D than larger firms. The stock response to R&D in smaller firms is between 4.25 and 6.41(s=0.9). The results also suggest that the stock response to advertising investment is not significantly different from zero for either of the firm size classes. By statistically determining whether parameter stability exists, and the break points for different size regimes, firm size is found to be a significant determinant of R&D profitability. In sum, Schumpeter's hypothesis does not hold in the pharmaceutical industry.

e. SEMICONDUCTOR INDUSTRY

Both the CUSUM and CUSUM of Squares tests cannot reject the hypothesis of structural stability, while the CUSUM of squares test rejects structural stability at the 5% level(see Figure 39 and 40). Results from Quandt's log likelihood ratio test reveals two possible points of structural change: \$40 million and \$42 million (see Figure 41). Both points are significant by themselves, but it is impossible to test whether structural change exists at both \$40 million and \$42 million due to insufficient degrees of freedom.

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[20] Test statistic: H_o: $-2\ln\phi=718.93$, $\chi^2_c(.01)=86.92$. Therefore the null hypothesis of no structural change is rejected.

Therefore, results for structural change occurring at $40 million are presented.[21] See Tables 20 and 21 and Figure 42.

Results indicate that smaller firms, those with annual sales less than $40 million, that the stock response to R&D that is not significantly different from zero. On the other hand, in regression number 2 and 3, the stock response to R&D in larger firms is negative and significantly different from zero. These results conform to the reality of the semiconductor industry in the 1970s when foreign competition almost wiped out the industry.

By performing the CUSUM test, statistical definitions of "large" and "small" firm size in this particular industry has been determined. Specification 1 found the stock response to R&D to be insignificant over the entire range. By testing for parameter stability and statistically determining break points the statistical definition of "large" and "small" firm size is determined and it is found that different size regimes exist. Thus again, in the semiconductor industry, the Schumpeter hypothesis is not supported.

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[21]Results from Quandt's test rejects the null hypothesis of no structural change at this point: $-2\ln \phi=171.11$, $\chi^2_c=86.92$.

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TABLE 12
PARAMETER STABILITY RESULTS: COMPUTER INDUSTRY

	1	2	3
constant	-23.48 (265.4)	-21.24 (227.7)	54.02 (132.4)
DS	28.08 (369.8)	27.37 (317.4)	
DL	1991.57** (346.6)	1843.27** (327.8)	
$Assets_{i,t}$-$Assets_{i,t-5}$	1.84** (0.34)	0.84** (0.1)	1.23** (0.1)
S($Assets_{i,t}$-$Assets_{i,t-5}$)	-0.60 (3.6)		
L($Assets_{i,t}$-$Assets_{i,t-5}$)	-1.06** (0.3)		
ΣRD	-0.04 (0.5)	1.20** (0.3)	0.80** (0.2)
SΣRD	-1.96 (6.1)	-3.17 (5.6)	-3.67 (4.0)
LΣRD	-1.93** (0.5)	-3.08 (0.4)	-0.94** (0.2)
ΣADV	-2.80 (1.4)	-2.53** (0.9)	-3.63** (0.7)
SΣADV	-0.78 (23.2)		
LΣADV	2.04 (1.9)		
R^2	.81	.75	.80
F	59.46	69.57	124.77
df	11,148	7,152	5,154

standard errors are in parentheses. **/* indicates significance at the 5%/10% level, respectively. DS and DL are dummy variables. DS=1 if annual sales are less than $180 million; 0 otherwise. DL = 1 if annual sales are greater than $1900 million; 0 otherwise.

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TABLE 13: SUMMARY OF COEFFICIENTS FOR SPECIFICATION 2 COMPUTER INDUSTRY

Stock Response to:	1	2	3
constant--small firms	4.60 (257.04)	6.14 (222.3)	
constant--average firms	-23.48 (0.09)	-21.24 (227.8)	54.03 (132.4)
constant--large firms	1967.52** (222.8)	1822.07** (268.2)	
tangible assets: small firms	1.24 (3.59)		
tangible assets: average firms	1.84** (0.34)	0.84** (0.1)	1.24** (0.1)
tangible assets: large firms	0.78** (0.05)		
R&D: small firms	-2.00 (6.03)	-1.97 (5.6)	-2.87 (4.0)
R&D: average firms	-0.04 (0.51)	1.20** (0.3)	0.80** (0.2)
R&D: large firms	-3.89** (0.18)	-1.88** (0.2)	-0.14 (0.2)
Advertising: small firms	-3.58 (23.16)		
Advertising: average firms	-2.80* (1.43)	-2.53** (0.9)	-3.43** (0.7)
Advertising: large firms	-0.76 (1.21)		
F	59.46	69.57	124.77
df	11,148	7,152	5,154
R^2	.81	.75	.80

Note: blank cells indicate that the stock response is the same as that to average firms (the coefficient is constrained to be zero).Small firms: <$180 million; Average: $180m.-$1.9b.; large: >$1.9b.

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TABLE 12a: COMPUTER INDUSTRY EXCLUDING FIRMS WITH ANNUAL SALES >$20 BILLION

	1	2	3
constant	-152.16	-176.39	86.74**
	(245.8)	(175.6)	(35.7)
DS	38.61	193.67	
	(252.2)	(173.5)	
DL	-5068.83**	-6763.70**	
	(1541.7)	(1279.9)	
$Assets_{i,t}$ - $Assets_{i,t-5}$	0.84	0.68**	1.22**
	(0.6)	(0.2)	(0.1)
S($Assets_{i,t}$ - $Assets_{i,t-5}$)	0.97		
	(0.6)		
L($Assets_{i,t}$ - $Assets_{i,t-5}$)	-0.48		
	(0.6)		
ΣRD	0.73	0.73	0.02
	(1.1)	(0.9)	(0.9)
SΣRD	-3.08**	-1.95*	-2.60**
	(1.2)	(1.0)	(1.1)
LΣRD	3.97**	4.16**	2.29**
	(1.3)	(1.0)	(0.9)
ΣADV	-1.13	0.46	-2.77**
	(2.0)	(1.2)	(1.1)
SΣADV	5.57**		
	(2.7)		
LΣADV	-0.89		
	(4.1)		
R^2	0.78	0.91	0.86
F	46.94	230.20	197.42
df	11,146	7,150	5,152
N	158	158	158

DS and DL are dummy variables. DS=1 if annual sales are less than $360 million; 0 otherwise. DL = 1 if annual sales are greater than $1900 million; 0 otherwise.

TABLE 13a: SUMMARY OF COEFFICIENTS FOR COMPUTER INDUSTRY (EXCLUDING FIRMS WITH SALES>$20 BILLION)

	1	2	3
constant--small firms	-113.55** (56.0)	17.28 (234.8)	
constant--average firms	-152.16 (245.8)	-176.39 (175.6)	86.74** (35.7)
constant--large firms	-5221.99** (1522.0)	-6940.08** (1269.7)	
tangible assets: small firms	1.81** (0.3)		
tangible assets: average firms	0.84 (0.6)	0.68** (0.2)	1.22** (0.1)
tangible assets: large firms	0.36 (0.2)		
R&D: small firms	-2.35** (0.6)	-1.22** (0.4)	-2.58** (0.6)
R&D: average firms	0.73 (1.1)	0.73 (0.9)	0.02 (0.8)
R&D: large firms	4.70** (0.8)	4.89** (0.4)	2.31** (0.3)
Advertising: small firms	4.44** (1.8)		
Advertising: average firms	-1.13 (2.0)	0.47 (1.2)	-2.77** (1.1)
Advertising: large firms	-2.02 (3.5)		
F	46.94	230.2	197.42
df	11,146	7,150	5,152
R^2	0.76	0.91	0.86

Note: blank cells indicate that the stock response is the same as that to average firms (the coefficient is constrained to be zero). Small firms: <$360m.; Average: $360m.-$1.9b.; large: >$1.9b.

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TABLE 14
PARAMETER STABILITY RESULTS: MACHINERY INDUSTRY

	1	2	3
Constant	42.84*	42.55**	49.58**
	(25.6)	(24.1)	(23.7)
DS	-64.33**	-64.07**	-70.11**
	(26.4)	(25.2)	(24.5)
DL	-125.60	-125.34	-130.69
	(223.8)	(222.1)	(226.5)
$Assets_{i,t}$-$Assets_{i,t-5}$	0.50**	0.50**	0.50**
	(0.1)	(0.1)	(0.1)
S($Assets_{i,t}$-$Assets_{i,t-5}$)	0.24		
	(0.2)		
L($Assets_{i,t}$-$Assets_{i,t-5}$)	0.00		
	(0.1)		
ΣRD	-1.11*	-1.11*	-1.10*
	(0.6)	(0.6)	(0.6)
SΣRD	2.00**	1.94**	2.01**
	(0.7)	(0.7)	(0.7)
LΣRD	2.39**	2.39**	2.38**
	(0.8)	(0.8)	(0.7)
ΣADV	-0.54	-0.52	-1.29
	(1.5)	(1.56)	(0.9)
SΣADV	0.10	1.85	
	(4.8)	(4.9)	
LΣADV	-0.78	-0.80	
	(2.1)	(2.2)	
R^2	.55	.57	.58
F	9.12	11.56	15.32
df	11,62	9,64	7,66

DS and DL are dummy variables. DS=1 if annual sales are less than $79 million; 0 otherwise. DL = 1 if annual sales are greater than $308 million; 0 otherwise.

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TABLE 15: SUMMARY OF COEFFICIENTS FOR THE MACHINERY INDUSTRY

Stock Response to:	1	2	3
constant--small firms	-21.49** (6.5)	-21.52** (7.3)	-21.53** (7.0)
constant--average firms	42.84* (25.6)	42.54** (1.8)	49.58** (24.5)
constant--large firms	-82.79 (222.3)	-82.80 (222.3)	-81.11 (220.4)
tangible assets: small firms	0.75** (0.2)		
tangible assets: average firms	0.50** (0.1)	0.50** (0.1)	0.50** (0.1)
tangible assets: large firms	0.50** (0.1)		
R&D: small firms	0.84** (0.3)	0.83** (0.4)	1.10** (0.4)
R&D: average firms	-1.11* (0.6)	-1.11* (0.6)	-1.10** (0.6)
R&D: large firms	1.28** (0.5)	1.28** (0.5)	1.28** (0.5)
Advertising: small firms	-0.44 (4.6)	1.33 (4.7)	
Advertising: average firms	-0.54 (1.5)	-0.52 (1.6)	-1.29 (0.9)
Advertising: large firms	-1.32 (1.4)	-1.32 (1.4)	
F	9.12	11.56	15.32
df	11,62	9,64	7,66
R^2	.55	.57	.58

Note: blank cells indicate that the stock response is the same as that to average firms.

