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THE STOCK MARKET RETURNS TO DISAGGREGATED INTANGIBLE INVESTMENTS

By

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ABSTRACT

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Innovative activity, particularly research and development, have public good characteristics that prevent firms from appropriating the full returns of their efforts, and thus firms under-invest in innovative activity. This argument has been used as a basis for implementing a number of government policies designed to stimulate investment in intangible assets. However, one could argue that these policies have been limited in their effectiveness because many aspects of the process of innovation remain poorly understood.

This paper seeks to determine the relative profitability to firms of tangible and intangible assets, and the effect of firm size on the values of each. Intangible assets consist of knowledge stock, represented by research and development expenditures, and marketing stock, represented by advertising expenditures. The value of these intangible assets are determined using a stock market valuation approach. In addition to aggregate R&D, I examine the value of various types of R&D, including product, process, applied, and basic research, and test for potential interactions between product and process R&D.

I find that intangible assets are more highly valued than tangible assets, but the value of different types of intangible assets varies widely. In general, the market places more value on R&D types lying closer to the output end of the innovation process, such

as applied R&D and product R&D. Investments associated with the beginning of the innovation process, such as basic research, are not highly valued by the market. In addition, I find that the value of product R&D and process R&D are complementary. In other words, the effect of appropriability spillovers is stronger than any impact from potential organizational design trade-offs. Finally, I find support for an "appropriability effect" in which the value of process R&D increases more rapidly with firm size than the value of product R&D.

To my parents,

Peter J. Marasco

And

Helen Kimball,

And to my wife,

Arlene

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INTRODUCTION

Technical innovation is a crucial input to economic growth and as such is a primary target for public policy designed to enhance national, state, and/or local innovation performance.[1] However, one could argue that these policies have been limited in their effectiveness because many aspects of the process of innovation remain poorly understood. Until recently, the majority of research on innovation has been focused on macroeconomic or industry effects, arguably at the expense of research aimed at the firm or business unit level. Accordingly, this study builds upon a relatively new and growing body of literature that investigates innovation at or below the firm level. Specifically, it examines the relative profitability to individual firms of different types of research and development expenditures and the value of alternative R&D resource allocation strategies.

Economists long have recognized the important link between technological change and economic growth, although the modern investigation of this topic can be traced to Joseph Schumpeter (1942).[2] Schumpeter hypothesized that only firms in non-perfectly competitive industries would be able to innovate and create the technological change necessary for economic growth. In his view, technological change could only be attained once firms grew large enough to raise prices above their competitive level and

[1] Examples include the Federal Research and Experimentation tax credit, the patent system, and numerous state and local tax and investment credits. For a discussion of the influence of government policies on innovation, see Horwitz (1979) and Hollomon (1979).
[2] Early references to the importance of technical change include Adam Smith's *The Wealth of Nations* (1776) and David Ricardo's *On the Principles of Political Economy and Taxation* (1817).

gain economic profits – profits that could then be used to invest in technical research and development. The idea that firm size and technological change are related has become known as the Schumpeter hypothesis. Although much effort has been devoted to investigating the validity of Schumpeter's hypothesis, today researchers are faced with the hard truth that the relationship between market structure, firm size, and technological change is not nearly as clear-cut as Schumpeter originally hypothesized. In addition to firm size, other industry and firm characteristics play an important role in innovative activity.[3]

Not surprisingly, the relationship between R&D and innovation has received a considerable amount of attention in the literature. There is little doubt a strong link exists between R&D and successful innovation, but thus far, empirical efforts to quantify this link have been varied in both method and result. The reasons for this are several. First, the true nature of the relationship between profit and R&D, be it linear, quadratic, or some other form, is not known with certainty. Second, long lags often exist between R&D investment and the realization of the returns from R&D. The lag introduces uncertainty in the appropriate specification of the model, and disqualifies many sources of data that are not long enough to cover the appropriate time span. Third, a significant lag time between action and the observation of results limits the firm or policy maker's

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[3] Examples include (1) the level of technological opportunities in the industry, (2) the appropriability conditions in the industry, (3) sunk costs in the status quo, and (4) the stage of the product life cycle. At the firm level, (5) the degree of interface between customer demand and the R&D department, (6) organizational design, and (7) applied R&D expenditures. See Acs and Audretch (1987), Scherer and Ross (1990), Hayes and Wheelwright (1984), and Utterback (1994).

use of the relationship as a tool for planning.

Another potential problem to measuring the returns to R&D lies in determining the correct proxy for innovation. That is, the composition of R&D with respect to product, process, or other types of R&D may by as important in determining the returns to innovation as the aggregate amount of R&D. Unfortunately, severe data constraints have limited empirical efforts to decompose total R&D into reliable measures of product, process, or other types of R&D.

From an empirical standpoint, the approach to measuring the returns to R&D taken in this study avoids many of these issues. This method, known as stock market valuation, relates R&D spending to the value placed on a firm's assets by financial markets. It leverages the idea that publicly traded corporations are bundles of assets (such as R&D spending, advertising, and tangible assets) by incorporating these assets directly into the valuation equation. Therefore, it is particularly well suited to measuring the value of intangible assets. This method also allows a great deal of flexibility in terms of data structure and hypothesis specification. Multiple types of R&D may be regressed against market value, thus enabling the relative value to the firm of each type of R&D to be determined. The approach can also be used to determine if the returns from one type of R&D are significantly affected by an increase in returns from the other. Recent studies using a stock market valuation approach include Hall (1993) and Doyle (1994).

Awareness that the composition of R&D is important to firm value is growing. Recent studies have indicated that some degree of success in both product and process innovation is necessary for a firm to be successful over the long term (Capon et. al., 1992). However, product and process R&D may not be equally valuable for all firms or completely independent of each other within firms. Cohen and Klepper (1996) suggest that larger firms benefit more from process innovation than from product innovation. They also suggest that external factors, such as market conditions, can lead to positive appropriability interactions between product and process R&D. Athey and Schmutzler (1995) suggest that long-run organizational design factors such as 'flexibility' may contribute to 'complementarities' (i.e. positive externalities) between product and process innovation that enhance the overall innovativeness of the firm and thus its long-run competitiveness.[4]

Yet, conventional wisdom suggests that firms have difficulty maintaining their efficiency in both product R&D and process R&D simultaneously over an extended period. This is sometimes referred to as a "trade-off" between product and process innovation. A 1993 article in *Harvard Business Review* is typical of this viewpoint.

> ".... either/or dichotomies dictated most managerial choices. A company could pursue a strategy of providing large volumes of standardized goods

[4] The term flexibility has been used in the economics literature to refer to a variety of concepts, although some of these concepts are closely related. For example, Moroni (1992) describes what he terms 'production flexibility', which he vaguely defines as the capacity of the firm to adjust to variations in external conditions. This definition of flexibility encompasses 'strategic flexibility', such as "the ability to change production processes, production elements endowments and the qualities of outputs in relation to changes in environmental conditions" (p. 168). It also includes the concept of 'operational flexibility', which "is related to the possibility of varying the quantities produced within a given mix, using a given productive structure." (p. 168).

or services at low cost, or it could decide to make customized or highly differentiated products in smaller volumes at a high cost. In other words, companies had to choose between being efficient mass producers and being innovative specialty businesses. Quality and low cost and customization and low cost were assumed to be trade-offs." (Pine, et. al., p. 111)

In this instance, U.S. automobile makers, in response to Japanese competition, adopted a variety of new organizational designs in an effort to overcome this trade-off and improve their competitiveness. To an extent, these designs, such as product teams, were successful; but they also created other problems, "Cross-functional coordination has improved, but at the cost of depth of knowledge within functions." (Sobek et. al, p. 37).

Anecdotal evidence of this apparent trade-off between success in one type of innovative effort and another abound. General Motors, IBM, Xerox, and Motorola, to name a few, have had technologically superior products in the past. However, despite their great size and obvious market power, each has had its ability to create or leverage innovative and technologically competitive products questioned (Chesbrough and Teece, 1996).

In addition to the research noted above, the potential for intra-firm interactions is reflected in the management science and organizational theory literature. This school of thought puts more faith in the notion of trade-offs than complementarities because they tend to view the firm as a complex, multi-function organization, rather than as a profit maximizing entity.[5] In general, theories of the firm other than the standard neoclassical economics viewpoint allow much more room for intra-firm interactions and sub-optimizing behavior.

Unfortunately, few theoretical models have been developed that account for the distinction between product innovation and process innovation. Of these, most tend to focus on the relationship between ex-post complementarities associated with appropriability and firm behavior. They generally ignore any factors that might impose constraints on firm behavior.[6] In chapter 2, a theory of R&D allocation is developed that takes into account organizational constraints and market conditions that can form the basis for interactions between product innovation and process innovation. The efficiency of overall R&D may be affected positively, negatively, or not at all by these interactions. In chapter 3, using a relatively new set of data, the contribution of R&D composition to firm profitability is investigated empirically. In particular, the relative value of product R&D and process R&D is examined, along with an investigation of the potential for interactions between product and process R&D.

In summary, the ability to measure the returns to different types of R&D will provide new insights into how the allocation of innovative resources affect an organization's profits and equity values, and how outside factors may influence these

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[5] Theories of the firm other than the standard neoclassical theory include contractual relationship theory, principal-agent relationship theory, decision theory, etc. See Tirole (1990).

[6] For example, Cohen and Klepper (1995) devise a model whereby firms choose to invest in product or process innovation based solely on profit incentives. They find that these incentives are complementary, but fail to consider the possibility of constraints in the firm's maximization problem. Klepper (1996) develops a model of product and process R&D based on this same incentive principle to explain many of the stylized facts of the PLC. It works rather well, but is too general to be useful from a policy perspective.

choices. The results of these inquiries can lead to improved R&D allocations by improving the information upon which the organization bases its R&D decisions. The results also will be a step forward in the quest to improve public policy towards R&D by providing policy makers with a better understanding of the determinants of firm innovativeness. For instance, one might argue that the R&D tax credit, depending upon how it is structured, benefits one type of R&D more than another, resulting in a sub-optimal allocation of R&D resources. Thus, a better understanding of the relative value of different types of R&D and the different conditions favoring each type would lead to a more efficient structure for the R&D tax credit.

The study is organized as follows. The review of the literature is presented in chapter I. Chapter II contains a theoretical framework and model for R&D allocation. Data, empirical specifications, and empirical results are contained in Chapter III. A summary of results and some opportunities for further research are presented in the Conclusion.

I. REVIEW OF THE LITERATURE

Innovation has been defined as "an idea, practice or a material artifact perceived to be new by the relevant unit of adoption" (Zaltman et al. 1973, p. 10) and "... the search for and the discovery, development, improvement, adoption and commercialization of new processes, products, and organizational designs and procedures" (Jorde and Teece, 1992).[7] This chapter presents a review of the literature on innovation, with a focus on research pertaining to conditions, behaviors, and structures that influence firm-specific innovation performance and value. I will discuss product, process, and other types of innovation and the influences of firm organization on the performance of each. Throughout this section I discuss the implications for innovation performance and behavior at the firm level. Finally, I discuss the returns to innovation in terms of determinants and measurement issues.

A. Product, Process, and Other Types of Innovation

Generally, product innovations affect the demand curve and process innovations affect the supply curve. Lee and Stone (1992) find that higher product R&D in an industry is correlated with higher price levels in the industry, while higher process R&D leads to

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[7] Innovation and invention are often confused. Innovation is a much broader concept – one that encompasses the entire process of developing a new product or process and bringing it to market. Invention is critical but it is merely one facet of the entire innovation process. Scherer and Ross (1990) define invention as the "act of insight by which a new and promising technical possibility is worked out..." (p. 616).

lower overall prices. More formally, product innovation has been defined in terms of any new product introduced by the organization (Knight 1967), or more broadly as any emerging technology or combination of technologies (Utterback and Abernathy, 1975). Tornatsky (1983) extends these to apply to any of the above that are exploited to produce goods for consumption. Process innovation, on the other hand, has been defined as "any operations technology that is new to the adopting organization," (Collins et. al., 1988, p. 1) or "a change in the way products are made or delivered" (Tushman and Nadler, 1986, p. 76). A broader definition put forth by Knight (1967, p. 482) defines process innovation as the "introduction of new elements in the organization's task, decision, and information system or its physical production or service operations."

The idea that a product innovation affects the demand curve implies that the intent of a product innovation is to achieve two related goals: (1) retain or increase market share (either by introducing a new product or improving an existing one) and (2) widen the price-cost margin by increasing the price (value) of an existing product or create value by introducing a new product. By extension, any change to a product that results in no new market share nor the ability to raise prices, all things being equal, can not truly be considered a commercial product innovation (at least not a successful one). In other words, one must apply the following litmus test; if one holds market share constant, does the innovation allow the firm to increase price? Alternatively, will demand for the product increase while price is held constant? If the answer to either question is yes, then the innovation can be considered a product innovation.

Again, the definition of a process innovation typically is dependent upon how it affects supply. For instance, Kamien and Schwartz (1982) define process innovation within the context of productivity increases. They state that contributions to increases in productivity over time arising from technical change can be associated with shifts in the production function. Therefore, process innovations are specifically designed to increase the price-cost margin of a product by lowering the costs associated with production, via improved manufacturing techniques and/or equipment (of course, lower costs also may contribute to increased market share).

However, the above definitions of product innovation and process innovation are inadequate in many respects. Most innovations display characteristics of both. Therefore, all innovations can be viewed as existing on a continuum with a pure product innovation at one extreme and a pure process innovation at the other, with most innovations lying somewhere in between. For instance, a given innovation could be viewed as a product innovation by the firm that created it, but a process innovation by a downstream firm that uses it in its manufacturing process. Consumers of the innovation (the downstream firm in this example) can decrease their costs and increase their productivity by using the new or improved good. Producers of the innovation increase their demand and obtain higher profits. In this case, an innovation displays characteristics of both a process innovation and a product innovation depending on who benefits from it. In general, most product innovations, with exceptions such as consumer goods, can be considered someone else's process innovation.