Small firms: <$79m.; Average: $79m.-$308m.; large: >$308m.

TABLE 16
PARAMETER STABILITY RESULTS: MEDICAL EQUIPMENT INDUSTRY

	1	2	3
constant	985.34**	985.49**	-0.41
	(294.5)	(294.2)	(6.7)
DS	-989.40**	-989.30**	
	(294.4)	(294.6)	
$Assets_{i,t}-Assets_{i,t-5}$	0.12	0.12	0.65**
	(0.2)	(0.2)	(0.1)
$S(Assets_{i,t}-Assets_{i,t-5})$	1.16**	1.16**	
	(0.3)	(0.3)	
ΣRD	1.33**	1.33**	1.06**
	(0.3)	(0.6)	(0.4)
SΣRD	-1.43*	-1.55**	-1.03**
	(0.7)	(0.6)	(0.5)
ΣADV	-0.80**	-0.81	-0.70
	(1.1)	(1.1)	(0.5)
SΣADV	-0.61		-0.44
	(1.2)		(0.8)
R^2	.78	.78	.55
F	67.92	79.86	32.79
df	7,124	6,125	5,126

standard errors are in parentheses.

**/* indicates significance at the 5%/10% level, respectively.

DS is a dummy variable. DS=1 if annual sales are less than $400 million; 0 otherwise.

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TABLE 17
SUMMARY OF COEFFICIENTS FOR SPECIFICATION 2: MEDICAL EQUIPMENT INDUSTRY

Stock Response to:	1	2	3
constant--small firms	-4.12 (7.3)	-3.85 (7.4)	
constant--large firms	985.34** (294.5)	985.49** (294.3)	-0.41 (6.7)
tangible assets: small firms	1.28** (0.2)	1.27** (0.2)	
tangible assets: large firms	0.12 (0.2)	.12 (0.2)	0.65** (0.1)
R&D: small firms	-0.10 (0.3)	-0.22 (0.4)	0.03 (0.3)
R&D: large firms	1.33* (0.6)	1.33** (0.6)	1.06** (0.4)
Advertising: small firms	-1.42 (1.4)		-1.14** (0.6)
Advertising: large firms	-0.80 (1.2)	-0.81 (1.1)	-0.44 (0.8)
F df	67.92 7,124	79.87 6,125	75.53 5,126
R^2	.78	.78	.74

standard errors are given in parentheses.

**/* indicates significance at the 5%/10% level, respectively.

Note: blank cells indicate that the stock response is the same as that to large firms (the coefficient is constrained to be zero). Small firms: <$400m.; large firms: >$400m.

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TABLE 18
PARAMETER STABILITY RESULTS: PHARMACEUTICAL INDUSTRY

	1	2	3
Constant	244.09	49.72	39.48
	(1163.1)	(44.4)	(47.0)
DS	-113.06		
	(1163.6)		
$Assets_{i,t}-Assets_{i,t-5}$	0.79	0.91	0.39**
	(1.02)	(0.8)	(0.2)
$S(Assets_{i,t}-Assets_{i,t-5})$	-0.38	-0.54	
	(1.0)	(0.8)	
ΣRD	1.16	1.03	1.44**
	(1.0)	(0.8)	(0.6)
SΣRD	3.09**	5.28**	4.97**
	(1.3)	(1.2)	(1.0)
ΣADV	0.07	0.07	0.13
	(0.8)	(0.7)	(0.7)
SΣADV	-3.87**	-2.15	-2.21
	(1.1)	(1.4)	(1.5)
R^2	.95	.63	.63
F	198.03	23.25	27.58
df	7,71	6,72	5,73

standard errors are in parentheses.

**/* indicates significance at the 5%/10% level, respectively.

DS is a dummy variable. DS=1 if annual sales are less than $700 million; 0 otherwise.

TABLE 19
SUMMARY OF COEFFICIENTS FOR SPECIFICATION 2: PHARMACEUTICAL INDUSTRY

Stock Response to:	1	2	3
constant--small firms	113.03** (11.7)		
constant--large firms	244.09 (1163.1)	49.72 (44.4)	39.48 (47.0)
tangible assets: small firms	0.41** (0.2)	0.37** (0.1)	
tangible assets: large firms	0.79 (1.0)	0.91 (0.8)	0.39** (0.2)
R&D: small firms	4.25** (0.9)	6.31** (0.9)	6.41** (0.9)
R&D: large firms	1.16 (1.0)	1.03 (0.8)	1.44** (0.6)
Advertising: small firms	-3.80** (0.8)	-2.08* (1.3)	-2.08* (1.3)
Advertising: large firms	0.07 (0.8)	0.07 (0.7)	0.13 (0.7)
F	98.03	23.25	27.58
df	7,71	6,72	5,73
R^2	.95	.63	.63

standard errors are given in parentheses.

**/* indicates significance at the 5%/10% level, respectively.

Note: blank cells indicate that the stock response is the same as that to large firms (the coefficient is constrained to be zero).

Small firms: <$700m.; large firms: >$700m.

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TABLE 20
PARAMETER STABILITY RESULTS: SEMICONDUCTOR INDUSTRY

	1	2	3
constant	-187.91**	-105.35**	-50.06**
	(108.9)	(5.3)	(5.9)
DS	183.47		43.21
	(480.0)		(35.6)
$Assets_{i,t}$-$Assets_{i,t-5}$	0.46**	1.84**	0.69**
	(0.1)	(0.2)	(0.1)
S($Assets_{i,t}$-$Assets_{i,t-5}$)	-8E-3		
	(27.8*		
ΣRD	-1.22	-0.68**	-0.32**
	(45.6)	(0.1)	(0.1)
SΣRD	0.74	3.96*	-1.76
	(0.7)	(2.4)	(3.34)
ΣADV	9.77	-1.81	2.49**
	(60.2)	(1.5)	(1.4)
SΣADV	3.50	17.49	16.54
	(3.0)	(41.0)	(42.84)
R^2	.80	.73	.87
F	54.07	50.89	102.85
df	7,84	5,86	6,85

standard errors are in parentheses.

**/* indicates significance at the 5%/10% level, respectively.

DS is a dummy variable. DS=1 if annual sales are less than $40 million; 0 otherwise.

TABLE 21
SUMMARY OF COEFFICIENTS FOR SPECIFICATION 2: SEMICONDUCTOR INDUSTRY

Stock Response to:	1	2	3
constant--small firms	4.44 (467.5)		-6.84 (35.2)
constant--large firms	-187.9* (108.9)	-105.35** (5.3)	-50.10** (5.9)
tangible assets: small firms	0.45** (27.8)		
tangible assets: large firms	0.46** (0.1)	1.84** (0.2)	0.69** (0.1)
R&D: small firms	-1.96 (45.5)	3.35 (2.7)	-2.08 (3.4)
R&D: large firms	-0.74 (0.7)	-0.68** (0.1)	-0.32** (0.1)
Advertising: small firms	13.27 (602.9)	16.32 (45.4)	19.03 (42.8)
Advertising: large firms	3.50 (3.0)	-2.02 (1.6)	2.49** (1.4)
F df	54.07 7,84	50.89 5,86	102.85 6,85
R^2	.80	.73	.87

standard errors are given in parentheses.

**/* indicates significance at the 5%/10% level, respectively.

Note: blank cells indicate that the stock response is the same as that to large firms (the coefficient is constrained to be zero).

Small firms: <$40m.; large firms: >$40m.

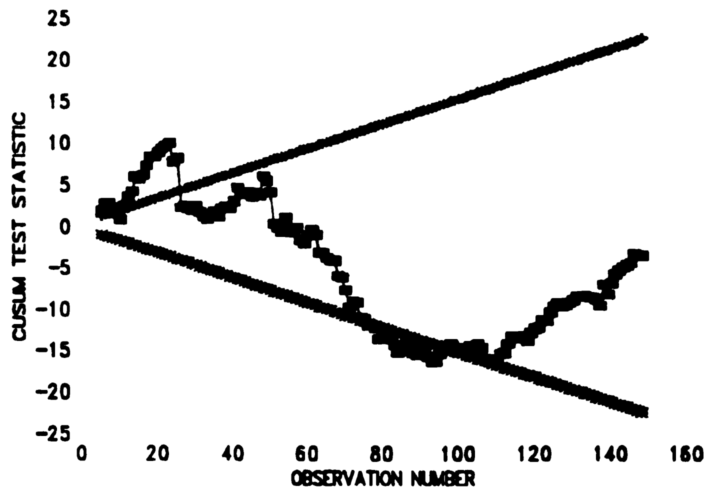

FIGURE 22: CUSUM TEST--COMPUTER INDUSTRY

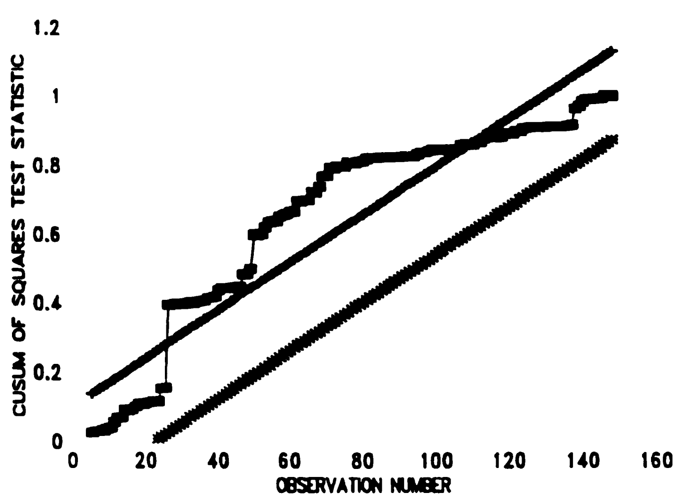

FIGURE 23: CUSUM OF SQUARES TEST--COMPUTER INDUSTRY

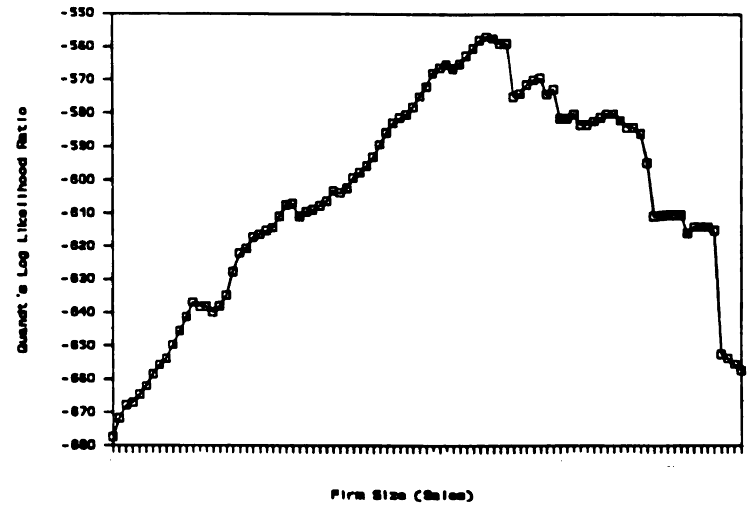

FIGURE 24: QUANDT'S LOG LIKELIHOOD RATIO TEST--COMPUTER INDUSTRY

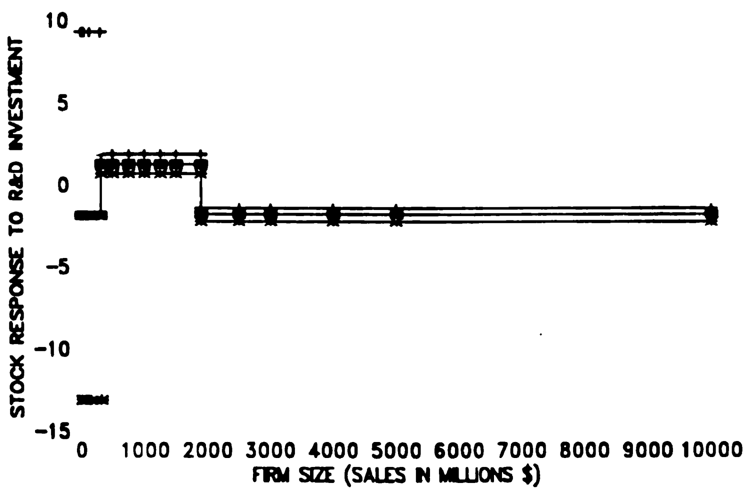

FIGURE 25: THE STOCK RESPONSE TO R&D INVESTMENT--COMPUTER INDUSTRY

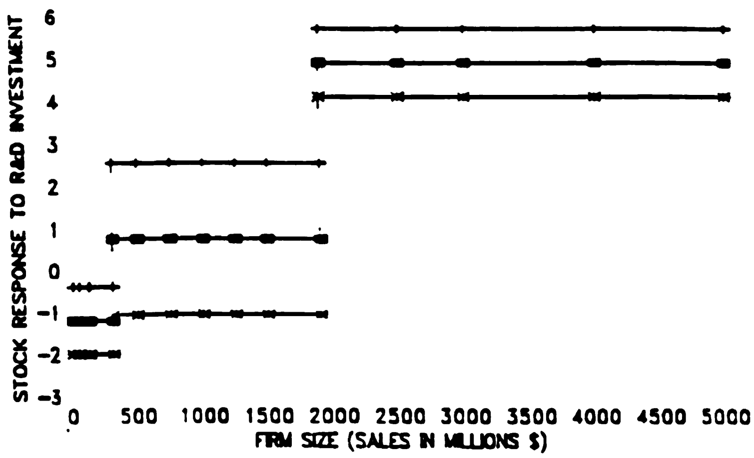

FIGURE 26: THE STOCK RESPONSE TO R&D INVESTMENT--COMPUTER INDUSTRY (EXCLUDING FIRMS WITH SALES > $20 BILLION)