Another illustration of the difficulty of classifying innovations as product or process is the case of a product improvement not only increasing the demand for the product, but also simultaneously becoming easier to manufacture than the earlier version. This would both increase the value of the product and decrease its production costs, thereby exhibiting characteristics of both a product innovation and a process innovation as viewed by a single firm. Conversely, a process innovation may simultaneously reduce the manufacturing costs of a product, improve its quality, and ultimately increase demand. In either case, unlike the previous example, the same innovation is affecting a demand and supply curve in the same market. Therefore, most innovations affect a demand curve and a supply curve either within the same market or in two or more markets.

Bhoovaraghavan et. al. (1996) attempt to address these definitional issues by classifying product and process innovation in terms of consumer choice rather than in terms of supply side/resource allocation. In their view, an innovation is classified as product or process based on the perception of the consumer towards the innovation in relation to an already established product(s) that satisfies the consumer's "core want". The classification of innovation depends upon the additional wants that are satisfied by the new product that were not satisfied by the already existing product(s). "Process innovations are always perceived by the consumer as products that cater to or supplement only existing core wants. Product innovations are perceived by the consumer to be products that either cater to a new core want or supplement existing core wants." (p. 237). Unfortunately, these definitions allow much room for interpretation and still place any innovation on the continuum somewhere between a pure product innovation and a pure process innovation.

Despite the issues with definitions, there are several reasons why drawing a distinction between process and product innovation can be useful. First, studying how firms allocate innovation-related resources provides insight into what industry deems important. Second, product and process innovations, from a macroeconomic perspective, affect the economy in different ways. For example, Japan's economic emergence has been attributed in large part to its focus on process innovation, in contrast to the United State's focus on product innovation (Mansfield, 1988). Third, product innovations are the basis for the creation of new markets.[8] In contrast, process innovations are usually created with the intent to increase productivity, lower costs, and/or redirect existing demand to different producers.

The distinction also helps shed light on strategic interactions among firms. Product innovations are associated with innovative spillovers. Once a product is sold, the innovation is much more difficult to keep from being imitated, even with patent protection. Conversely, process innovations are easier to keep within the firm (Cohen and Klepper, 1998).

Product and process are not the only possible innovation distinctions. Another useful distinction can be made between input and output innovation investments. Input investments include research and development (R&D), physical capital, and any investments undertaken before the innovation is ready for sale. Output investments are those that are intended to facilitate the sale of the innovation once it is at or near its final form. These include advertising, patents, liquidity, legal fees, distribution networks, sales forces, etc. Although much attention is paid to R&D, some estimate as much as half or

[8] New technological trajectories are an important example of this. See CED (1980).

more of the total investment needed for a successful (profitable) innovation usually comes after the completion of the R&D effort (CED, 1980). In other words, an input investment will determine the ex-ante capability to generate an innovation whereas an output investment will increase appropriability, i.e., enhance the ex-post capability to profit from an innovation once it has been created.

Bernstein (1986) incorporates the distinction between input and output investments by decomposing the production function of the firm into three primary inputs: labor, physical capital, and formal R&D. He analyzes the relationship between these inputs in the innovation process and finds two main effects. First, he finds a "substitution" effect among the inputs such that physical capital and R&D are complements, whereas labor is a substitute for the other two. In other words, ceteris paribus, an increase in the expenditure on physical capital also increases the expenditure on R&D, and vice versa, but reduces that of labor. However, increases in inputs presumably lead to increases in output as well, and thus demand increases for all inputs, including labor. He identifies this as the "output" effect. Essentially, there are complementarities (positive interactions) between input investments and output investments.

Innovation-related investment also can be classified as tangible (physical) or intangible. Intangible investment is usually firm specific, such as organizational design, management, firm culture, knowledge, reputation, and informal R&D. A growing literature indicates that intangible capital may play a disproportionately large role in high technology and start-up firms, and is a growing proportion of corporate R&D (Crawford, 1991). This could be attributed to the fact that start-up firms in general do not have the financial resources of larger, more established firms, and are forced to develop other strategies to compete, such as a heavier reliance on superior technology or superior management. Still another reason that firms may be becoming more intangible could be that technology itself is becoming less physical capital intensive and more information oriented (computers, software, internet, etc.).[9]

Innovative activity is categorized often as basic research or applied research. Basic research can be defined as "original investigations that advance scientific knowledge but do not have specific commercial objectives, although such investigations may be in fields of present or potential interest to the ... company" (IRI/CIMS survey documentation, 1999). Applied research can be defined as "Investigations directed to the discovery of new scientific knowledge having specific commercial objectives with respect to products, processes or services" (IRI/CIMS survey documentation, 1999). An innovative firm undertakes both types of research to remain competitive.

Finally, innovative activity, particularly R&D, often is classified as internal or external. Internal innovation is research and development performed in-house, whereas external innovation is outsourced. External R&D can take the form of research joint ventures, purchased R&D, purchased technology, patent purchasing and licensing, limited partnerships, and certain mergers and acquisitions. Crawford (1991) suggests that technology/knowledge gathered outside the firm is a growing proportion of total R&D.

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[9] R&D in general commonly is referred to as intangible, although here I am using the term to differentiate R&D itself.

Mowery (1994) also provides evidence that external R&D is growing in importance.[10]

Given the apparent growing importance of external R&D, treatments of external R&D issues have not been prominent in the literature. Exceptions are Audretsch et. al. (1996) who analyze a data set from a survey of Dutch manufacturing firms. The firms were asked to report whether or not they had conducted external R&D during a specified year (1983). Unfortunately, the amount of external R&D and the type, product or process, was not specified. A probit model was used to compare the frequency of external R&D to a variety of independent variables, such as firm size, capital intensity, skilled labor, amount of total R&D, etc. They find that capital intensity (positively) and skilled labor (negatively) were significantly correlated with external R&D. They explain their findings by theorizing that a high level of 'asset specificity', in this case labor assets (researchers and scientists), tends to increase the value of internal R&D but not that of external R&D. On the other hand, "a highly capital intensive firm will tend to produce a relatively standardized product, which can only be copied with great difficulty by another firm. Thus, ceteris paribus, external R&D is expected to be more prevalent in firms which are capital intensive." (p. 521). This explanation is consistent with Bernstein's (1986) results that showed a complementary relationship between physical capital

[10] The changing nature of technology itself may contribute to the ability of firms to find compatible external R&D. Information technology (computer design, faxes, internet, and e-mail), decreasing barriers to transportation (lighter materials, faster transport, etc.), and other technologies are giving firms access to a larger pool of potential research partners.

accumulation and R&D investment, a significant portion of which, in light of the results reported by Audretsch et. al., may consist of external R&D.[11]

B. Product and Process Innovation within an Organization

Do factors other than profit maximization, such as organizational design constraints, influence the returns to R&D? In general, the standard neoclassical viewpoint of the firm does not allow for intra-firm interactions and sub-optimizing behavior. Other, less restrictive, viewpoints allow a variety of factors to affect the R&D allocation decision and to depart from an exclusive focus on profit maximization. As Athey and Stern (1998) point out, the objective function faced by the agent responsible for R&D decision making is not necessarily limited to the overall economic profits of the firm.

If one views the firm as a bureaucratic organization, with all of an organization's complex interactions, then there are several theoretical reasons to believe externalities may exist between product and process R&D. Athey and Schmutzler (1995) suggest that long-run organizational design factors such as "flexibility" (in either the product or the process dimension) may contribute to complementarities between dimensions that enhance the innovativeness of the firm and thus its long-run competitiveness.[12] They

[11] Gompers and Lerner (1998) suggest that corporate investments in venture-type endeavors can be nearly as successful as private venture capital projects provided they are strategically aligned with the parent company. They find these strategic investments stable over time, which is consistent with the theory that firms use external R&D to address structural shortcomings in their internal R&D program.
[12] See footnote 4.

develop a two-period decision model. In the first period a firm chooses its ability to generate innovations, or in their language, chooses product and process flexibility and physical research capabilities. In the second period the firm takes these as given and maximizes profit by choosing a degree of innovative intensity in both dimensions. Their results suggest that there are complementarities in the innovation process that manifest themselves in three particular ways: complementarities between dimensions in the short-run resource allocation decisions, complementarities between dimensions in the long-run capability decisions, and complementarities between the long-run and the short-run decisions.

Although Athey and Schmutzler support the idea of a positive interaction between product and process innovation, management theory offers some support to the idea that trade-offs, not complementarities, characterize the relationship between product and process innovation. This opposing position is based on the belief that the complexity of the firm necessitates compromises among multiple organizational functions, typically characterized as engineering, marketing, and manufacturing (Clark and Wheelwright, 1993, p. 161). Likewise, Volderba (1998) and Teece et. al. (1997) suggest the firm is composed of a spectrum of 'capabilities'. Chesbrough and Teece (1996) stress the importance of balancing the benefits of centralization against the potential rewards from risk-taking, which over-centralization can undermine.

The idea of the firm as a bureaucratic organization also is common in principle-agent and contractual relationship lines of research. In this spirit, allocation decisions between product and process innovation can be viewed as a function of organizational design. Organizational design is a term that encompasses the administrative and management structure of the firm (how decisions are made), the manufacturing system (e.g. "continuous process improvement" strategies and "teams"), the extent and structure of the distribution network, incentive packages, etc. Organizational design determines how physical capital is used and is an intangible asset (whereas research facilities, equipment, and personnel are tangible in nature).

Hayes et. al., (1988) point out that flexibility in the manufacturing process is important to the long-term survival of the firm, but that within the firm there may be trade-offs between product flexibility and process flexibility. Utterback (1979), echoes this idea, "... conditions necessary for rapid (product) innovation are much different from those required for high levels of output and efficiency in production" (p. 40). Reasons for this trade-off are numerous and include both tangible and intangible factors. For example, a tangible factor could involve the firm's manufacturing equipment. The nature of the equipment may impose constraints on the ability to retool in response to a product innovation that has different manufacturing requirements than the previous product. Intangible factors include organizational and administrative design limitations, such as the failure to learn across functions and projects and/or the existence of cultural rigidities within the firm.[13] For example, Hayes et. al. (1988) describe how the failure to align development "windows" properly between product and process innovations can undermine innovation (pp. 298-99), and they emphasize that strategic interactions

[13] See Hayes et.al (p. 338) for discussions relating to organizational functions. See Ginn (1995, pp. 357-410) for a discussion relating organizational culture to technical creativity.

between the two dimensions are of primary importance to the success of any project.[14] Many of these factors could be characterized as side-affects stemming from problems related to firm size, such as excessive bureaucracy, communication breakdowns, and labor issues.[15]

In the economics literature, the idea of a trade-off is reflected in research that details empirical differences in the intensity and composition of R&D among firms. Acs and Audretsch (1987, 1991) provide evidence that not only does R&D intensity vary among firms in different industries, but among firms in the same industry according to firm size (and other factors). They find that many of the most important innovations are produced by relatively small, new firms, whereas large firms tend to focus on incremental innovations. This implies one or both of the following: (1) firm size provides incentives for larger firms to concentrate on incremental product innovation, or (2) firm size inhibits the ability to create drastic product innovations. Doyle (1994) provides evidence that the *value* of overall R&D varies with firm size in high technology industries. Of course, this suggests the question: does the efficiency/value of product R&D and process R&D vary with the size of the firm, and if so, how?

Whether the interaction, if it exists, is positive, as Athey and Schmutzler suggest, or negative, as much of the management literature implies, could have important consequences for firm evolution. For example, the trade-off hypothesis provides a

[14] For further evidence, see Gruber, 1981. There is also evidence that venture-type corporate programs are more successful and stable if they fit the overall strategy of the corporation (Gompers and Lerner, 1998). The fact that non-strategic ventures are less successful is consistent with the idea that organizational factors are important to R&D.

plausible explanation for Cohen and Klepper's (1996) finding that process innovation increases with firm size. Organizational constraints, be they tangible or intangible, prevent the firm from performing product R&D and process R&D with equal efficiency as the firm grows in size.

If externalities between product and process R&D exist, they will be influenced by observable internal and external firm and industry characteristics. These characteristics are closely linked to organizational factors within the firm and external appropriability incentives.

> "Forces both inside and outside the industrial firm influence the (innovation) process. Outside forces include users' needs, changing prices of inputs, competitive stresses, and government stimuli and regulations. The inside forces include the firm's resource allocations; the product and process technologies themselves; the people, organization, and communication patterns involved in producing innovations, and the technical resources and strengths of the firm" (Utterback, 1979).

In addition, a trade-off would likely be a result of a combination of both organizational design constraints and tangible factors. For example, organizational design constraints may imply that a fertile product-innovating environment requires "a stimulating, supportive leadership and a positive, encouraging organizational climate that

[15] For example, see Hayes and Wheelwright (1984), Utterback (1994).

allows employees to take risks" (Holt and Seetzen (1975), p. 226), whereas a fertile process-innovating environment requires a structured organization with a focus on cost containment and repetition. These goals may very well be mutually exclusive. Creating an environment conducive to one inhibits the ability to create an environment that fosters the other. Furthermore, the firm could be faced with tangible constraints as well. For example, if the firm competes successfully in a market with a relatively fast innovation pace (a short technological-life-cycle), it will be proficient, by definition, at product innovation. However, it will also have less time to develop production efficiencies (process innovate) because the optimal production process may change over the course of the PLC. This will impose additional costs on manufacturing because of the constant need to retool and alter production processes to meet the demands of the new product. In this way, a product innovation may create an externality on the process side by necessitating different production techniques and/or forcing the firm to retool.