FIGURE 27: CUSUM TEST--MACHINERY INDUSTRY

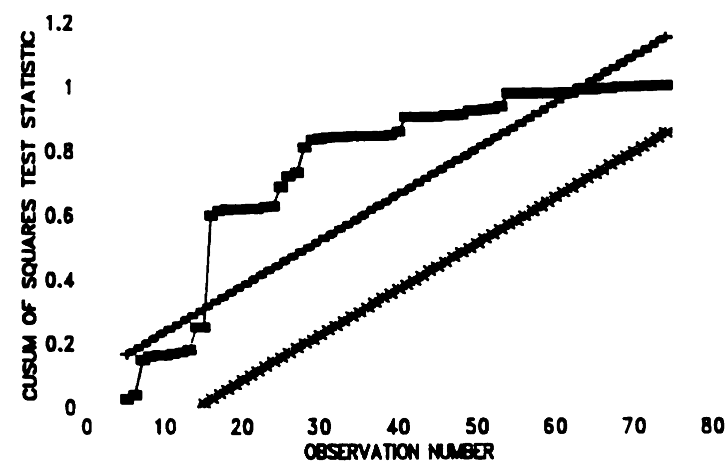

FIGURE 28: CUSUM OF SQUARES TEST--MACHINERY INDUSTRY

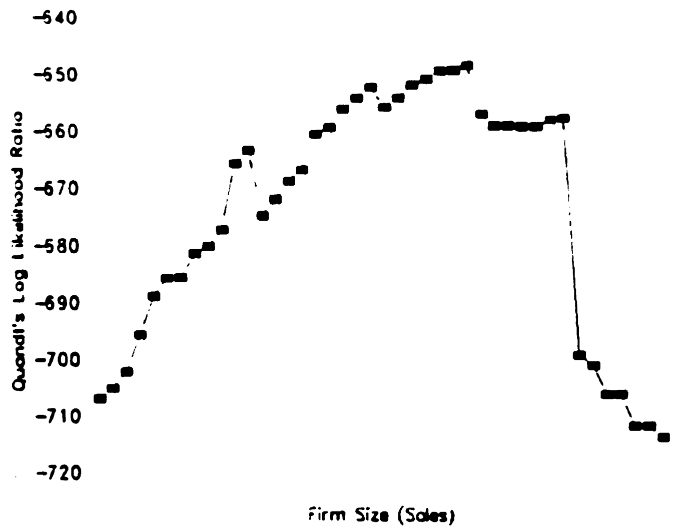

FIGURE 29: QUANDT'S LOG LIKELIHOOD RATIO TEST--MACHINERY INDUSTRY

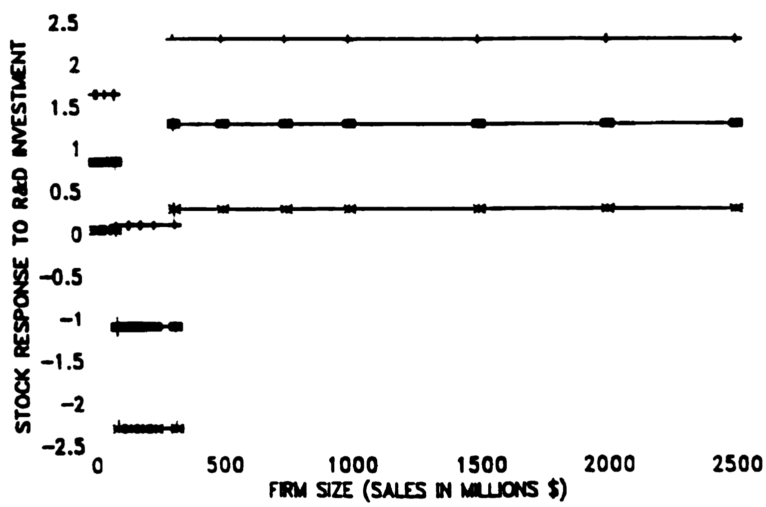

FIGURE 30: THE STOCK RESPONSE TO R&D INVESTMENT--MACHINERY INDUSTRY

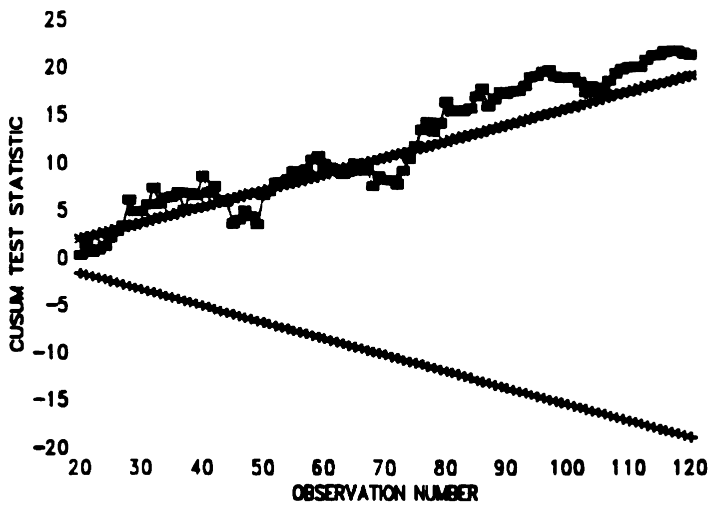

FIGURE 31: CUSUM TEST--MEDICAL EQUIPMENT INDUSTRY

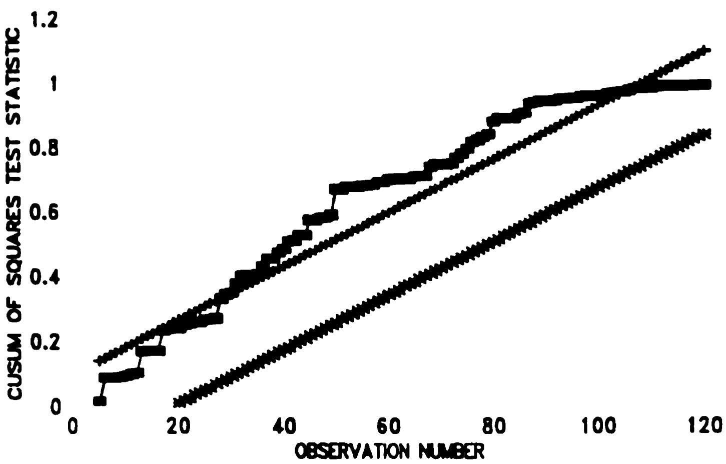

FIGURE 32: CUSUM OF SQUARES TEST--MEDICAL EQUIPMENT INDUSTRY

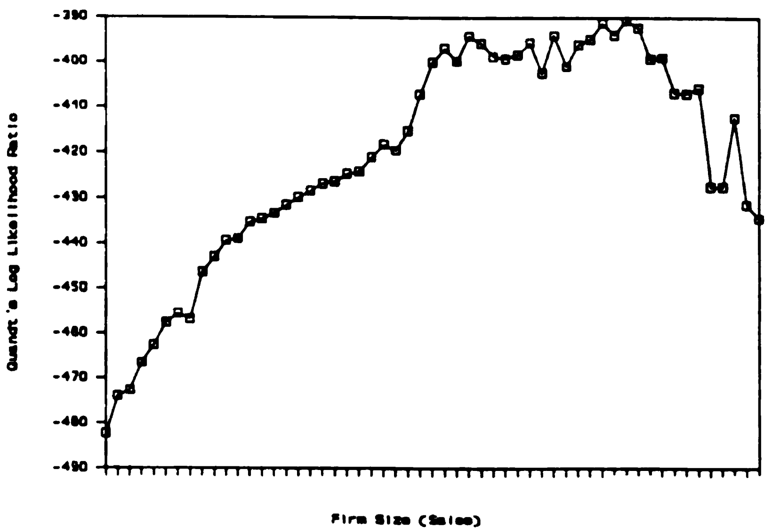

FIGURE 33: QUANDT'S LOG LIKELIHOOD RATIO TEST--MEDICAL EQUIPMENT INDUSTRY

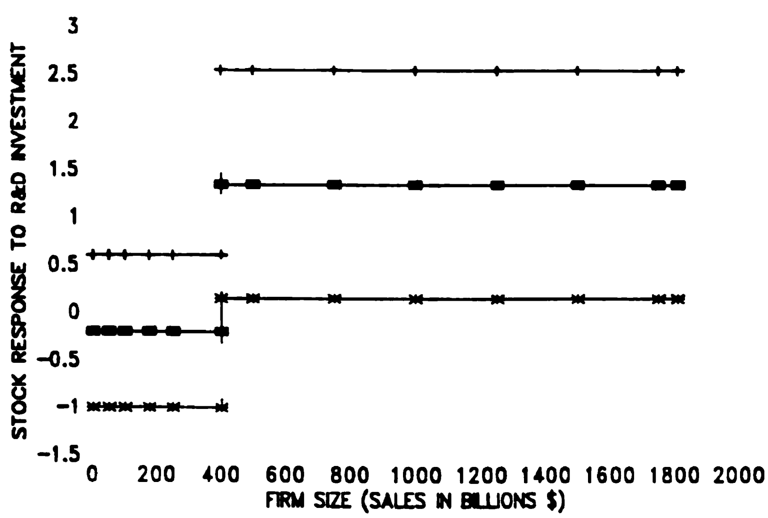

FIGURE 34: THE STOCK RESPONSE TO R&D INVESTMENT--MEDICAL EQUIPMENT INDUSTRY

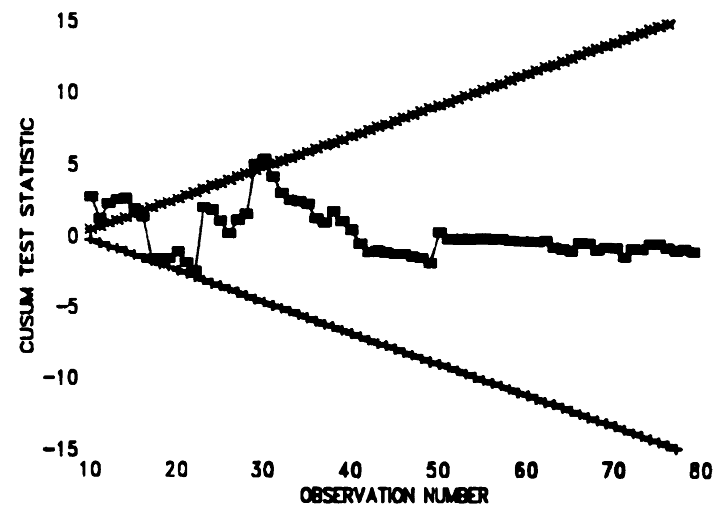

FIGURE 35: CUSUM TEST--PHARMACEUTICAL INDUSTRY

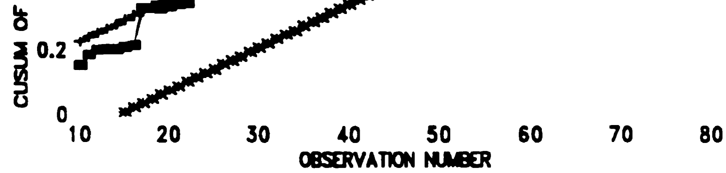

FIGURE 36: CUSUM OF SQUARES TEST--PHARMACEUTICAL INDUSTRY

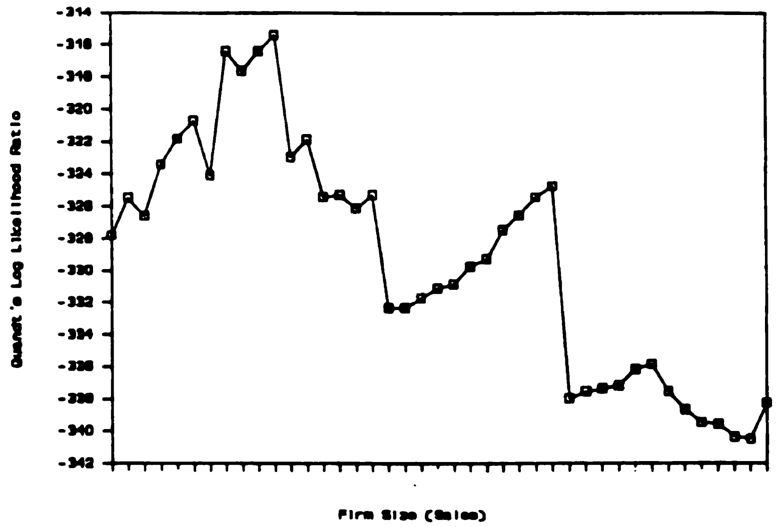

FIGURE 37: QUANDT'S LOG LIKELIHOOD RATIO TEST--PHARMACEUTICAL INDUSTRY

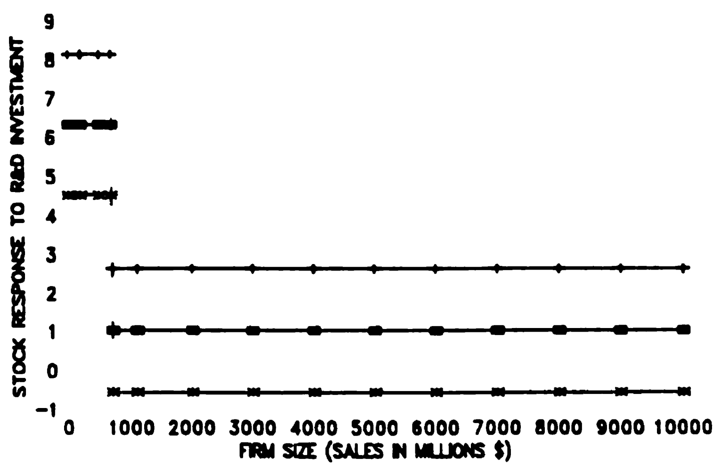

FIGURE 38: THE STOCK RESPONSE TO R&D INVESTMENT--PHARMACEUTICAL INDUSTRY

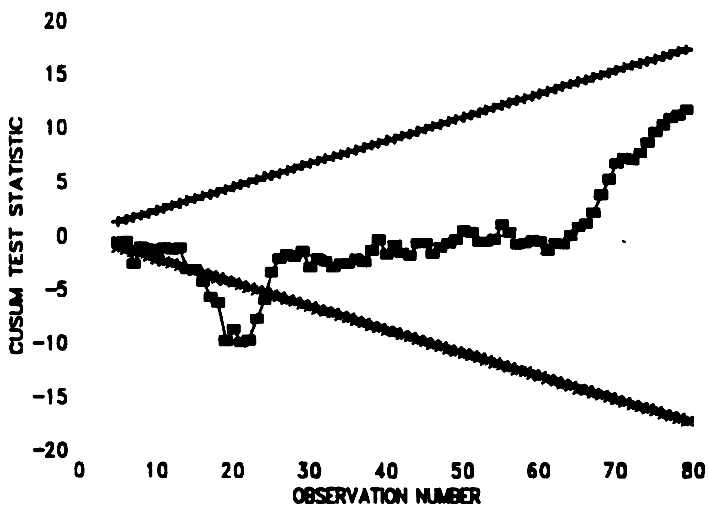

FIGURE 39: CUSUM TEST--SEMICONDUCTOR INDUSTRY

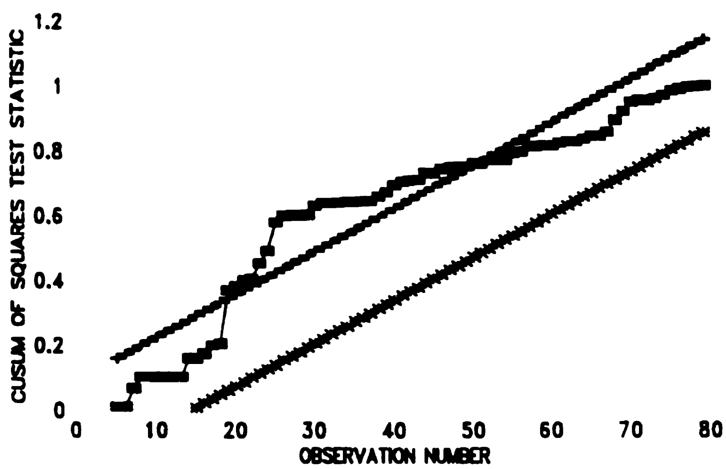

FIGURE 40: CUSUM OF SQUARES TEST--SEMICONDUCTOR INDUSTRY

D. SUMMARY OF RESULTS

In order to compare the results from Specification 1 and 2, the stock response to R&D must be calculated for Specification 1. As explained in Chapter 4, Specification 1 tests the Schumpeter hypothesis by analyzing rates of change in market valuation since it is easier to see when the market valuation of R&D changes sign. The stock response to R&D investment in Specification 1 is calculated as follows:

$$\textit{Stock Response} = \gamma_2 + \gamma_3 \textit{Sales} + \gamma_4 \textit{Sales}^2 \quad \text{(33)}$$

The standard error of the stock response is:

$$[Var(\gamma_2) + Sales^2 Var(\gamma_3) + Sales^4 Var(\gamma_4) + 2Cov(\gamma_2,\gamma_3) + 2Sales^3 Cov(\gamma_3,\gamma_4) + 2Sales^2 Cov(\gamma_2,\gamma_4)]^{1/2} \quad \text{(34)}$$

The actual ranges in which the market positively values R&D investment and negatively values R&D investment in Specification 1 are not expected to be identical to the range(s) found in Specification 2 since the estimation process in which these were derived were not the same. Specification 1 assumes a continuous functional form whereas Specification 2 statistically tests for different size regimes. However, in checking for robustness of the

results for the two specifications, the qualitative pattern of the stock response is expected to be similar. That is, suppose that the stock response to R&D in Specification 1 is not significantly different from zero for small firms, positive and significantly different from zero for medium size firms and then not significantly different from zero for large firms. Then the stock response to R&D is expected to be higher in medium size firms compared to small or large size firms in specification 2 as well. However, the "definition" of small, medium, and large (that is, the actual range in which the stock response to R&D investment is positive, negative, or not significantly different from zero) may be different from that in Specification 1. Since Specification 2 statistically tests for firm size regimes, I put more weight on these results as compared to the results obtained in Specification 1.

Table 22 summarizes the results of Specification 1 and 2 for each of the five high-technology industries analyzed. It indicates the range of firm size for which the market values R&D investment positively, negatively, or zero, respectively.

In the computer industry, results are consistent across specifications: the stock response to R&D investment is not significantly different from zero for small firms, positive and significant for medium size firms, and for large firms, the market does not positively value R&D investment. As expected, the definitions of small, medium, and large differ across specifications. As mentioned previously, the effect of the differences in firm size regimes is most likely exacerbated by the very large firms in the sample. When the largest firms in the sample are excluded (firms with annual sales greater than $20 billion) the results indicate that market does not value R&D investment positively for smaller size firms while for larger firms the stock response is positive and significant.

TABLE 22: SUMMARY OF RESULTS FROM SPECIFICATION 1 AND 2

	Firm Size in which the Stock Response to R&D Investment is: Positive and Significant		Negative and Significant		Not Significantly Different from zero	
	Spec. 1	Spec. 2	Spec. 1	Spec. 2	Spec. 1	Spec. 2
Comp	$3.5b. to $35b.	$180m. to $1.9b.	---	>$1.9b.	0 to $3b. & >$35b.	<$180m.
Comp*	$10.5b. to $12.5b.	>$1.9b.	---	<$390m.	0 to $10.5b. & >12.5b.	$390m. to $1.9b.
Mach	<$160m.	<$79m. & >$308m.	$1.1b.to $3.3b.	$79m. to $308m.	$160m. to $1.1b. & >$3.3b.	---
Medi	$250m. to $1.55b	>$400m.	---	---	<$250m. & >$1.55b	<$400m.
Phar	<$3 b.	<$700m.	---	---	>$3b.	>$700m.
Semi	---	---	---	>$40m.	entire range	<$40m.

Comp: Computer Industry

Comp*: Computer Industry, excluding firms with sales greater than $20 billion.

Mach: Machinery Industry

Medi: Medical Equipment Industry

Phar: Pharmaceutical Industry

Semi: Semiconductor Industry

Specification 1 also finds that for the largest firms in the sample (greater than $12.5 billion in annual sales) the stock response to R&D investment is not significantly different from zero. Quandt's log likelihood ratio test would not have been able to detect a structural change at this point since there are not enough degrees of freedom.

In the machinery industry the results from both Specifications indicate that the stock response to R&D is positive and significantly different from zero for small firms. The definition of small is less than $160 million in Specification 1 whereas Specification 2 determines that small is less than $79 million. Both Specifications indicate that the stock response to R&D in medium size firms is not valued positively by the market. In Specification 2, the stock response to R&D is not significantly different from zero for firms with sales between $160 million and $1.1 billion, and the stock response is negative and significant for firms with sales between $1.1 billion and $3.3 billion in Specification 1. In Specification 2, the market values R&D negatively for firms with sales between $79 million and $308 million.[20] The stock response to R&D in large firms is not significantly different from zero in Specification 1, whereas it is positive and significant in Specification 2. Thus, the qualitative pattern of the stock response to R&D is similar in Specification 1 to that in Specification 2: it is positive and significant for small firms, negative and significant for medium size firms, and then the stock response to R&D investment increases again for larger firms.

In the medical equipment industry both Specification 1 and Specification 2 find that larger firms are more profitable in R&D than smaller firms. In Specification 1 the

[20]Although the difference between $308 million and $1.1 billion appears rather large, there are only 4 observations (5% of the sample) in this category.

definition of small is less than $250 million, whereas in Specification 2 the definition of small firms is less than $400 million. These results are actually quite similar since there are only 4 observations (or 3% of the sample) in which sales are between $250 million and $400 million. Whereas Specification 2 finds that the stock response to R&D for firms with annual sales greater than $400 million is positive and significant, Specification 1 finds that it is positive and significant up to $1.55 billion in annual sales and after that it is not significantly different from zero. Again, in order to perform Quandt's log likelihood ratio test, there were not enough degrees of freedom available to test for a point of structural change for these firms. This may explain the finding that the stock response to R&D in the largest firms is not significantly different from zero in Specification 1.

The results are consistent across Specifications in the pharmaceutical industry in that small firms are more profitable in R&D than larger firms. But, the definition of small and large are different. In Specification 1, small is defined to be less than $3 billion and in Specification 2 it is less than $700 million. Again, the discrepancies in the firm size can be attributable to the assumption of a continuous relationship between firm size and the stock response to R&D investment in specification 1. The general pattern of the market's valuation is similar: positive and significant for small firms and not significantly different from zero for larger firms.

In the semiconductor industry, Specification 1 found that the stock response to R&D is not significantly different from zero for the entire range of firm size. Specification 2 is able to test for different size regimes and finds that for firms with sales less than $40 million, the stock response to R&D is not significantly different from zero

(30% of the sample), whereas for larger firms, the stock response is negatively valued by the market.

V. SUMMARY AND CONCLUSIONS

Ever since U.S. industry began feeling the sting of successful foreign competition, there have been calls for more cooperation of research efforts of private industry. One of the recurring arguments in the ensuing policy discussion has been that domestic enterprises cannot muster enough resources to maintain technological leadership in an increasingly global marketplace. This view has also been voiced in other industrialized countries, such as France, Germany, and Japan (Scherer (1992)). In order to encourage a greater amount and greater efficiency of R&D investment, Congress passed the National Cooperative Research Act in 1984. It institutes a "rule of reason" for evaluating the legality of cooperative R&D ventures on a case-by-case basis, rather than declaring them per se illegal. In addition, this act limits the potential liability of such consortia to actual, rather than treble damages. Policies like these are referred to as Schumpeterian, in reference to Joseph Schumpeter.

Schumpeter postulated that there exists a positive relationship between firm size and technological progress, and that static economic efficiency should be foregone in order to achieve long-run technological progress. Proponents of that view stress the importance of complementary activities which make it easier for large firms to turn successful research into successful products and processes. On the other hand, opponents of Schumpeter stress that small firms may have an advantage in R&D due to diseconomies of firm size and greater motivation of scientists and engineers in smaller firms.

This study tests whether firm size is a significant determinant of R&D profitability. It estimates a stock market valuation model for five high-technology industries: computer, machinery, medical equipment, pharmaceutical, and semiconductor. However, it is not able to determine why large firms are, or are not, relatively more profitable in R&D. It offers a possible explanation for differences in large and small firms' R&D profitability rates in terms of industry conditions.

I first estimate a market valuation model of the firm assuming that there exists a continuous relationship between firm size and R&D profitability. In testing the Schumpeter hypothesis, the mixed partial derivative of the change in market valuation with respect to both firm size (sales) and the stock of R&D capital is analyzed. It indicates the effect of a one dollar increase in sales, holding the stock of R&D constant, on the change in the market value of the firm. I evaluate how this mixed partial derivative changes as firm size changes. Results indicate that Schumpeter is supported only in the computer and medical equipment industry. As firm size increases the change in market valuation with respect to both firm size and R&D profitability increases in both of these industries. In the semiconductor industry I find that firm size is not a significant determinant of R&D profitability across the relevant range of firm size. Schumpeter is not supported in both the machinery industry and the pharmaceutical industry; size has a negative effect on R&D profitability.

One possible reason for lack of support of Schumpeter is the assumption of a continuous relationship between firm size and R&D profitability. In fact, Markham

(1965) first suggested that Schumpeter's theory might better be viewed as a threshold theory because technological progress is not necessarily an increasing and continuous function of market power or business size. The second part of the empirical analysis allows for such a threshold effect. I test for parameter stability of the estimated coefficients by using the CUSUM and Cusum of Squares statistical test (Brown, Durbin, Evans (1975)). I find that parameter stability can be rejected for all five industries implying that the coefficients are not stable over firm size. Unfortunately, the CUSUM and Cusum of Squares tests are not able to indicate either the specific point(s) of structural change or the unstable parameter(s). In order to determine the point(s) of structural change, Quandt's log likelihood ratio test was applied. The thus obtained point(s) of structural change are used to divide firms into different groups and dummy size interaction terms are created for each group. Schumpeter's hypothesis was tested by comparing the stock response to R&D over the different size classes. If the stock response to R&D is found to be significantly greater in larger firms than that in smaller firms, Schumpeter can be supported. On the other hand, if the stock response to R&D in small firms is significantly greater than that in smaller firms, or if there is not a significant difference in the stock response to R&D investment for different size classes, Schumpeter cannot be supported.

These results are consistent with the first part of the empirical analysis that assumes a continuous relationship between firm size and R&D profitability. I still find that Schumpeter is supported in just two of the five industries. I place more confidence in the results from the second type of analysis because it does not assume a continuous relationship between firm size and R&D profitability. In addition, by allowing for endogenously determined thresholds, this methodology is able to determine the definition of large and small firm size. The Schumpeter hypothesis is supported both in the computer and medical equipment industry; large firms are more profitable in R&D compared with their smaller counterparts.[1] However, the "definition" of large firms is not homogeneous across the different industries. For example, "large" firms were found to be greater than $1.9 billion in annual sales in the computer industry and greater than $400 million in the medical equipment industry. Both small and large firms are more profitable in R&D than medium size firms in the machinery industry which implies that Schumpeter is not supported. In the pharmaceutical and semiconductor industries Schumpeter is not supported as well; large firms are less profitable in R&D then their smaller counterparts. Small firms are found to be firms with annual sales less than $700 million in the pharmaceutical industry and firms with annual sales less than $40 million in the semiconductor industry.