Pine et. al. (1993) discuss innovation within the context of mass customization and the problems inherent in establishing an organizational design supportive of both dimensions. They relate a particularly illuminating story about the difficulties Toyota Motor Company encountered as it attempted, beginning in the late 1980's, to transform itself from a firm that focused on 'continuous process improvement' to one which was able to make "... varied and often individually customized products at the low cost of standardized, mass-produced goods" (p 108). Mass customization, in which a firm strives to add additional value to each good produced yet manufacture them at low cost, could be considered a product AND process-improving system. It attempts to increase demand for the product using product enhancements while simultaneously keeping costs to a minimum through process enhancements. As Toyota came to realize, mass customization is an entirely different world than continuous process improvement (whereby a firm endeavors to manufacture goods at low costs -- although with the co-requisite of preserving quality), which could be considered a one-dimensional process innovating system. The authors illustrate this point by noting that after some early success, Toyota was forced to retreat from its goal of becoming a mass-customizer. Part of the problem was the economic recession in the early 1990's, but that wasn't the whole story. Management was forced to acknowledge that "continuous improvement and mass customization require very different organizational designs, values, management roles and systems, learning methods, and ways of relating to customers" (p.109). Whereas process improvement requires a relentless pursuit of quality through a vision of "being the best" and managers constantly striving to tighten the links between processes, mass customization requires a "... dynamic network of relatively autonomous operating units" (p. 110). In attempting to evolve into a firm proficient in innovation in two dimensions, Toyota discovered that success in one dimension may not be compatible with success in the other.

C. Returns to Innovation

1. Determinants

The following discussion is concerned exclusively with returns from private firms and does not consider the determinates or measures of value derived from innovation in the public domain, such as Universities or publicly funded research institutes. With that said, before a firm can undertakes an R&D project it "... must consider the cost of doing research, the probability of succeeding, and the likely degree of competition..." (Quirmbach, 1993).

The cost of doing research is heavily influenced by the firm's level of commitment and its ability to manage costs, which in turn rests upon the efficiency of the firm's organization -- a consideration I already have discussed. The other two considerations, the probability of succeeding and the degree of competition, depend on three types of uncertainty: (1) technological uncertainty, (2) strategic uncertainty, and (3) market uncertainty. Technological uncertainty refers to the possibility that the firm may not possess the necessary technical expertise to develop an opportunity into a viable commercial innovation. Strategic uncertainty arises from the possibility that the firm may not be the first to introduce the innovation to the market. Market uncertainty results from a potential lack of demand from buyers.[16]

An alternative but related way of looking at these considerations, sans costs, is within the conditional probability framework developed by Mansfield et. al. (1977).

They use three success probabilities to characterize the success rate of innovations: (1) the probability that a technical goal will be achieved, (2) the probability that the resulting innovation, conditional on technical success, will be commercialized, and (3) the probability, conditional on successful commercialization, that the innovation will yield a profitable return. On average, 27% of the projects they studied ultimately were profitable.

Mansfield's first success probability corresponds closely to technological uncertainty. His third success probability can be seen to include strategic uncertainty and perhaps market uncertainty. Success probability 2 is less concrete. It could refer to market uncertainty in that the firm decides simply to shelve the product because there is no anticipation of demand. It also could refer to financial constraints, to a firm's inability to adequately take advantage of its resources, or to all of the above. In any case, R&D costs and the rate of success of any of these probabilities most certainly will vary among firms and therefore will depend upon two considerations. First, the characteristics of the firm itself (its assets and organizational design), and second, the characteristics of the industry or industries in which it competes (market conditions).

I have already discussed the impact of organizational constraints on innovation, so I will turn my attention to the importance of market conditions, or "outside forces" in Utterback's terminology, to determine the profitability of innovation. Market conditions provide the external incentives that drive the firm to innovate, and include technological

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[16] Adapted from Encaoua et. al. (1996).

push, market pull, and appropriability.[17] Technological push refers to the idea that there are exogenous technological innovation opportunities that firms can develop and commercialize profitably. Market (or demand) pull refers to the firm's perception of the potential demand for the innovation.[18] Appropriability is the extent to which a firm can capture the new economic rents associated with a product or process innovation, and depends inversely on the extent to which the innovation is a public good.

In regard to the first two conditions, the essential point is that the firm's ability to develop technical opportunities is squandered if it cannot identify which of those opportunities will have a market demand. The ability to both recognize and develop technical opportunities allows a firm to define a set of possible and "demanded" innovations (in the case of a process innovation, the demander can be thought of as the firm itself) which will lead to profitability. Calantone et. al. (1996) point out that although a firm's R&D department responds primarily to technological push factors, without an effective interface with the demand-pull source of innovative ideas, technologically superior products can be developed that fill no need in the marketplace. Thus, an organizational failure can be the cause of a lower success probability 2.

Profit from innovation ultimately is determined by appropriability conditions in the industry. Therefore, of those innovations that pass the first two criteria, the firm must reasonably be sure that the returns are proprietary and large enough to earn a profit. Demand for the product must translate into demand for the product *produced by the firm*.

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[17] Scherer and Ross (1990).

[18] Holt and Seetzen (1975, p. 225) refer to this as "need pull".

If other firms can quickly and cheaply offer a competitive product and compete the economic rents to zero, then the product likely will not pay for its development costs. The level of appropriability in large part is a function of the concentration in the industry, the essential idea behind Schumpeter's Hypothesis. Appropriability also is influenced greatly by patent laws and regulation. See Scherer and Ross (1990) for a discussion of appropriability and patent protection.

Quirmbach (1993) analyzes appropriability under a variety of industry conditions; he considers alternative market structures (Bertrand competition, Cournot competition, and collusion), patent protection or no patent protection, and projects with a high probability of success vs. projects with a low probability of success. He restricts his analysis to product innovation, primarily to cases where patent protection is unavailable and imitation is not immediate. He points out that a higher technical success probability, assuming it is industry-wide, could adversely affect the industry's level of appropriability and reduce incentives to perform R&D. This effect tends to increase as collusion decreases or the new technology exhibits increasing returns to scale.

His results also suggest that the anticipation of post innovation collusion encourages R&D investment in the short run, but realized collusion later may discourage continued R&D investment if patent protection is available. Under his assumptions, patents also are more likely to increase appropriability in industries where new technologies exhibit increasing returns to production. Generally, appropriability is lower in Bertrand industries if the industry is not perfectly collusive (in fact, expected profits are zero if there is more than one firm). Appropriability is generally higher in Cournot industries with the level varying depending on the project parameters.

Although Quirmbach derives a wide range of results under a variety of conditions, he does not consider process innovation. This is an important omission because the level of appropriability can vary between product innovation and process innovation. There is little doubt that revenue incentives to innovate are strong in both dimensions. In addition, it is likely that these incentives are complementary. Recall that studies by Capon et. al. (1992) and Landau and Rosenberg (1992) indicate that those firms who are able to perform well in both areas of innovation are usually the most competitive and profitable. Taking this idea a step further, Cohen and Klepper (1996) develop a model of product and process R&D based on such complementary incentives. They derive a positive relationship between ex ante output and process R&D intensity, as measured by the ratio of process R&D to the sum of process and product R&D. The returns to a product innovation are enhanced if the firm subsequently decreases its production costs via a process innovation. They state their basic relationship as follows:

$$p = fq^{\beta_1} / (fq^{\beta_1} + g(hq + K)^{\beta_2}) \qquad [1.1]$$

where p = the ratio of process R&D to total R&D. The numerator represents the profit maximizing level of process R&D as a function of ex ante output q. The second term in the denominator represents the profit maximizing level of product R&D as a function of q and as a function of K, the additional output derived from new product innovation. The parameters f and g represent industry level technological opportunities for process and product innovation, respectively. The parameters β_i represent the marginal returns to innovation and can differ between product and process innovation.

The implication of equation 1.1 is that the derivative of p with respect to q is positive ".. as long as the marginal return to process R&D declines sufficiently slowly relative to product R&D" (p. 235). Their equation implies that a process innovation will reduce costs and increase the price-cost margin. Both of these factors will increase the returns to a given product innovation which itself increases the price-cost margin but now can be applied to a larger quantity, thanks to the ex-ante process innovation. Given an innovation in one dimension, any improvement in the other will allow an increase in the firm's ability to *appropriate* the returns to the second. These revenue complementarities provide incentives to allocate R&D resources to both types of innovation, but not symmetrically. As the firm's sales grow, the incentive to process innovate begins to surpass the incentive to product innovate, thus implying a positive relationship between firm size (sales) and the returns to process innovation intensity.

Unfortunately, neither Quirmbach nor Cohen and Klepper consider organizational factors in the R&D allocation decision. Although it may be true that improvements in one area lead to more revenue as another area improves, this does not necessarily imply that improvements in one area will make improvements in the other area less costly. Not only are there the usual diminishing returns to R&D investment within a particular dimension, but the rate of diminishment could be affected by the other dimension.

2. Measurement

The value of innovative activity is determined by a variety of factors. Not surprisingly, measuring the value of innovative activity is a complex issue. Regardless of methodology, measuring the returns to innovation requires choosing an appropriate proxy for the innovative activity itself. There are two common candidates: research and development expenditures (R&D) and patents.[19] Both are considered excellent, although not perfect, indicators of the level of innovativeness. Patents are theoretically appealing because they are considered a true output. Griliches (1990) has argued that patent statistics, which are very detailed, are a superior indicator of innovative ability. However, many innovations are not patented. For example, Cordes, et. al. (1987) find that many high technology firms do not patent their innovations because of the short technological-life-cycles in their industries.[20]

R&D, on the other hand, is a better indicator of the effort put forth by the innovator. However, R&D expenditures do not necessarily translate into successful innovations, and R&D spending may not be the only source of innovation. Moreover, R&D expenditure data "are subject to considerable error in reporting; firms are given considerable latitude in classifying activities used for financial reporting" (Doyle,

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[19] Not surprisingly, large corporations are responsible for the majority of both. In 1988, for instance, 73% of the patents granted to US inventors were to corporations (82% of foreign patents were to corporations), with 25% going to individual inventors (Griliches, 1990).

[20] See Griliches (1990) and Hall (1998) for a summary of the advantages and disadvantages of each.

1994).[21] Thus, determining the micro or macro impact of R&D spending on innovation is empirically difficult. However, the situation appears to be improving. In the U.S., Standard and Poor's Compustat data compiles extensive R&D information primarily from 10-K reports to the Securities and Exchange Commission. The National Science Foundation conducts annual R&D surveys, and surveys by others are conducted periodically.[22] Beginning in 1989, the U.K. began requiring firms to report R&D expenditures as a standard accounting practice. In summary, the choice between using patents, R&D spending, or some other metric as a proxy for innovation boils down to methodology and data availability.

Another common issue involves the choice of an appropriate measure for the returns to innovation. Several measures have been used, including profitability itself, profit margin (rate of return), total factor productivity, and market value. For example, a stock market event study measures the change in the market value of a stock before and after a specified event has occurred. The problem is determining the appropriate points in time for the each measurement. This approach often is used to study the impact of patents, although it is important to choose the patent(s) carefully (Austin, 1993). Many patents are redundant because often there are "many viable solutions to a technical problem, and other firms can 'invent around' a given patented solution" (Scherer and

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[21] Mansfield (1986) and Hulten and Robertson (1984) both find that the introduction of the R&D tax credit in 1981 resulted in a considerable amount of non-R&D related spending being reclassified as R&D investment to take advantage of the credit.
[22] Examples include the Industrial Research Institutes R&D survey annually conducted by the Center for Innovation Management Studies (which I use in this study), the survey conducted by Levin, Bohen, and Mowery, 1985, and the European Innovation Monitoring System (EIMS).

Ross (1990) p. 624), and many patents are simply not commercially viable. It is known that the distribution of the value of patents is extremely skewed, and thus many patents contribute little to economic growth.

Other methodologies include creating a metric for innovation success and regressing it against profits (McGrath and Romeri, 1994), or regressing various firm and industry characteristics against the firm's rate of return. Geroski et. al. (1993) use this latter approach to estimate the impact of innovation on the profit margin of a large sample of UK firms. Using the number of significant innovations produced by a firm as their measure of innovativeness, they found that an additional innovation contributed anywhere between 6.1% and 16.5% to a firm's profit margin.

The most common approach to measuring the returns to innovation involves relating total factor productivity to some measure(s) of innovation data (R&D often is the more natural choice because of its input nature). For instance, another study by Geroski (1989) examined the effect of innovation and other characteristics on total factor productivity growth using a sample of 79 industries in the United Kingdom spanning a three-year period. He found that innovation was by far the most important factor in the study, accounting for as much as 70% of observed productivity growth. He also found evidence that the impact of a single innovation is more durable over time than the impact of other factors, such as entry by domestic or foreign firms. Despite the important results from this methodology, this approach and others like it may be difficult to implement for several reasons: first, long lags often exist between R&D spending and the realization of the returns from R&D. The lag introduces uncertainty in the appropriate specification of the model, and disqualifies many sources of data that are not long enough to cover the appropriate time span. Second, a significant lag time between action and the observation of results limits the firm or policy maker's use of the relationship as a tool for planning. Third, the measurement of innovative activities at the firm or industry level can be difficult to match with other inputs, partly as a result of these same lags, and partly because of data limitations. Therefore, it can be difficult to incorporate other inputs, such as other costs, into the analysis (Hall, 1998).

One popular alternative to measuring the returns to innovation, used in this study, is a stock market valuation approach using R&D expenditure data. This approach has gained popularity since it was first introduced by Griliches (1981). The market valuation approach regresses R&D expenditures, other intangible assets, and tangible assets against the market value of the firm. The advantage to this method is that it avoids the problems presented by the lag between R&D and its returns. This method is not a panacea, however, because it is limited to evaluating private firms that are traded on a well functioning financial market, and therefore it does not evaluate the public returns to innovative activity. In addition, it limits the researcher's ability to incorporate line of business data into the study. Nevertheless, it is particularly well suited to measuring the value of intangible assets because it incorporates these assets directly into the valuation equation, thereby leveraging the idea that publicly traded corporations are bundles of assets (such as knowledge, reputation, and tangible assets).