One potential reason for differences to exist between large and small firm's R&D profitability rates is the importance of complementary assets. In industries in which patents or copyright protection is highly effective in appropriating the returns from R&D investment, the innovator is almost assured of protection from imitators. Even if the innovator does not have the required amount of complementary assets, a patent protects the innovator's intellectual property and gives the innovator time to acquire these assets either by contracting out with other firms or by acquiring the assets. In such industries it is often the case that smaller firms that are more profitable in R&D since size provides

[1] The Schumpeter hypothesis is supported once firms with annual sales greater than $20 billion are excluded from the sample.

no advantage in terms of marketing or sales. In fact, size may prove to be a hinderance due to decisions having to pass through layers of management as well as scientists becoming less motivated due to administrative and hierarchical constraints. However, industries in which patents are highly effective in appropriating returns are the exception rather than the rule. In these industries, a patent provides little or no protection in appropriating the returns to R&D investment, for example, because it is fairly easy to reverse engineer a product. In fact, Levin et al.(1987) found that secrecy, lead time, and sales and service efforts were often times more important than patents as a means of appropriating the returns to R&D investment. This result implies that "success" in innovation is not enough for commercial success.

The simultaneous model of innovation used in this study (see Chapter 3) incorporates both technological success and the ability to make use of complementary assets as determinants of commercial success of R&D efforts. Accordingly, innovators must turn to business strategy to protect innovative rewards from imitators. Therefore, if patents are not effective in appropriating the returns from R&D investment, the firm needs other complementary assets to protect its investment. Large firms are more likely to possess these specialized assets which may better allow them to take advantage of their technology. Small firms are less likely to have incorporated relevant specialized assets within their organizational boundaries and so will either have to incur the expense of trying to build them, or of trying to develop coalitions with competitors/owners of the specialized assets, and may put them at a disadvantage.

The results of the empirical analysis can be explained by applying the concept of appropriability conditions and complementary assets to the five high-technology industries.

In both the computer and medical equipment industry, complementary activities such as sales, service efforts, and distribution are especially important. Since the core technology is fairly easy to imitate, commercial success is conditional upon the terms and conditions upon which the required complementary assets can be accessed. These complementary assets give large firms advantages over smaller firms, which seems to suggest why large firms were found to be more profitable in R&D relative to their smaller counterparts (see Chapter 3). For example, in the case of cardiac pacemakers, the technology was easy to imitate and so competitive outcomes quickly came to be determined by who had easiest access to complementary assets--in this case specialized marketing (see Teece (1986)). The small pocket calculator, introduced by Bowmar, serves as another example. It was fairly easy to innovate and Bowmar was not able to withstand competition from Texas Instruments, Hewlett Packard and others, and went out of business. Had Bowmar relied more on business strategy (sales and marketing), it may have had a better chance.

An example of an industry in which patent effectiveness is high is the pharmaceutical industry. In this industry small firms were found to be more profitable in R&D then large firms. In the pharmaceutical industry patents deny imitators access to the relevant knowledge and therefore the innovator is almost assured of translating its innovation into market value. Marketing is important in the pharmaceutical industry, however, if the innovating company does not possess the desirable endowment of complementary assets, protection of intellectual property will afford it time to access these assets either through a contractual relation or through building those assets in-house. For example, the first co-promotion in the industry occurred in 1981 when Glaxo did not have the necessary sales force to market its anti-ulcer drug Zantac. Glaxo signed an agreement with Hoffmann-La Roche in which their salespersons would market and sell the drug (Economist (Feb., 1989)). Although one might expect large firms to have an advantage in the semiconductor industry because distribution channels are extremely important and semiconductor chips are fairly easy to reverse engineer, the results indicate that large firms actually earn a negative return on their R&D investment. However, because of the rapid changes that took place during this decade, the 80s represent a special case. Many small firms were started by former employees of the larger semiconductor companies. A large percentage of these entrepreneurs had left their previous jobs because of frustrations over not having their ideas approved and/or not being able to reap the benefits from their innovative efforts. Since these employees took their research ideas from the larger firms, this would explain the result that larger firms actually earned a negative return on their R&D investment, whereas smaller firms did not.

Since it is fairly easy to reverse engineer products in the machinery industry, appropriability conditions are below average. Large firms have built up strong marketing departments and distribution channels are also important for commercial success. According to the above argument, one would expect Schumpeter to be supported, and therefore large firms to be more profitable than their smaller counterparts. Yet results indicate that both small and large firms are more profitable in R&D compared to medium size firms. One potential explanation for this finding is that small firms have tended to serve the niche markets, sometimes even supplying the larger firms.

This study represents a start in addressing a question recently posed by Scherer (1992): "... at what kinds of innovative activities do large organizations have (the) comparative advantage? Comparative disadvantage?" First, it finds that striking differences exist in the relationship between firm size and R&D profitability for a group of high-technology industries. In some, Schumpeter is supported whereas in others, the Schumpeter hypothesis cannot be supported. The reasons for this may be attributable to appropriability conditions and complementary assets. This suggests that the Schumpeter hypothesis needs to be qualified in the sense that it must take into account an industry's appropriability conditions. Second, the definition of what constitutes large and small firms is found to differ across the industries studied. Previous studies have not accounted for this which might explain why they have not found that firm size is a significant determinant of technological progress. These results represent a contribution to the ongoing debate on how to design policies to foster R&D efforts. Even in the high-technology sector of the economy it seems that Schumpeter's general hypothesis needs to be qualified by closely studying industry specific conditions.

Further research on the relationship between appropriability conditions and large and small firms' R&D profitability will clarify the type of relationship between appropriability conditions, firm size and R&D profitability. It is conceivable that the observation of higher R&D profitability for small firms in some of the high-technology industries analyzed was influenced by the length of the time period analyzed. Small firms might use their resources more effectively over a period of approximately five years, however, it need not be the case that such a relationship continues to uphold over a longer period of time. They might not follow through with their efforts in continuously investing in development work (Ferguson (1988)). Further research needs to be done on the relationship of innovation and firm size over the long run. For example, it would be interesting to know how results within and across industries differ if a longer time period, such as a twenty year interval, is analyzed.

APPENDICES

APPENDIX A

APPENDIX A

DEFLATION OF MARKET VALUATION

The change in the market value of the firm is deflated by the change in the Standard and Poor's 500 Composite index. This allows for the separation of increases in market value that are due to overall increases in the general level of the market, compared with increases due to tangible and intangible asset investment. Data are obtained from the Dow Jones-Irwin Business and Investment Almanac (1991). Since first differences are computed, I deflate the difference by the change in the index in the current period compared to the change during a given base period. For example, I use three different time periods: 1982-1987, 1983-1988, and 1984-1989. First, the change in the Standard and Poor's Industrial Average is determined for each period, then I divide this by the change in the index during the base period: 1982-1987.

TABLE 23: STANDARD AND POOR'S COMPOSITE INDEX

Year:	1982	1983	1984	1985	1986	1987	1988	1989
S&P:	158	186	186	234	270	286	320	398
$\Delta S\&P_{(1987-1982)}=128$			$\Delta S\&P_{(1988-1983)}=134$			$\Delta S\&P_{(1989-1984)}=212$		

Thus, I deflate by 1.047 for 1983-1988, and 1.682 for 1984-1989.[1] These weights indicate that the change in the Standard and Poor's index was 4.7% greater during the time period 1983-1988 than from 1982 to 1987. Similarly, the change in the Standard and Poor's index was 68.2% greater during the time period 1984 to 1989 than from 1982 to 1987.

Two additional general stock market indexes are available: the S&P 500 average of daily closing price, and the Dow Jones Industrial Average. Similar regression results are obtained when using the S&P average of daily closing price. On the other hand, in some cases, results obtained using the Dow Jones Industrial Index are slightly different from those employing the Standard and Poor's Index. I attribute this to the small number of companies included on the Dow Jones Index. Since my data set includes a large number of small firms, I utilize the broader index: the S&P 500.

Industry market indexes for each industry are also available. However, these indexes contain only a small number of companies. For example, in the semiconductor industry, only 5 firms are included, while just 15 are included in the computer industry index. Furthermore, the firms included are very large firms, which may not be representative of overall industry performance.

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[1] $\frac{\Delta S\&P_{(1988\text{-}1983)}}{\Delta S\&P_{(1987\text{-}1982)}} = 1.047; \quad \frac{\Delta S\&P_{(1989\text{-}1984)}}{\Delta S\&P_{(1987\text{-}1982)}} = 1.682$

APPENDIX B

APPENDIX B

TEST OF THE EQUALITY OF COEFFICIENTS OF THE FIVE HIGH-TECHNOLOGY INDUSTRIES

The null hypothesis of constant coefficients for the five industries is tested using three models. The basic model includes only three independent variables: the change in tangible assets over a five year period ($Assets_{i,t}$-$Assets_{i,t-5}$), and the sum of R&D and advertising expenditures over a five year period (ΣRD and ΣADV, respectively). The second model is equivalent to Specification 1; independent variables include sales-intangible asset interaction terms (Sales*ΣRD, Sales*ΣADV, $Sales^2$*ΣRD, $Sales^2$*ΣADV). And the third model is similar to Specification 3(which is presented in Appendix 4); the difference being that in this case, all industries have identical break points. That is, firms are divided into 3 equal size groups and dummy size-interaction terms are created. On the other hand, in Specification 3 I separate firms into 3 equal groups for each industry, therefore the break points differ across industry. For example, here, since industries are pooled, the computer industry has a large number of firms categorized as "small", with only a few "large" firms, whereas in the pharmaceutical industry, most firms are categorized as "large".

Table 24 presents results for the basic model. Not surprisingly, the change in tangible assets is the primary determinant of the change in the market value of the firm. Overall, R&D expenditures are a significant determinant of the change in a firm's value. Only in the computer industry is this coefficient not significant. Pooling industries, the stock response to R&D investment is 1.09(s=0.14), yet this varies significantly across industries. For example, in the pharmaceutical industry, the stock response to R&D investment is 4.18(s=0.49), while in the semiconductor industry this value is -0.67(s=0.15). The negative coefficient indicates that, in general, R&D investment was not profitable during this time period. The stock response to advertising expenditures is positive and significantly different from zero when industries are pooled: 1.27 (s=0.13). Yet, when each industry is examined separately, only in the computer and semiconductor industry is the coefficient on advertising expenditures significant. The hypothesis of constant coefficients across the five industries is rejected at the 1% significance level ($F=150.78$ $F_c=2.37$).