The market valuation approach is basically a variation of the hedonic regression method, which attempts to "determine the marginal value of a particular intangible asset by regressing the market price for firms that possess the asset on various characteristics of the firms" (Hall (1998), p. 4). In the market valuation of R&D application, one measures the marginal value of an additional dollar of investment in a given type of corporate asset, namely R&D. A central issue with this methodology is the method of valuing the firm. The method most often employed follows traditional finance literature. The market value of the firm is determined by the present discounted value, or net present value, of its expected cash flow into the future.

$$V = NPV(discounted\ cash\ flow)\ . \qquad [1.2]$$

In the finance literature, cash flow to the common stock owner usually is represented by current and future expected dividends. In turn, the dividends paid out by the firm will be a direct function of its earnings, or income stream.

$$V_{i,t} = NPV(income\ stream\ (dividends))\ . \qquad [1.2']$$

A more explicit representation of Equation 1.2' is the following:

$$V_{i,t} = Income_t + Income_{t+1} /(1+k) + Income_{t+2} /(1+k)^2 + \ldots + Income_{t+n} /(1+k)^n \quad [1.2'']$$

where k is the required rate of return on the common stock. For a depreciable asset, n will equal the number of periods before the asset's value is fully depreciated. All things equal, higher depreciation rates will imply smaller n, reduce the number of terms in the net present value computation, and therefore lower market values. Likewise, higher required rates of return also will lower market value.[23]

Finally, in considering the market value effects of firm assets, it is necessary to control for the expected level of investor risk. Risk comes in two varieties, systematic and unsystematic. Unsystematic risk refers to risk unique to the firm, such as management capabilities, R&D uncertainty, competition, or regulation. Systematic risk refers to risk the variability of a stock's return attributable to factor's affecting the market as a whole, such as interest rate changes, inflation, and consumer confidence. Theoretically, all unsystematic risk can be eliminated through diversification, and thus the reward to bearing risk should depend solely on its systematic risk (Ross et. all. (1995) p. 347). Therefore, the value of an asset depends on its expected cash flow discounted appropriately, where systematic risk is a necessary factor in the discounting process, and influences the investor's required rate of return. In fact, following Doyle (1994, p. 59) the required rate of return, k^*, for a firm can be represented as

$$k^* = r_f + \beta_f(k_m - r_f) \qquad [1.3]$$

where r_f is the risk free rate (e.g. treasury security yield), k_m is the market's expected

[23] Given some simplifying assumption regarding income (or dividend) growth over time, two special cases of equation 1.2'' can be determined. First, if a zero growth rate is assumed, equation 2.1'' simplifies to $V_{i,t} = Income/k$. Second, assuming a constant growth rate in income, equation 2.1'' simplifies to

return on the overall market portfolio, and β_f is the firm's beta. The beta is a traditional financial measure of risk relating the volatility of an individual common stock to the volatility of a broad market index, such as the Standard and Poor's 500, the DOW, or the NASDAQ. Higher volatility relative to the index implies higher risk, but also larger returns.[24] Instead of the interest rate, k^* is used as the discount rate in equation 1.2'' to obtain the net present value of the firm's cash flow/income, and hence its market valuation. Thus, the higher the perceived risk by investors, the higher the beta, the higher the required rate of return, and the lower the firm's market valuation.

In order to apply the above analysis toward the goal of measuring the returns to innovation, the typical model of market value hypothesizes that the discounted value of current and future income, and hence the value of the firm, is a function of its n number of assets:

$$V_{i,t} = f_t(Income\ stream_t\ (A_{1,t}, A_{2,t}, \ldots\ldots A_{n,t})), \qquad [1.4]$$

or more simply,

$$V_{i,t} = f_t(A_{1,t}, A_{2,t}, \ldots\ldots A_{n,t}) \qquad [1.4']$$

$V_{i,t}$ = *Income(1+g) /(k-g)*, where g is the growth rate.

[24] In some cases, rather than the beta, the Standard & Poor's ranking of earnings and dividend stability is used (Hirschey, 1982).

In the case of constant returns to scale of the profit function and a single asset, we obtain the familiar result that the market value of the firm is a product of the book value of its assets times a 'shadow price', commonly referred to as Tobin's q.

$$V_t = q_t\, g(A_1, A_2, \ldots\ldots) \; . \qquad [1.5]$$

Several assumptions underlie this method: first, it is assumed that firms invest in these assets in a value-maximizing manner. Second, appealing to the efficient markets hypothesis, it is assumed that the financial market on which the firm trades is efficient, and that all optimal asset trades have occurred. Finally, although the true functional form of the function f (or g) is unknown, it is assumed that a satisfactory approximation exists. Typically, and primarily for econometric considerations, these approximations assume a linear or a traditional Cobb-Douglas form.

The assets within the function f generally are classified as tangible or intangible. Tangible capital usually is represented by the book value of the firm at time t, and intangible capital reflects the stock of knowledge capital and advertising capital at time t. Advertising capital, typically represented by the sum of the weighted flow of advertising expenditures over the previous x number of years (typically 5 years), reflects the value imputed from the product's reputation. Likewise, the flow of R&D expenditures over the previous x number of years is used to represent knowledge capital. The method of weighting previous expenditures varies from study to study. Occasionally, current profits or cash flow is included in the valuation equation to account for market power or long-run profitability not related to advertising or R&D (Hall, 1993 and Hirschey, 1982). Also occasionally, the growth rate of sales is included as a proxy for expected future growth of the firm, which some view as an important factor in common stock valuation (Hall, 1993).

Given the above, several specifications for estimating market valuation are possible. After taking the natural logarithm of both sides and applying approximations, the linear model and the Cobb-Douglas model as specified by Hall (1998) are

$$Log\ V_{i,t} = log\ q_t + \sigma_t\ Log\ A_{i,t} + \gamma_t\ K_{i,t}/A_{i,t}\ , \qquad [1.6]$$

and

$$Log\ V_{i,t} = log\ q_t + \sigma_t\ Log\ A_{i,t} + \alpha_t\ Log\ (K_{i,t}/A_{i,t})\ , \qquad [1.7]$$

respectively, where $V_{i,t}$ represents the market value of the firm at time t, q_t is Tobin's q, which in the regression represents the intercept term, $A_{i,t}$ represents tangible assets, and $K_{i,t}$ represents intangible assets. The last term in each specification is expanded additively to include each type of intangible asset: advertising, R&D, risk, and any other included terms.

Alternatively, some researchers, notably Hirschey (1982) and Doyle (1994) specified valuation equations without the log transform. Like Hall, Hirschey used the ratio of intangible assets to tangible assets as independent variables, while Doyle refrained from using ratios, instead preferring to apply a Taylor expansion to equation

1.5. One advantage to Doyle's methodology is that it more easily lends itself to working with first-differenced equations. If the time period over which the data extends is of short duration, as is often the case, it may be difficult to construct a reliable measure of the stock of intangible capital, and transforming the data through first-differencing allows the researcher to work with flow variables instead of stock variables. Furthermore, first-differencing allows more flexibility in the treatment of risk.

According to Hall (1998), researchers using United States data on manufacturing firms typically find that each dollar invested in R&D leads to an additional market capitalization of between \$2.5 and \$8, with the stock of R&D valued between 0.5 to 2 times the value of ordinary assets. Despite expectations to the contrary, the addition of industry specific dummies does not change the estimates on average. Another interesting result is that the shadow value of R&D is not stable over time, and is sensitive to the period examined. For example, the late sixties and seventies was a period of high valuation of R&D, while the late eighties and nineties was a period of low valuation. Hall offers two explanations for this: first, variations in the value of ordinary assets caused the value of intangible assets to vary in an inverse manner. Second, beginning in the 1980's, declines in the value of R&D assets occurred in high-tech industries where the returns to R&D are short-lived. Another possibility, which Hall does not consider, is that financial markets value some types of R&D more than other types. Thus, changes in the composition of R&D over time will change the valuation of intangible assets as a whole.

II. THEORETICAL FRAMEWORK AND MODEL

Geroski (1995) stated that "entry appears to be relatively easy, but survival is not" (p. 435). Clearly, the firm's ability to adapt to changing market conditions will determine whether it survives. In my view, an essential component of this process of adaptation is the efficient allocation of R&D resources between the product dimension and the process dimension within the constraints of the organization. Organizational design is an essential ingredient for analyzing innovation. In the theory that follows, the purpose of defining organization-related concepts is not necessarily to build a model using each concept, but to provide a reasonable explanation for observed R&D allocation strategies and the value placed on them by financial markets.

This section develops a theoretical model that describes the firm's allocation of innovative resources between product R&D and process R&D. I show that investment in organizational design is not necessarily without hidden costs or benefits; organizational strategies in one dimension could interact with strategies in the other to create externalities from one dimension to the other. I first discuss and develop a general framework of the model and define important concepts. Then I develop a corresponding mathematical theory from which I derive some specific hypotheses.

A. Interactions Between Product and Process Innovation

Recall that Acs and Audretsch (1987) and Cohen and Klepper (1996) discuss the idea that the returns to process innovation are greater relative to product innovation as the level of firm output increases. I refer to this as the *appropriability effect*. Specifically, the appropriability effect states that a given process innovation will generate more net revenue than a given product innovation as output increases (when this occurs, I refer to the appropriability effect as positive -- if the reverse is true, I refer to the effect as negative). Thus, there are appropriability incentives to focus innovative efforts on process R&D as output increases. However, incentives do not always translate to behavior. Internal factors necessary for the firm to capitalize on the appropriability effect influence firm allocation strategies, but have not been explored in previous research. For example, a product innovation may require different manufacturing techniques than the firm currently uses, and impose adjustment costs on the process side. In addition, organizational factors likely will influence the effectiveness of innovative efforts in and across dimensions. For these reasons, the existence of the appropriability effect may not provide enough incentive for the firm to allocate R&D resources in accordance with it.

In the model that follows, the basic input that determines the firm's ability to produce commercial innovations, in addition to direct R&D expenditures, is organizational design. I define organizational design as a collection of organizational design practices (ODP's). An ODP refers to a part of the organization with a distinct form of its own and which has a specific function or purpose within the firm. It could be a training program, a specific management structure, an R&D center, a 'total quality management' strategy, a team, an operational learning and control system, etc. Organizational design practices are mechanisms for establishing firm specific capabilities, particularly as they relate to the two innovative dimensions within the firm -- product and process. A well functioning, well-managed organization comprises a collection of ODP's in each dimension, and is highly flexible.[25]

Anderson and Schmittlein (1984) and Milgrom and Roberts (1990) describe a tendency for ODPs to be "clustered" in firms, thereby providing evidence that many ODP's are complementary.[26] This is consistent with Athey and Stern's hypothesis that product innovation and process innovation are complementary. Another plausible hypothesis for clustering may be that some ODP's are more suited for product innovation than process, and vice versa. Those firms with a strategic orientation towards process (product) innovation would naturally tend to have a collection of ODP's more suited to process (product) innovation.

It is also possible that ODP's afford a pathway through which one dimension can interact with the other. This could happen if those ODP's more suited to one dimension are functionally incompatible, or functionally complementary, with ODP's more suited to the other dimension. For an example of ODP incompatibility, suppose the firm has a product innovation ODP comprised of teams organized around specific product lines. A

[25] By flexible I refer to how easily ODPs change and respond to outside stimuli. See footnote 4 for definitions of flexibility.

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subsequent adoption of a process oriented ODP, such as an operational control system, may interfere with the creative flow of the design teams and limit their effectiveness. Therefore, to the degree that these ODPs interfere with each other, the efficiency of the overall organization will be impaired, and the firm will exhibit trade-offs between product and process innovation. In contrast, complementary ODP's would have the opposite effect; they would provide incentives to invest in both dimensions and enhance the effectiveness of the overall organization.

The existence of an interaction may also affect the firm's ability to respond to external conditions. The more likely it is that potential ODP's are incompatible with existing ODP's, the more limitations placed on the firm's ability to change or augment its current OD as market conditions dictate, thereby impairing its flexibility. On the other hand, if ODP's are overall complementary, then the firm should have a higher degree of flexibility, all else equal.

If incompatibilities exist, the firm conceivably could choose to invest primarily in a single dimension. An exclusive collection of ODP's in one particular dimension may allow the firm to reap the benefits of their within-dimension complementarities while avoiding any negative organizational externalities. This will provide it a more efficient, albeit one-dimensional, organization while retaining a high degree of flexibility in that dimension. Of course, there may be adverse revenue consequences down the road. However, a firm may augment its internal R&D with external R&D, thus avoiding negative interactions while maintaining a profitable two-dimensional structure. In

[26] Athey and Stern (1998) develop a method to test for these relationships.

contrast, complementary ODP's would have the opposite effect; they would provide incentives to invest in both dimensions and eventually lead to positive revenue consequences, and provide more flexibility for R&D allocation. The point is that product innovation and process innovation are not conducted independent of each other. It is quite possible that interactions between them, via organizational considerations or some other mechanism, produce either trade-offs or complementarities between dimensions and affect the optimal allocations of product and process R&D.

In summary, it is clear that the appropriability effect will tend to create incentives for higher process R&D activity relative to product R&D activity as the size of the firm increases. However, it also is possible that organizational requirements for successful product innovation may interact with the organizational requirements for successful process innovation in one of two ways: in a complimentary fashion that enhances innovation in each dimension, or as a trade-off that reduces innovation efficiency in each dimension. The implication is that a large enough interaction between product and process innovation, either positive or negative, may interfere with the appropriability effect. For example, a trade-off between product and process innovation could induce the firm to become one-dimensional; that is, abandon innovation in one dimension altogether and focus solely on the other, and look to increase external R&D. Alternatively, an asymmetric spillover from one dimension to the other may significantly change the optimal allocation strategy from one that supports the appropriability effect to one that supports a negative appropriability effect. The following model, which builds upon

Cohen and Klepper (1996), incorporates appropriability incentives and interactions between product and process innovation into a formal structure.

B. The Model

The model that follows is based on Cohen and Klepper's (1996) product and process R&D incentive model. I extend their model to incorporate interactions between product and process innovation while retaining their basic revenue incentive framework.

The goal of the R&D decision-maker is to maximize profit generated from innovative output in each innovation dimension *i*, product and process.[27] Suppose at time *t* the firm introduces a new product variant. The product variant will increase the price buyers are willing to pay for the product, and thus increase the price-cost margin on each unit of output produced. The introduction of a process innovation also will increase the price-cost margin, but through a decrease in the average cost per unit of output. The total revenue generated from either type of innovation will be a direct function of the price-cost margin times the level of ex-ante output.

Following Cohen and Klepper, let q_t denote ex-ante output, measured as the number of units of output sold. In the product innovation dimension, let h_t denote the fraction of the firm's existing buyers that purchase the firm's new product variant, Z_t the units of output produced (and sold) of the new product variant that results from product innovation, and $A_{D,t}$ the time until the market imitates the product innovation (the parameter $A_{D,t}$ reflects the level of competition in the industry). Therefore, the total net revenue generated *from product R&D expenditures* in time *t* can be represented as

$$V_t(D_t) = A_{D,t}(h_t q_t + Z_t)U_t(D_t)\,, \qquad [2.1]$$

where $U_t(D_t)$ represents the price cost margin attained from product R&D expenditures (D_t). The price cost margin is an absolute measure of the increase in the price attained from the product enhancement. It is the difference, attributed to product R&D, between the price of the new variant and the price of the old variant. In an industry that was perfectly competitive prior to product innovation (price equals marginal cost), $U(D_t)$ would be equal to the post-innovation price minus average/marginal cost.[28] To reflect the idea that more product R&D expenditures increases the price cost margin but at a declining rate, I assume $U'(D) > 0$ and $U''(D) < 0$.

In the process dimension, h=1 and Z=0, and thus the revenue generated from *process R&D expenditures* can be denoted,

[27] In the model that follows, I will abstract from any moral hazard that would provide incentives for the decision-maker to invest in R&D in a non profit maximizing manner.

[28] I could have defined Z as a function of ex ante output, q. However, Z is defined as the number of *new* customers attracted to the enhanced product that did not previously buy the obsolete version. Although there may be a relationship, I do not see it as a direct, first order relationship, but as an indirect influence (neither do Cohen and Klepper). Therefore, the parameter h reflects an indirect relationship, and there is no need to define Z as a function of q. Furthermore, this specification does not detract from the basic intuition of the model nor affect the directional impact of the results of the analysis below, but it would complicate the analysis.

$$V_t(R_t) = A_{R,t}q_tU_t(R_t) \quad [2.2]$$

where R_t represents process R&D expenditures. Analogous to product R&D, I assume $U'(R) > 0$ and $U''(R) < 0$. Also analogous to product R&D, $A_{R,t}$ represents the time until the cost advantage is matched by the industry.

Given 2.1 and 2.2, total firm net revenue generated from R&D activities at time t, Π_t, can be represented as,

$$\Pi_t = A_{D,t}(h_tq_t + Z_t)U_t(D_t) + A_{R,t}q_tU_t(R_t) - D_t - R_t. \quad [2.3]$$

This is the basic revenue-incentive framework used by Cohen and Klepper.[29] It implies revenue incentives are greater for process R&D than product R&D as firm ex ante sales increase. However, rather than specify an explicit functional form for $U(*)$, they specify a general form for its derivatives: $U'(R) = m_RR^{-1/\beta}$ and $U'(D) = m_DD^{-1/\beta}$, where β defines the rate at which the marginal return to process R&D and product R&D decline. In other words, the efficiency with which R&D is performed is a direct function of the value of β. The parameters m_R and m_D represent industry level technological opportunities for process and product R&D. They chose this specification for the following reasons: "it is convenient because it allows 'R' and 'D' to be solved for explicitly as a function of q. This makes it possible to characterize the conditions that need to h

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need to hold to obtain the simple intuition suggested above as well as to derive detailed predictions that allow further testing of the model" (p. 234). Although they allow β to vary in theory, they impose the restriction that β is equal for product R&D and process R&D, which implies "the marginal returns to process and product R&D decline at the same rate as a function of the level of process and product spending" (p. 235).

In many respects, Cohen and Klepper's specification of $U(*)$ is extremely powerful in its simplicity, but it is still somewhat limited for my purposes for several reasons. First, they do not consider a possible interaction between product and process innovation. Second, their assumption that β is equivalent in each dimension is somewhat suspect. It amounts to the assumption that each dimension conducts innovative activity with equal efficiency. However, as the previous section demonstrated, this efficiency is dependent upon the organizational design of the firm. Therefore, to the extent that organization design is asymmetric between dimensions, this assumption is unwarranted.

To extend Cohen and Klepper's framework to incorporate the organizational design aspects of innovation, I alter their original specification by defining the price cost margin attained from product R&D as

$$U(D) = m_D D^{\alpha(1+\lambda)}, \qquad [2.4]$$

[29] All variables represent current period and thus the subscript t can be dropped from now on with no confusion.

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where m_D represents the level of technological opportunities in the industry in the product dimension. The parameter α is analogous to Cohen and Klepper's $\beta(D)$; it determines the efficiency with which the firm employs its product R&D expenditures. I assume $0 \leq m_D \leq 1$ and $0 \leq \alpha \leq 1$. The parameter λ represents a spillover effect from process innovation. This parameter lies between negative 1 and one; $-1 < \lambda < 1$.

Likewise, the price-cost margin function for process R&D can be defined as

$$U(R) = m_R R^{\delta(1+\theta)} \qquad [2.5]$$

where $0 \leq m_R, \delta \leq 1$ and $0 \leq \theta \leq 1$.

The discussion in the previous section suggests the parameters α and δ are functions of organizational design. If O_D represent the level of organizational design in the product dimension, then $\alpha = \alpha(O_D)$. Extending this idea further, assume the efficiency of product R&D increases as the level of organizational design increases, but at a decreasing rate, i.e., $\alpha' > 0$ and $\alpha'' < 0$. Likewise, for the process dimension, $\delta = \delta(O_R)$ and $\delta' > 0$ and $\delta'' < 0$.

Finally, the parameters λ and θ represent the interactions between product and process innovation and also are dependent upon organizational design; $\lambda = \lambda(O_R)$ and $\theta = \theta(O_D)$. Thus, if organizational design increases or decreases in one dimension, there are spillovers into the next dimension through these interaction terms. To reflect the idea that the effect of the spillover into one dimension increases as the level of organizational design in the other dimension increases, but at a decreasing rate, and that the increase is in the same direction as the initial sign of the term, I assume $|\lambda'|>0$, $|\lambda''|<0$ and $|\theta'|>0$, $|\theta''|<0$. In addition, assume the interaction is equally dependent on innovation efficiency for each dimension; i.e., $O_R = O_D$ implies $\lambda = \theta$ and $\lambda' = \theta'$. The purpose of the interaction terms is to capture the basic intuition behind the organizational design aspects of innovation outlined in the previous section, and this assumption in no way detracts from this basic intuition. I also make the simplifying assumption that the signs of λ and θ are the same. Therefore, $\lambda,\theta > 0$ implies complementarities between product and process innovation, $\lambda,\theta < 0$ implies a trade-off, and $\lambda,\theta = 0$ implies there is no interaction.[30]

This specification is convenient because it defines an explicit functional form for *U(*)* while retaining the useful properties of Cohen and Klepper's original specification – i.e., it allows *D* and *R* to be solved for explicitly as functions of *q* and the exogenous parameters by solving the first order conditions for *D* and *R*. It also characterizes the impact of organizational design on the effectiveness of R&D expenditures in a manner

[30] Fixing the signs of λ and θ to be the same amounts to the assumption that there is roughly an equivalent spillover effect on each dimension. For most firms, I see no reason for this assumption not to hold. Furthermore, this assumption does not detract from the basic intuition of the model nor affect the directional impacts of the interactions in the analysis below, but it would complicate the analysis.

consistent with the intuition outlined in the previous section.[31]

Equations 2.4 and 2.5 imply that equation 2.3 now can be written as:

$$\Pi = A_D\,(hq + Z)\, m_D\, D^{\alpha(1+\lambda)} + A_R\, q\, m_R\, R^{\delta(1+\theta)} - D - R\,. \qquad [2.3']$$

The relationships between profit, revenue, cost, and each type of R&D are depicted in Figures 1 and 2. It is clear that the optimal (profit maximizing) levels of R&D occur where the slope of the revenue curves equal 1, the slope of the total cost curve. The position of the revenue curve depends on the exogenous parameters in the model. If $A_D m_D > A_R m_R$ then industry effects favor product innovation over process innovation, and total revenue from product innovation will be greater than that from process innovation, all else equal. Likewise, the firm specific efficiency and interaction parameters may favor one dimension over another. In addition, within the same industry, firm specific parameters will determine relative positions of revenue curves. The model allows for the profit maximizing level of R&D to differ for each type of R&D, and for total profit from each type of R&D to differ.

[31] In the analysis that follows, the parameters α, λ, δ, and θ are assumed exogenous to the current period allocation decision. This assumption may not be realistic in that it removes the ability of the firm to control the interaction. However, it is doubtful that organizational changes occur quickly. Athey and Stern (1998) consider such organizational changes as long-run decisions. Therefore, in a static framework like we have here, treating these parameters as exogenous is appropriate. While a static framework limits the power of the model, it simplifies the analysis dramatically, and still allows meaningful results to be derived. A more comprehensive analysis would endogenize these parameters within the framework of a dynamic model. I leave this task to future researchers.

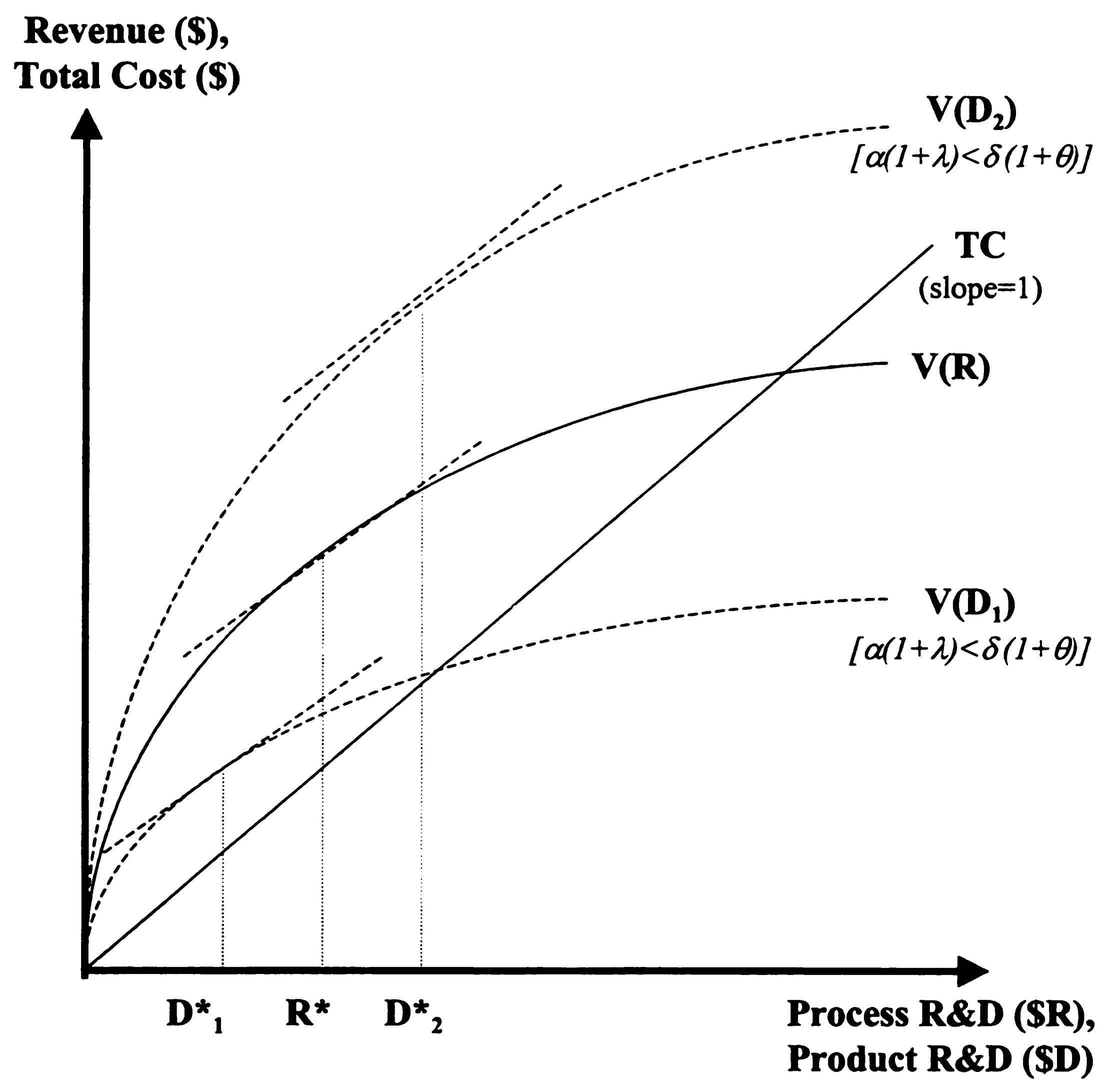

Figure 1. Relationship between revenue, cost, and R&D expenditures.