The regression results for model 2 (Sales-intangible assets interaction terms) is shown below. Separate results for each industry are presented in Table 11, see Chapter 4. Again, the hypothesis of constant coefficients across the industries is rejected at the 1% significance level ($F=80.53$ $F_c=1.94$).[2]

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[2] Pooling all data, the stock response to R&D increases as firm size increases, it attains a maximum at approximately $5 billion in annual sales, then it begins to decrease. The stock response to R&D is not significantly different from zero for firms with sales less than $150 million. For the average firm size of $830 million, it is .46(s=.14), while for the largest firm size of $22 billion, it is negative and significantly different from zero.

TABLE 24: BASIC MODEL

	constant	$\Delta Assets_{i,t-i,t-5}$	ΣRD	ΣADV	N	R^2	F df
All	-51.71 (77.12)	0.65** (0.06)	1.09** (0.14)	1.27** (0.13)	503	.61	388.38 3,499
Comp	-78.68 (80.52)	1.22** (0.06)	0.13 (0.12)	1.26** (0.37)	164	.82	44.09 3,160
Mach	-37.79 (26.66)	0.54** (0.06)	1.09** (0.24)	-1.26 (0.98)	73	.58	38.98 3,75
Medi	121.44** (68.19)	0.49** (0.05)	1.20** (0.29)	-0.60 (0.42)	111	.80	280.12 3,107
Phar	-138.5** (35.0)	0.64** (0.27)	4.18** (0.49)	0.19 (0.64)	79	.69	77.23 3,75
Semi	-88.34* (52.22)	1.13** (0.12)	-0.67** (0.15)	4.65** (1.43)	79	.74	76.90 3,75

Standard errors are in parentheses.

**/*statistically significant at the 5%/10% level, respectively.

All: All 5 high-technology industries, pooled; Comp: Computer industry, including IBM; Mach: Machinery industry; Medi: Medical equipment industry; Phar: Pharmaceutical industry; Semi: Semiconductor industry; $Assets_{i,t-i,t-5}$: Change in the book value of tangible assets over a five year period; $\Sigma RD/\Sigma Adv$: Sum of R&D/advertising expenditures over a 5 year period, respectively.

POOLED RESULTS: MODEL TWO

$V_{i,t}-V_{i,t-5}$	$= -53.53$ (13.98)**	$+.85\Delta$Assets (0.19)**	$+.29\Sigma$RD (0.05)**
+	.0002SalesΣRD (.000006)**	-.2E-7Sales$^2\Sigma$RD (0.4E-8)**	+3.04ΣADV (0.51)**
-	0.0009SalesΣADV (.0002)**	+.8E-7 Sales$^2\Sigma$ADV (0.2E-7)**	$+ \varepsilon_{i,t}$
N=502		F = 3428.43 df = 7,497	R^2=0.76

standard errors are in parentheses.

** indicates significance at the 5% level.

POOLED RESULTS: MODEL THREE

$V_{i,t}-V_{i,t-5}$	$= -0.82$ (0.57)	+ 1.15ΔAssets (0.12)**	+ 0.19ΣRD (0.67)
+	1.64 DS*$\Sigma RD_{i,t}$ (0.99)**	- 1.51 DL*ΣRD (0.75)**	- 1.85ΣADV (2.61)
-	2.37 DS*ΣADV (4.99)	+4.47 DL*ΣADV (2.64)*	$+ \varepsilon_{i,t}$
N=502		F = 251.21 df = 7,497	R^2=0.68

standard errors are in parentheses.

**/* indicates significance at the 5%/10% level, respectively.

The third model separates firms into three equal groups based on firm size.[3] The break points are $29.40 million and $195.22 million in annual sales, with each group containing either 167 or 168 observations (see results above).

For the smallest size category, the stock response to R&D is 1.83(s=.19), while for the largest size category it is -1.32(s=.42). On average, the stock response to R&D is not significantly different from zero.[4]

The null hypothesis of constant coefficients across all five high-technology industries is again rejected at the 99% significance level ($F=73.36$, $F_c=1.94$).

Since all three models reject the hypothesis of constant coefficients over the five industries, each industry is analyzed separately.

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[3] Results exclude International Business Machines.

[4] At first glance, this appears to refute the previous model. However, in this model we are defining large to be firms with sales greater than $180 million, which according to the previous analysis, combines firms in which the stock response to R&D is positive and significant, negative and significant, and not significantly different from zero. Therefore, while the two models may be difficult to reconcile because of the differences in break points, one does not refute the other.

The stock response to advertising expenditures is not significantly different from zero for the smallest and average size categories, while it is positive and significantly different for the largest category. For the smallest size category, the stock response to advertising expenditures is -4.22(s=1.98), while for the largest size category it is 2.62(s=1.07).

APPENDIX C

APPENDIX C

HETEROSKEDASTICITY CORRECTION

I assume an additive form of heteroskedasticity in which the estimated variance of the disturbance (σ^2_i) takes the form:

$$\sigma_i^2 = a + b(Sales_i) + c(Sales_i^2) \tag{35}$$

where a,b and c are constants to be estimated. In some cases, c=0. To obtain asymptotically efficient estimators of the regression coefficients I perform the following steps:

(a) estimate the least squares equations (Specifications 1 and 2).

(b) Apply the least squares method to:

$$e_i^2 = a + b(Sales_i) + c(Sales_i^2) + v_i \tag{36}$$

where e_i^2 are the ordinary least squares residuals from the equation estimated in part (a) above. The "first round" estimate of σ_i^2 is:

$$\hat{\sigma}_i^2 = \hat{a} + \hat{b}(Sales_i) + \hat{c}(Sales_i^2) \tag{37}$$

(c) These first round estimates of a, b, and c are not asymptotically efficient because v_i is heteroskedastic. Therefore the "second round" estimators of a,b,and c are obtained by applying the least squares method to:

$$\frac{e_i^2}{\hat{\sigma}_i^2} = a\frac{1}{\hat{\sigma}_i^2} + b\frac{Sales_i}{\hat{\sigma}_i^2} + c\frac{Sales_i^2}{\hat{\sigma}_i^2} + v_i^* \tag{38}$$

These estimators a,b, and c are asymptotically efficient. Then, the second-round estimator of σ_i^2 is:

$$\tilde{\sigma}_i^2 = \tilde{a} + \tilde{b}Sales_i + \tilde{c}(Sales)_i^2 \tag{39}$$

(d) Asymptotically efficient coefficients of Specification 2 are estimated using σ_i as weights:

$$\begin{aligned}\frac{V_{i,t}-V_{i,t-5}}{\tilde{\sigma}_{i,t}} &= \alpha_{i,t}\frac{1}{\tilde{\sigma}_{i,t}} + \gamma_1\frac{Assets_{i,t}-Assets_{i,t-5}}{\tilde{\sigma}_{i,t}} + \gamma_2\frac{(\sum_{T-5}^{T} RD_{i,t})}{\tilde{\sigma}_{i,t}} \\ &+ \gamma_3\frac{(Sales*\sum_{T-5}^{T} RD)}{\tilde{\sigma}_{i,t}} + \gamma_4\frac{(Sales^2*\sum_{T-5}^{T} RD)}{\tilde{\sigma}_{i,t}} + \gamma_5\frac{(\sum_{T-5}^{T} ADV_{i,t})}{\tilde{\sigma}_{i,t}} \\ &+ \gamma_6\frac{(Sales*\sum_{T-5}^{T} ADV)}{\tilde{\sigma}_{i,t}} + \gamma_7\frac{(Sales^2*\sum_{T-5}^{T} ADV)}{\tilde{\sigma}_{i,t}} + e_{i,t}\end{aligned} \tag{40}$$

The heteroskedasticity correction procedure for Specification 2 is similar to that of Specification 1.

APPENDIX D

APPENDIX D

SPECIFICATION THREE RESULTS

Specification 3 entails dividing firms into 3 equal size groups and then creating dummy size-interaction variables. For example,

Specification 3:

$$V_{i,t}-V_{i,t-5}=\alpha_1+\alpha_2(Assets_{i,t}-Assets_{i,t-5})+\alpha_3\sum_{T-5}^{T}RD_{i,t}+\alpha_4 D1*\sum_{T-5}^{T}RD_{i,t}$$
$$\alpha_5 D3*\sum_{T-5}^{T}RD_{i,t}+\alpha_6\sum_{T-5}^{T}ADV_{i,t}+\alpha_7 D1*\sum_{T-5}^{T}ADV_{i,t}+\alpha_8 D3*\sum_{T-5}^{T}ADV_{i,t}+\epsilon_{i,t}$$

(41)

where:

$V_{i;t}$-$V_{i;t-5}$: the change in the market value of the firm over a five year period. $V_{i;t}$-$Vi_{i;t-5}$ is deflated by the change in a market index over the relevant time period. This allows us to control for general trends in the stock market. See Appendix 1 for details.

$Assets_{i;t}$-$Assets_{i;t-5}$: the change in the value of the firms tangible assets over a five year period.

ΣRD/ΣADV: sum of R&D/advertising expenditures over a five year period, respectively.

D1*ΣRD(and D1*ΣADV): Dummy interaction variable. D1=1 if annual sales are less than a specified value, which is different for each industry.

D3*ΣRD(and D3*ΣADV): Dummy interaction variable. D3=1 if annual sales are greater than a specified value, which is different for each industry.

This specification is similar to Specification 2, however, here break points are a priori assumed instead of statistically determining whether or not they exist. This may lead to the rejection of the hypothesis that different size regimes exist when in fact size regimes do exist.[5]

For medium size firms, the stock response to R&D is α_3. The stock response to R&D for small firms is the sum of the coefficients "$\alpha_3 + \alpha_4$"--the coefficients on ΣRD_i

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[5] For example, suppose that the break point between "medium" and "large" firms is $1 billion in annual sales according to specification 3 above, but the "true" break point, as found in specification 2, is somewhat larger, say $1.5 billion. Also suppose that the true definition of large firms includes approximately one half of the firms that specification three classifies as large (firms with annual sales between $1 billion and $1.5 billion). Next, assume that the stock response to R&D for the "true" medium firms (sales<$1.5 billion) is not significantly different from zero, while for the "true" large firms it is positive and significant. Then, by combining "true" medium size firms into the "true" large firm size category (as specification 3 does), the hypothesis that the stock response to R&D is positive and significant in large firms may be rejected. Similarly, the hypothesis that the stock response to R&D investment in large firms is not significantly different from that in medium firms when it actually is different. Thus, a significant difference between the stock response in different size regimes may not be found when there actually is a difference.