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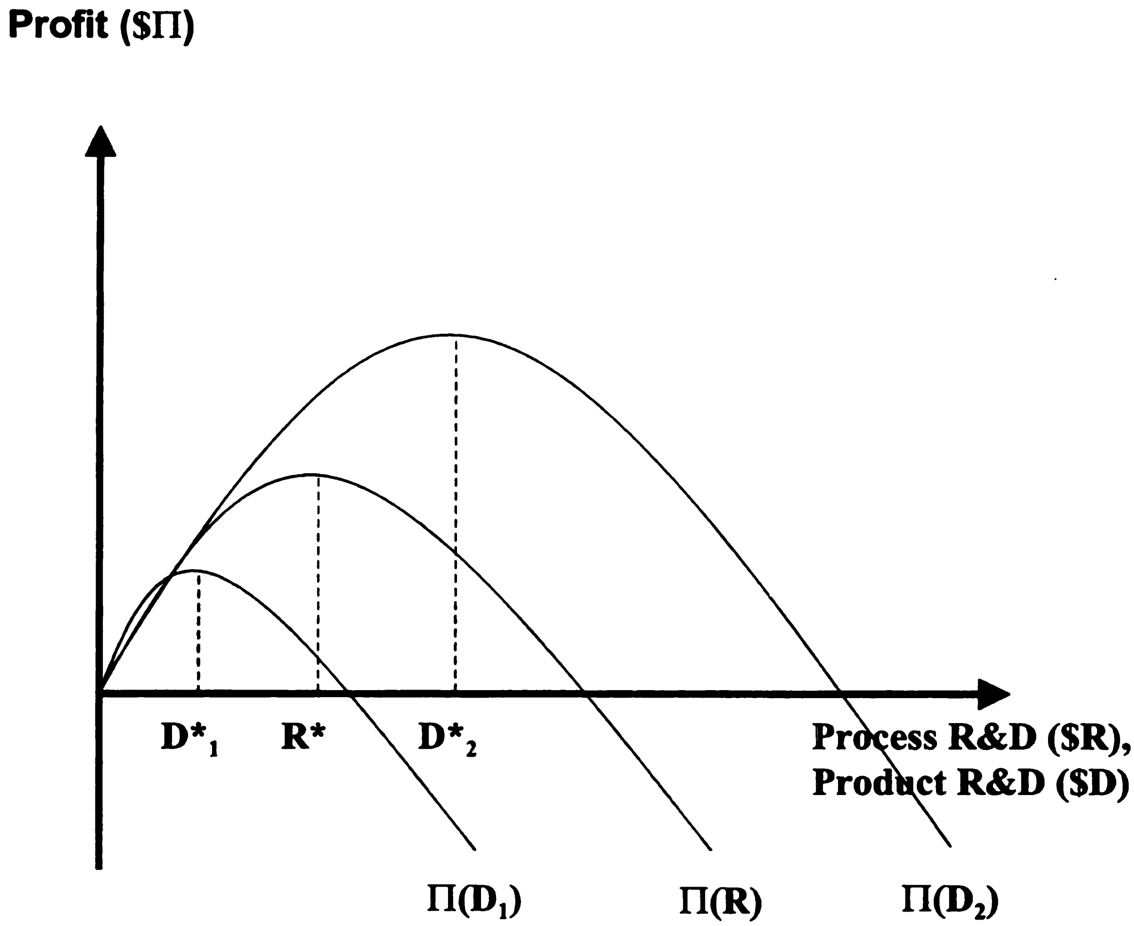

Figure 2. Relationship between R&D profit and R&D expenditures.

An important feature of the model is the dependency between process and product innovation through the interaction terms. By definition, if organizational design is enhanced in one dimension, it increases the efficiency of R&D in that dimension, but it also has an impact on the efficiency of R&D in the other dimension. This implies the following hypothesis:

Hypothesis 1:

The efficiency of product (process) R&D influences the efficiency (and revenue) of process (product) R&D according to the sign of the interaction terms.

To derive further predictions from the model, I first need to derive the profit maximizing levels of product R&D and process R&D. This is determined by setting marginal revenue equal to marginal cost for each type of R&D and solving for D and R. The first-order conditions for equation 2.3' with respect to R&D expenditures are:

$$\frac{\partial \Pi}{\partial D} = \Pi_D = \alpha(1+\lambda)\, m_D A_D (hq + Z) D^{\alpha(1+\lambda)-1} - 1, \qquad [2.6]$$

and

$$\frac{\partial \Pi}{\partial R} = \Pi_R = \delta(1+\theta) m_R A_R\, q R^{\delta(1+\theta)-1} - 1, \qquad [2.7]$$

To prevent the marginal revenue schedules from increasing, I impose the restrictions that $\delta(1+\theta) < 1$ and $\alpha(1+\lambda) < 1$. This ensures downward sloping marginal revenue curves.

Graphical representations of the marginal cost curve and alternative marginal revenue curves are depicted in Figure 3. As the graph shows, higher firm specific parameters in one dimension imply higher profit maximizing levels of R&D in that dimension. Thus, higher optimal spending on product R&D (D^*_2) versus process R&D imply exogenous parameters favoring product innovation. Conversely, unfavorable parameters for product innovation lead to a lower optimal product R&D allocation (D^*_1). In other words, for an equivalent amount of R&D, marginal revenue can be different for different types of R&D. The actual curves will vary from firm to firm based on the values of the exogenous industry and firm specific parameters in the model. Figure 3 demonstrates that if the parameters favor one dimension over the other, the optimal (profit maximizing) level of R&D will be higher in that dimension.

Setting equations 2.6 and 2.7 equal to zero amounts to setting marginal revenue equal to 1 (marginal cost). Doing so and solving for D and R yields the net revenue maximizing levels of product and process R&D:

$$D^* = [\alpha(1+\lambda)A_D m_D(hq + Z)]^{1/(1-\alpha(1+\lambda))}, \qquad [2.8]$$

and

$$R^* = [\delta(1+\theta)A_R m_R q]^{1/(1-\delta(1+\theta))}. \qquad [2.9]$$

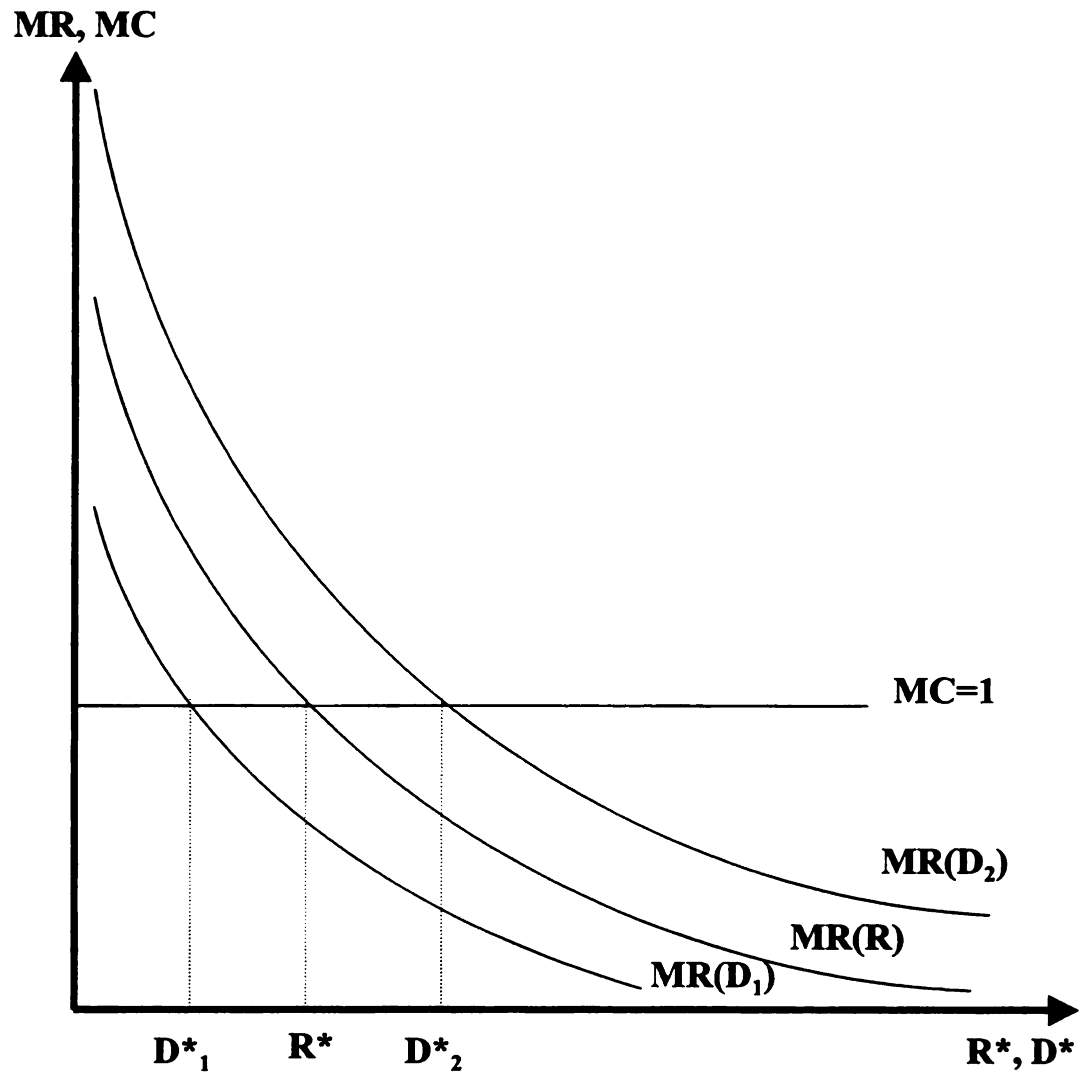

Figure 3. Relationship between marginal revenue and marginal cost.

Using this specification, I can determine if and under what conditions the appropriability effect is positive. Recall, the appropriability effects states that the appropriability of process innovations increases relative to product innovations as firm sales increase. That is, larger firms can generate proportionately more net revenue from process innovation than product innovation. This implies that net revenue from process R&D should be an increasing function of sales. It also implies that the magnitude of the effect of sales on net revenue generated from process R&D should be greater than the effect of sales on net revenue generated from product R&D. Formally,

$$\frac{\partial(\Pi(R) - \Pi(D))}{\partial q} > 0 . \qquad [2.10]$$

Equation 2.3' implies:

$$\Pi(R) - \Pi(D) = m_R A_R qR^{\delta(1+\theta)} - m_D A_D(hq + Z) D^{\alpha(1+\lambda)} . \qquad [2.11]$$

Taking the derivative of this expression with respect to ex ante output q yields,

$$\frac{\partial(\Pi(R) - \Pi(D))}{\partial q} = m_R A_R R^{\delta(1+\theta)} - m_D A_D h D^{\alpha(1+\lambda)} . \qquad [2.12]$$

The case in which we are most interested is the sign of this expression at the optimal levels of product and process R&D. Inserting R* and D*, the net revenue-maximizing values for process and product R&D, respectively, into expression 2.12 and simplifying yields,

$$\frac{\partial(\Pi(R^*)-\Pi(D^*))}{\partial q} = A_R m_R[\delta(1+\theta)A_R m_R q]^{\delta(1+\theta)/(1-\delta(1+\theta))} - hA_D m_D[\alpha(1+\lambda)A_D m_D(hq+Z)]^{\alpha(1+\lambda)/(1-\alpha(1+\lambda))} \quad [2.12']$$

Other than the dimension specific parameters, the primary difference between each term in this expression is the inclusion of h in the second (product R&D) term. Since h is always less than one, this expression will tend to be positive, supporting the appropriability effect. Therefore, the more successful the product innovation at retaining existing customers and attracting new ones, the less likely the appropriability effect will hold. Under the assumptions that all parameters in each dimension are held equal, with the exception of h and Z, the net revenue curves with respect to ex ante sales for each type of R&D are depicted in Figure 4.[32] As the figure demonstrates, the difference in the slopes is determined by h, the proportion of existing accounts retained after product innovation. The intercept (I) for marginal revenue of product R&D occurs at $m_D A_D Z D^{\alpha(1+\lambda)}$. The appropriability effect is supported in the region to the right of the intersection of the two curves. Notice however, if h=1, the curves never cross and the appropriability effect is never positive.

[32] There are two exceptions to this conclusion: first, if the exogenous parameters unduly favor the product dimension, and second, if hq+Z is significantly larger than q. Either of these situations could make the second term in equation 2.12' greater than the first. I examine these situations in more detail below.

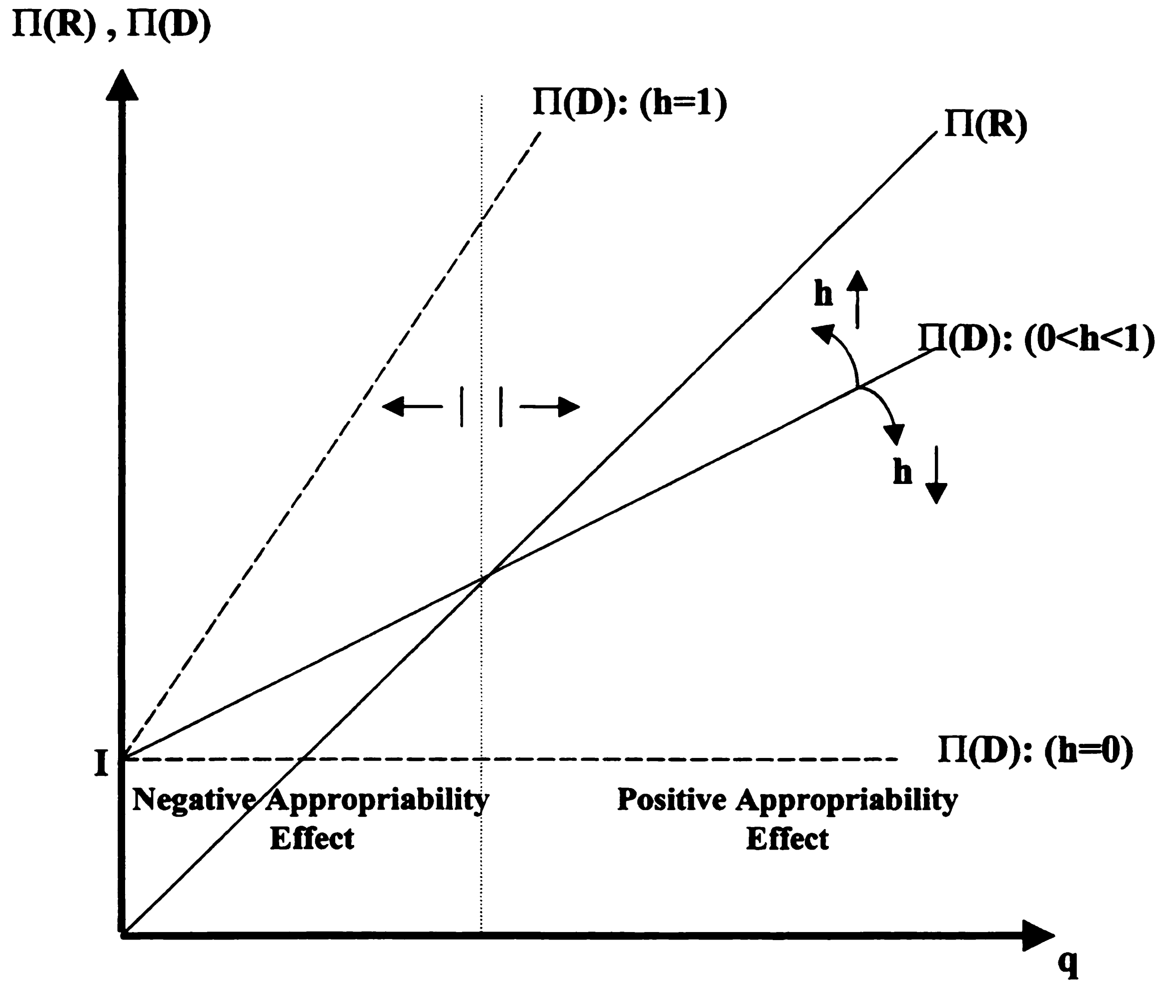

Figure 4. Relationship between marginal net revenue (profit) and ex ante sales for each type of R&D assuming all parameters except h equivalent in each dimension.

Based on the above analysis, one would fully expect the firm's allocation strategy to reflect the appropriability effect. In other words, if the appropriability effect exists and is positive, one would expect the expenditures on process R&D to rise with firm sales at a rate greater than that of product R&D expenditures. Therefore, another way to determine if the appropriability effect exists at the optimal levels of R&D expenditures is to examine the relationship between the firm's optimal allocation strategy and ex ante sales. Define process intensity, P, as the ratio of the optimal level of process R&D (R*) to the optimal level of product R&D (D*):

$$P = \frac{[\delta(1+\theta)A_R m_R q]^{1/(1-\delta(1+\theta))}}{[\alpha(1+\lambda)A_D m_D(hq + Z)]^{1/(1-\alpha(1+\lambda))}} . \qquad [2.13]$$

A positive derivative to this expression with respect to q implies that process intensity rises as firm size increases, and the firm's allocation strategy reflects a positive appropriability effect. In contrast, a negative derivative with respect to q would imply the opposite, and a derivative equal to zero would imply the optimal allocation strategy is independent of firm size. Figure 5 depicts the shapes of the optimal R&D expenditure curves with respect to sales. At zero ex ante sales, it still is possible to have positive optimal product R&D. Generally, the slope of the process R&D curve is larger than that of the product R&D curve, and all else equal, it has more curvature. Figure 6 depicts the relationship between the marginal change in optimal (profit maximizing) R&D expenditures and ex ante sales assuming all exogenous parameters are equal to their counterpart in other dimension.

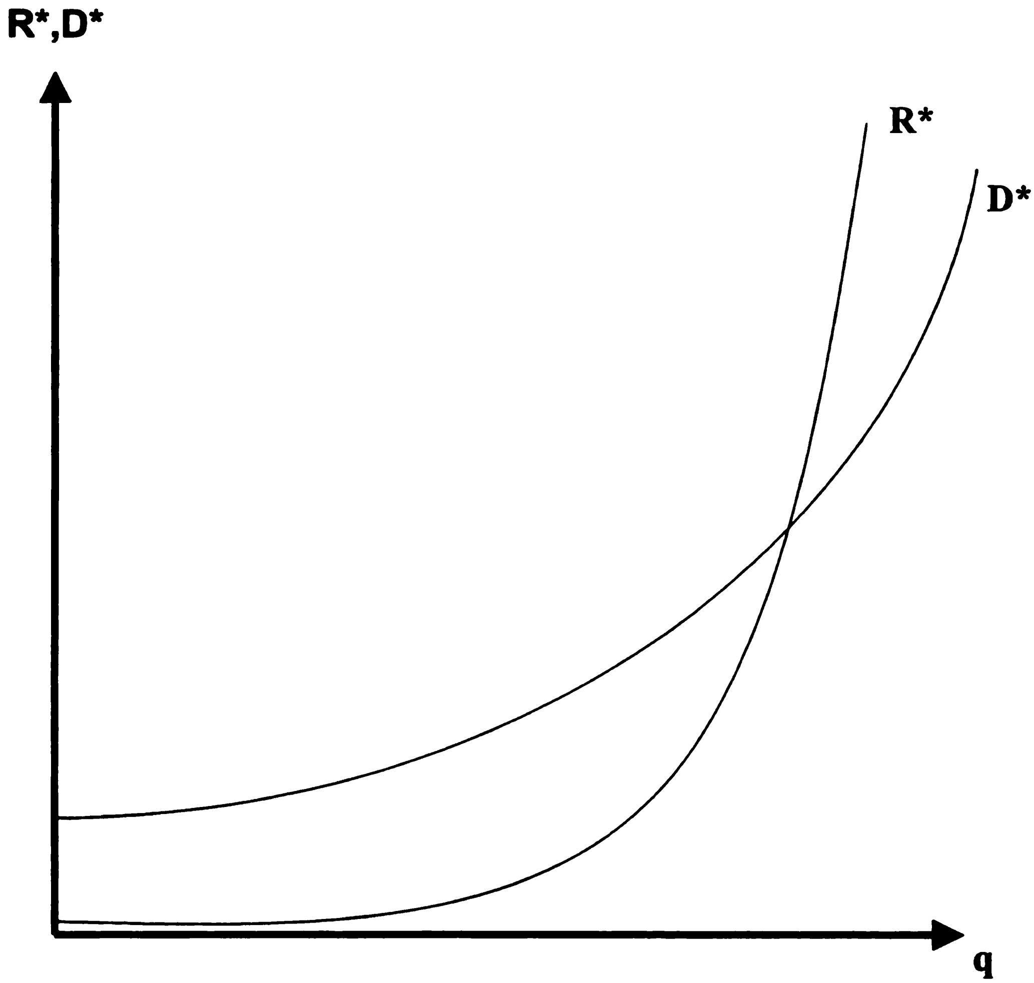

Figure 5. Relationship between optimal (profit maximizing) R&D expenditures and ex ante sales.

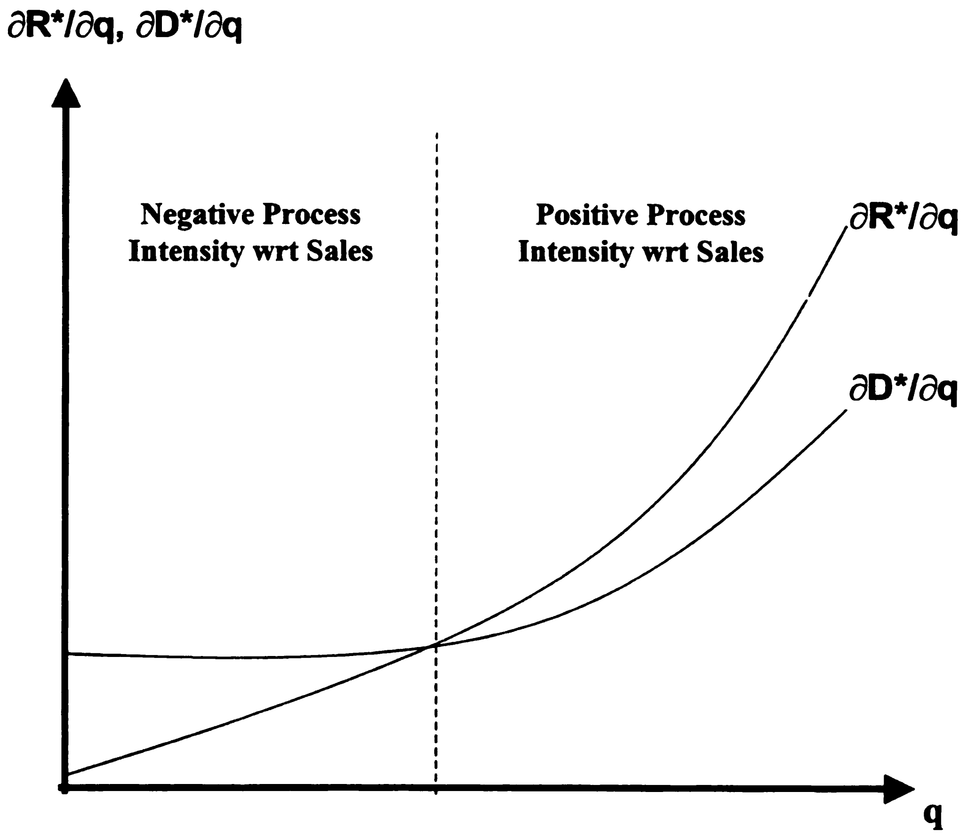

Figure 6. Optimal allocation strategy with respect to sales.

After taking the derivative of this expression with respect to q, one derives the following condition that must hold for the derivative of expression 2.13 to be positive.

$$(1 + Z/hq) > (1 - \delta(1+\theta)) / (1-\alpha(1+\lambda)) . \qquad [2.14]$$

(The proof is provided in appendix A). When this condition holds, firms allocate resources in accordance with a positive appropriability effect.

Expression 2.14 has several interesting implications with regard to the optimal allocation strategy. To simplify things for the analysis below, assume the interaction terms are equal; i.e., $\theta = \lambda$. This assumption means that the spillovers from one dimension to another are symmetrical. This has an implicit assumption that organizational design levels in each dimension are roughly equivalent. Although this may be a strong assumption, it allows me to isolate the impact of first-order changes in the other parameters, and still allows for meaningful analysis of interactions in general.

In expression 2.14, notice that the sign does not depend on industry level parameters A_i and m_i. This implies that industry effects are not critical in determining the optimal allocation strategy with respect to firm size. In addition, unless $Z=0$, the left-hand-side of the equation is always greater than one. Therefore, this expression will always hold if $\delta(1+\theta) \geq \alpha(1+\lambda)$. Since we're assuming the interaction effects are roughly equivalent, this implies positive appropriability effects when the process R&D efficiency parameter is greater than or equal to the product R&D efficiency parameter (in this case the marginal return schedule for process R&D will be larger and less steep than the schedule for product R&D). Although this is a sufficient condition, it is not a necessary condition. Even an efficiency parameter for product R&D greater than that of process R&D does not preclude a positive appropriability effect. Therefore, I expect the appropriability effect should be positive in general.

Hypothesis 2:

As firm size increases, the marginal returns to process R&D will be larger than the marginal returns to product R&D at the optimal allocation.

It is clear that the appropriability effect will be zero or negative if and only if $\delta(1+\theta) \geq \alpha(1+\lambda)$. What is the minimum level of α for which the appropriability effect remains positive? Rearranging equation 2.14 yields:

$$\alpha(1+\lambda) < 1 - \frac{[hq\,(1-\delta(1+\theta)]}{[hq + Z]}\,. \qquad [2.14']$$

If this condition does not hold, then the appropriability effect is not positive. First, note that as Z increases, this condition is more likely to hold. Therefore, the more new customers obtained by the product innovation, the more likely the appropriability effect will be positive. Next, examine the term hq+Z. This term represents the number of customers retained after the product innovation, plus the number of new customers acquired via the product innovation. Therefore, it represents total demand in the current period. If I let g represent the growth rate of sales in the current period, then hq+Z ≡

(1+g)q. That is, demand in the current period will equal demand in the previous period times the growth rate. Solving for Z and inserting the result into equation 2.14' yields

$$\alpha < \frac{1+g+h(\delta(1+\theta)-1)}{(1+\lambda)(1+g)}. \qquad [2.14'']$$

This expression states that the likelihood that the appropriability effect is positive or negative can be determined by examining the following factors: the efficiency parameters of product and process R&D, the interaction terms, the proportion of existing customers retained, and the growth rate of sales.

Any change in the parameters on the right-hand-side of condition 2.14'' that increases the RHS will support a positive appropriability effect, whereas any change to a parameter that decreases the RHS will support a negative appropriability effect. It can be shown that as the efficiency parameter of process R&D (δ) increases, the RHS increases (as one would expect). In contrast, as the proportion of existing customers retained (h) increases, the RHS declines, which does not support a positive appropriability effect (as we concluded from equation 2.12'). In addition, higher growth rates for sales (g) implies a smaller RHS. If $\theta \neq \lambda$, then larger spillovers onto process R&D will increase the RHS whereas larger spillovers onto product R&D will decrease the RHS. However, the effects of the interaction terms are somewhat more complicated when we assume $\theta=\lambda$, or the somewhat weaker assumption that the interaction terms move concurrently. It can be shown, under the assumption that the interaction terms move concurrently, that the condition h<(1+g) ensures the RHS will increase as the interaction terms increase. This condition should always hold. The above analysis implies the following propositions:

Proposition 1:

A positive appropriability effect is less likely to exist when the firm retains a high proportion of its ex ante sales.