Note that conflicting results may be obtained from specifications 1 and 3 because of their limitations. For example, results from specification 1 could indicate that the stock response to R&D in the mean size firm is positive and significantly different from zero, but because of the classification scheme used in specification 3, results may indicate that the stock response to R&D investment for the mean firm size is not significantly different from zero. Or, because specification 1 assumes a continuous relationship, one could come to the conclusion that medium size firms earn a positive and significant return to R&D, when actually there is a jump between small and large firms returns. This particular functional form is not able to compensate for that particular scenario.

+ D1*ΣRD_i. For large firms, the stock response to R&D is the sum of the coefficients on ΣRD_i + D3*ΣRD_i, or $\alpha_3 + \alpha_5$. Just as in Specification 2, a test of the Schumpeter hypothesis entails testing whether the stock response in large firms is significantly different from that in small firms. A similar analysis is performed on the advertising coefficients.[6]

I now present regression results for each of the 5 industries (see Tables 25 and 26).

A. COMPUTER INDUSTRY

Firms are divided into three equal groups based on firm size: (1) annual sales<$70 million (2) $70 million ≤ annual sales < $400 million, and (3) annual sales ≥ $400 million. Dummy interaction variables (D1*ΣRD, D3*ΣRD, D1*ΣADV, D3*ΣADV) are constructed and the omitted group is the medium size group, category 2. On average, the stock response to R&D is negative and significant, implying that many of these firms experienced unsuccessful projects during the 1980s. Yet, these results vary with the size of the firm. For the largest category of firms (sales > $400 million), the stock response to R&D is 1.13 (s=0.51), whereas the stock response to R&D investment for the smallest group of firms is not significantly different from zero.

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6 $$Stderror(\hat{\alpha}_3+\hat{\alpha}_4)=\sqrt{s_3^2+s_4^2+2Cov(\hat{\alpha}_3,\hat{\alpha}_4)}$$

Where s_i is the standard error for the coefficient γ_i.

These results are consistent with the previous specifications--larger firms are more profitable R&D. Yet, each of the two specifications use a different definition of large firm size.[7]

B. MACHINERY INDUSTRY

Results from Specification 3 substantiate the previous two specification results in that the stock response to R&D investment for small firms is positive and significant. The break points for the three groups are at $83.5 million and $268 million in annual sales, which are similar to the "true" break points in Specification 2: $79m. and $308m.. The stock response to R&D for both the smallest and the largest group of firms is positive and significantly different from zero, while on average it is negative. For small firms the response is 1.44 (s=.24), while for the largest firms, it is 1.00 (s=0.55). The null hypothesis that the response is equal in both small and large firms can not be rejected

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[7] These results are difficult to reconcile with results from specification 2 due to the differences in break points. This example highlights the problems associated with this specification 2: the a priori assumption of particular break points. It appears that this specification combines "true" small firms (sales < $180 million) in the medium size category. Thus results indicate that the stock response to R&D for firms with sales between $70 million and $400 million is negative and significant, when it may be due to those firms with sales less than $180 million. Also, here I combine true medium size firms ($180 million < sales < $1.9 billion) in the large firm category. Thus suggesting that large firms (greater than $400 million), earn a positive and significant return to R&D when it is only due to those firms with sales between $180 million and $1.9 billion--the true "medium" firms.

(t=.59). In small firms and large firms, the stock response to advertising expenditures is negative but not significantly different from zero.[8]

Thus, results from both specifications reveal that the stock market values R&D investment positively in small and large firms.

C. MEDICAL EQUIPMENT INDUSTRY

Again, firms are split into different categories based on firm size: (1) sales<\$18 million (2) \$18 million ≤ sales < \$100 million, and (3) sales ≥ \$100 million, in which the excluded category is group two. Results from this specification corroborate previous results. The stock response to R&D in the smallest and medium size category is not significantly different from zero; whereas for the largest size category it is positive and significant (stock response: 1.47 (s=0.61)). Advertising expenditures do not appear to play a significant role in determining the change in a firm's market value. In general, for the average firm, the stock response to advertising investment is negative and significantly different from zero. Thus, in all 3 specifications the Schumpeter hypothesis is supported.

D. PHARMACEUTICAL INDUSTRY

Break points for the firm size categories in are assumed to be \$385 million and \$2970 million in sales. The stock response to R&D investment is positive and

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[8]The stock response to advertising in small firms is -.38 (s=2.62), while in large firms it is -1.08 (s=2.29).

significantly different from zero for all three size regimes. However, there is not a significant difference in the stock response in any of the size regimes. The stock response in small firms is 4.29(s=1.40), while in large firms it is 2.29 (s=0.53). The stock response to advertising is not significantly different from zero for all 3 size regimes.[9] Thus, these results highlight the problems with this specification: assuming a priori a definition of large and small size regimes. Based on these results, the hypothesis of differences in R&D profitability in different size regimes is rejected, but, based on the CUSUM test and Quandt's log likelihood ratio test there exist different size regimes.

E. SEMICONDUCTOR INDUSTRY

The break points for Specification 2 are assumed to be $50 million and $220 million in annual sales. Results suggest that the stock response to R&D in the smallest size category is not significantly different from zero, whereas it is negative in firms with sales larger than $50 million. The stock response in the smallest size category is .43(s=.49), and in the average and largest categories it is -1.54/-0.81(s=.50/.41), respectively. The stock response to advertising expenditures in small firms is positive and significantly different from zero whereas in firms larger than $50 million, it is not significantly different from zero.[10]

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[9]The stock response to advertising expenditures for small/large firms is -7.8/0.03 (s=6.84/0.32), respectively.

[10]The stock response to advertising in the smallest/largest size category is 4.68/4.30 (s=2.26/3.75), respectively. On average, the stock response to advertising investment is 2.68(s=4.17).

All three specifications indicate that the stock response to R&D in small firms is not significantly different from zero, whereas in larger firms it may be either negative or not significantly different from zero. Although Specification 1 finds that the stock response to R&D decreases as firm size increases, it is found to be insignificant over the relevant range. Specification 3 finds that firms with less than $50 million in annual sales earn a stock response to R&D that is not significantly different from zero, while it is negative and significant in larger firms. Thus, these results are consistent with Specification 2 in that the stock response to R&D in large firms is negative and significant. While the difference between $40 million and $50 million in annual sales (the break point between small and medium size firms in Specification 2) may sound minor based on the magnitudes that we have been discussing, there are 26 observations (32% of the sample) which fall into this category. Therefore by arbitrarily determining break points, a structural change may have only been determined by pure luck.

TABLE 25: THE STOCK RESPONSE TO R&D INVESTMENT SIZE-DUMMY INTERACTION TERMS

	Computer	Machinery	Medical Equipment	Pharma-ceutical	Semicon-ductor
constant	-117.01**	-17.52**	-2.66	-22.92	-35.02**
	(18.57)	(2.72)	(2.22)	(30.86)	(10.39)
ΔAssets	1.24**	0.71**	1.35**	0.98**	1.18**
	(0.17)	(0.13)	(0.31)	(0.36)	(0.14)
D1ΣRD	8.08**	2.52**	-0.04	2.49	1.98**
	(1.32)	(0.43)	(1.74)	(1.60)	(0.62)
ΣRD	-1.26	-1.08**	-1.39	1.80*	-1.54**
	(1.25)	(0.38)	(1.53)	(1.00)	(0.50)
D3ΣRD	1.99	2.08**	2.86	0.49	0.74
	(1.33)	(0.67)	(1.66)	(1.01)	(0.64)
D1ΣADV	13.11*	-11.85**	2.41	-8.62	2.00
	(5.70)	(3.02)	(3.15)	(6.53)	(4.72)
ΣADV	-8.11	1.47	-0.20	0.82	2.68
	(5.09)	(1.31)	(0.09)	(1.44)	(4.17)
D3ΣADV	7.43	-2.55	-0.38	-0.79	2.30
	(6.19)	(2.66)	(2.40)	(1.48)	(5.64)
N	164	73	111	79	79
R^2	.69	.61	.57	.69	.57
F	50.2	14.2	21.50	25.2	16.06
df	7,157	7,66	7,103	7,72	7,72

Standard errors are in parentheses

**/* Indicates significance at the 5%/10% level, respectively. ΔAssets: change in the tangible assets of the firm over a 5 year period. D1ΣRD:dummy variable-Sum of R&D expenditures interaction term. D1ΣAdv:dummy variable-Sum of advertising expenditures interaction term. D3ΣRD:dummy variable-Sum of R&D expenditures interaction term. D3ΣAdv:dummy variable-Sum of advertising expenditures interaction term.

TABLE 26: THE STOCK RESPONSE TO R&D INVESTMENT SUMMARY OF COEFFICIENTS FROM SPECIFICATION THREE

COMPUTER INDUSTRY (break points: $70 mil. and $400 mil.		
Stock Response to R&D:	small firms:	0.33 s=2.91
	large firms:	1.13 s-0.51
Stock Response to Adv.:	small firms:	-11.81 s=11.10
	large firms:	-1.62 s=1.81
MACHINERY INDUSTRY (break points: $83.5 mil. and $268 mil.)		
Stock Response to R&D:	small firms:	1.44 s=0.24
	large firms:	1.00 s=0.55
Stock Response to Adv.:	small firms:	-0.38 s=2.62
	large firms:	-1.08 s=2.29
MEDICAL EQUIPMENT INDUSTRY (break points: $18 mil. and $100 mil.)		
Stock Response to R&D:	small firms:	-1.43 s=1.04
	large firms:	2.86 s=0.61
Stock Response to Adv.:	small firms:	2.21 s=2.11
	large firms:	-0.58 s=1.19
PHARMACEUTICAL INDUSTRY (break points: $385 mil. and $2.97 bil.)		
Stock Response to R&D:	small firms:	4.29 s=1.40
	large firms:	2.29 s=0.51
Stock Response to Adv.:	small firms:	-7.80 s=6.84
	large firms:	0.03 s=0.32
SEMICONDUCTOR INDUSTRY (break points: $50 mil. and $220 mil.)		
Stock Response to R&D:	small firms:	0.43 s=0.49
	large firms:	-0.81 s=0.41
Stock Response to Adv.:	small firms:	4.68 s=2.26
	large firms:	4.30 s=3.75

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