Proposition 2:

A positive appropriability effect is less likely to exist in the presence of high sales growth.

Proposition 3:

A positive appropriability effect is more likely to exist in the presence of trade-offs than in the presence of complementarities between product and process R&D.

C. Summation of Hypotheses/Propositions

Hypothesis 1:

The efficiency of product (process) R&D influences the efficiency (and revenue) of process (product) R&D according to the sign of the interaction terms.

Hypothesis 2:

As firm size increases, the returns to process R&D will increase relative to the returns to product R&D.

Proposition 1:

A positive appropriability effect is less likely to exist when the firm retains a high proportion of its ex ante sales.

Proposition 2:

A positive appropriability effect is less likely to exist in the presence of high sales growth.

Proposition 3:

A positive appropriability effect is more likely to exist in the presence of trade-offs between product and process R&D than in the presence of complementarities.

III. EMPIRICAL FORMULATION AND RESULTS

This section applies empirical analysis to the above hypotheses. First, I summarize my data sources and structure. Then, I specify the empirical models for each hypothesis and estimate them using statistical methods.

A. Data

This study uses a relatively recent set of survey panel data developed by the Industrial Research Institute/Center for Innovation Management Studies (IRI/CIMS) from their Annual R&D Survey. The survey encompasses a wide array of information on R&D expenditures from a large cross section of industrial firms. One hundred six corporations participated in the survey, collectively accounting for a large percentage of formal R&D in the United States. The information was collected at the firm, industry segment, and laboratory level beginning in 1992. The data used for this study is annual information covering fiscal years 1992 through 1997, reported at the firm level. It contains information on total firm R&D expenditures and on the type of R&D undertaken. This includes product R&D, process R&D, basic research expenditures, applied research expenditures, support R&D, and external R&D. The data also includes figures on annual sales.

In addition to the survey data, Compustat market valuation data was appended for each firm in the survey. This includes each firm's stock market value at the end of fiscal year, the value of its tangible assets (book value), annual advertising expenditures, and annual sales. Compustat also supplied total annual R&D expenditure data for each firm in the IRI survey. In all but a small number of cases, figures for R&D expenditures and sales as reported from each source tied-out to within a small degree of error.

A number of firms surveyed did not provide complete responses in any given year, and many did not respond at all in some years. Therefore, the survey data contains a number of missing data points. This raises the question of whether the non-responders were chosen randomly. If not, estimates of coefficients on any regression will be biased. Fortunately, Compustat supplied information on total R&D, sales, market value, and asset value for many of the missing and non-missing observations in the survey. A comparison of each variable from each source revealed, with one exception, a similar distribution for data reported in the survey with that of data not reported in the survey but supplied by Compustat. The one exception is total R&D. The average value of R&D expenditures supplied by Compustat is 26.5% higher than survey R&D. This may indicate that firms with higher R&D expenditures were less inclined to respond to the survey, which would imply that estimated coefficients on R&D-type expenditures using survey data alone might be biased downward. However, the survey data includes firms with a wide range of R&D expenditures, with a standard deviation twice as large as the sample mean. This suggests the sample of survey R&D expenditures adequately represent the R&D expenditures of firms in general. Summary statistics of survey responders and non-responders are depicted in Appendix E.

In order to arrive at a consistent sample data set to use for each analysis below, a number of adjustments were made to the original data. First, obvious reporting errors were corrected. Second, two firms were omitted from the sample because of reported average sales in excess of $100 billion, which were nearly twice as high as the next highest sales figures. Omitting these two firms considerably mitigated heteroskedasticity.

Third, advertising expenditures were missing for a large number of firms for some or all years. Therefore, instead of excluding these observations, I employed an instrumental variables approach to estimate the missing values. Advertising expenditures were predicted based on the firm's sales, total R&D expenditures, and tangible assets. Sales was chosen as a variable because it is assumed that the purpose of advertising is to increase brand awareness and therefore sales. Total R&D expenditures and tangible assets were chosen based on Doyle (1994, p. 86), who employed a similar technique to estimate advertising expenditures. First, I run regressions including only those firms reporting advertising expenditures using the following specification:

$$ADV^{*}_{i,t} = \alpha_{i,t} + \beta_1 \, Sales_{i,t} + \beta_2 \, Sales^2_{i,t} + \beta_3 \, RD_{i,t} + \beta_4 \, TA_{i,t} + \varepsilon_{i,t} \; , \quad [3.1]$$

where $ADV_{i,t}$ represents advertising expenditures of firm i at time t, $Sales_{i,t}$ represents sales revenue of firm i at time t, $Sales^2_{i,t}$ is sales revenue squared, $RD_{i,t}$ represents R&D expenditures of firm i at time t, and $TA_{i,t}$ represents tangible assets of firm i at time t. Then, I use these estimated coefficients to compute a firm's predicted advertising expenditures for those firms not reporting advertising expenditures. I also tried the following specifications:

$$ADV^{*}_{i,t} = \alpha_{i,t} + \beta_1\, Sales_{i,t} + \beta_2\, Sales^2 + \beta_3\, RD_{i,t} + \beta_4\, TA_{i,t} + \varepsilon_{i,t}\ , \qquad [3.1']$$

$$ADV^{*}_{i,t} = \alpha_{i,t} + \beta_1\, Sales_{i,t} + \beta_2\, RD_{i,t} + \varepsilon_{i,t}\ , \qquad [3.1'']$$

Results did not differ significantly, although I used specification 3.1 because it yielded a moderately higher adjusted r-squared.

Fourth, 13 firms did not report disaggregated R&D information for any year. Although employing an instrumental variables approach to estimate the missing values as I did with advertising expenditures was considered, there were not enough instruments available to estimate them all. Therefore, these firms were excluded. Furthermore, four firms were excluded because they reported disaggregated R&D information for only one year of the survey and reported zero process R&D expenditures for that year and zero expenditures for at least one other R&D type. This is significant because less than 5% of all firms surveyed with multiple observations reported zero process R&D expenditures in each year they participated in the survey. In addition, only a small minority of firms reported zero expenditures for more than one type of R&D in any given year. Given this, I find it extremely likely that these four observations are unreliable. Finally, although the majority of firms were matched to their Computat market valuation for each year 1992-1997, a small number did not have market value information appended for either 1992 or 1997. Therefore, since the primary unit of observation in each analysis below is the five-year average for each variable included in the analysis (see the next section), a computation of the average market value would be biased for those firms that do not have market values recorded in the first and last years of the survey. Omitting these firms ensures the average market value for each firm in the regression is computed using the exact same time frame. Finally, a number of firms did not have R&D information for each year of the survey. Some firms were excluded based on more than one of the above criteria. However, R&D information is extremely stable from year to year for the overwhelming majority of firms. Therefore, to preserve as large a sample as possible, these firms were not excluded. What remained was a sample of 71 firms. Tables 1, 2a, and 2b furnish summary information for relevant variables before and after exclusions.

Table 1. Summary Statistics: Before Independent Variable Based Exclusions ($MM)					
	# Obs	Mean	Std Dev	Minimum	Maximum
Market Value	83	$10,816	$15,574	$61	$73,929
Total R&D	83	$268	$429	$4	$2,251
Advertising Expenditures	83	$482	$623	$79	$3,157
Sales	83	$8,654	$11,461	$6	$63,554
Tangible Assets (Book Value)	83	$3,038	$3,776	-$322	$17,630
Process R&D	75	$32	$49	$0	$200
Product R&D	76	$150	$306	$0	$1,624
Applied R&D	75	$55	$114	$0	$634
Basic R&D	77	$9	$25	$0	$134
Technical Service R&D	77	$27	$47	$0	$255

Notes: Computed from average firm data over 6 years of survey. All survey firms with valid reported aggregate R&D information are included. Only firms with non-missing market value data in years 1992 and 1997 are represented.

Table 2a. Summary Statistics – Sample Data after Exclusions ($MM)					
	# Obs	Mean	Std Dev	Minimum	Maximum
Market Value	71	$9,500	$12,407	$61	$51,681
Aggreg. R&D	71	$225	$362	$4	$1,526
Advertising Expenditures	71	$467	$583	$79	$3,111
Sales	71	$7,991	$10,593	$6	$63,554
Tangible Assets (Book Value)	71	$2,869	$3,601	-$322	$17,630
Process R&D	71	$33	$50	$0	$200
Product R&D	71	$124	$250	$2	$1,400
Applied R&D	71	$49	$110	$0	$634
Basic R&D	71	$9	$25	$0	$134
Technical Service R&D	71	$28	$48	$0	$255

Notes: Computed from average firm data over 6 years of survey. All survey firms with valid reported disaggregated R&D information are included. Only firms with non-missing market value data in years 1992 and 1997 are represented.

Table 2b. Summary Statistics by Year-Sample Data ($MM)						
	1992	1993	1994	1995	1996	1997
Average Aggreg. R&D Exp.	$212	$231	$219	$235	$237	$257
Average Advertising Exp.	$332	$337	$358	$423	$488	$502
Average Market Value	$6,824	$7,255	$7,407	$9,210	$11,652	$14,916
Average Firm Size ($Sales)	$7,594	$7,494	$7,578	$8,322	$8,859	$8,776
Average Ratio R&D/Sales	5.7	4.9	4.2	3.8	3.8	3.9
Tangible Assets	$2,726	$2,657	$2,862	$2,912	$3,098	$3,166
Average Product R&D	$104	$124	$103	$98	$106	$191
Average Process R&D	$29	$44	$29	$28	$34	$38
Average Applied Research R&D	$27	$32	$31	$50	$41	$70
Average Basic Research R&D	$8	$12	$11	$9	$10	$15
Average Technical Service R&D	$37	$38	$37	$28	$30	$30

Notes: Computed from firms included in final sample dataset (71 firms).

B. Estimation and Results

1. Empirical Framework

The following analysis derives the basic empirical equation used to estimate the returns to innovative activity. It is based on a stock market valuation approach. The stock market value of the firm is an excellent proxy for long-run expected profit because, based on traditional financial analysis, it is assumed that the market accounts for all relevant information about the firm's expected future profitability, including the firm's investment in R&D. I follow common practice and use R&D expenditures as a proxy for innovative activity. Therefore, the stock market valuation approach relates R&D investment to the stock value of the firm. If the stock response to R&D is positive, the market should believe that the expected profitability of R&D investment is positive.

In the market valuation model, the firm's problem is to maximize the discounted value of its future income streams (profits) while accounting for risk. Its market value is a function of the assets it holds, both tangible (TA) and intangible (IA). Let V(*) represent the firm's value function. Generalizing equation 1.3'

$$V_{i,t} = f_{i,t}(A_1, A_2, \ldots\ldots) \ , \qquad [1.3']$$

yields,

$$V_{i,t} = f_{i,t}\,(TA_{i,t}, IA_{i,t}, Risk_{i,t})) \,. \qquad [3.1]$$

Tangible assets refer to physical capital, which can be measured as the book value of all assets held by the firm. Intangible assets comprise knowledge stock and marketing stock. Risk is represented by the firm's beta. Therefore, I can derive the following expression for the value of the firm:

$$V_{i,t} = f(TA_{i,t}, MS_{i,t}, KS_{i,t}, beta_{i,t})) \,, \qquad [3.2]$$

where *KS* represents knowledge capital, and *MS* marketing capital.

As discussed in Chapter 1, the true functional form of equation 3.2 is unknown. For reasons outlined below, I choose to follow Doyle (1994) and use a linear approximation and apply a linear Taylor expansion to equation 3.2. This yields

$$V_{i,t} = \beta_0 + \beta_1\, TA_{i,t} + \beta_2\, MS_{i,t} + \beta_3\, KS_{i,t} + \beta_4\, beta_{i,t} + \alpha_i + \gamma_t + \varepsilon_{i,t} \,. \quad [3.3]$$

The coefficients on each asset variable represent the value response to a change in the level of that asset. The parameter γ_t captures any time series effects that may influence affect market valuations of all firms equally across time. The parameter α_i represents potential unobserved heterogeneity that may result from variables conceivably omitted from the model, and can be considered an individual effect for each firm cross section. If the model is perfectly specified, α_i will be zero and will drop out of the equation. If the model is not perfectly specified, as is likely the case (few models are) then a central issue is the treatment of α_i, the individual effect from each firm cross section. If one uses longitudinal data, as I do in this study, the statistical treatment of the individual cross section effects is crucial to the analysis.

Unobserved heterogeneity can arise from many sources. For instance, the population of interest in this study is all firms who innovate. However, the sample being used may not be representative of this population. The sample excludes many innovating firms based on several factors: firms who do not perform formal R&D, firms not in the survey, firms not operating on well behaved financial markets, and firms in the survey but not reporting complete information (these omissions may indicate self selection bias). Another, perhaps more important, source of unobserved heterogeneity is the omission of a relevant variable. For instance, the market may include information in its valuation equation that is not accounted for in the variables in equation 3.3. Indeed, some specifications in the literature have specified a different and/or broader concept of intangible assets. In addition to the variables specified in 3.3, they have included one or more of the following: earnings, market share, industry concentration (C4), debt, patents, and firm growth rate. My specification assumes most of the explanatory power from these other variables reside in the variables included in 3.3. However, it is possible some information is not accounted for by the included variables, and thus reside in the fixed effect parameter α_i.

If these unobserved effects are constant over time, *and unrelated to the other variables in the model*, then α_i effectively can be ignored, and pooled ordinary least squares will provide consistent and efficient estimates. However, more than likely the effects are related to the other variables in the model, in which case α_i must be dealt with in another way.

Several statistical techniques are available to estimate equation 3.3. The primary focus of each method is to transform specification 3.3 into one that eliminates the fixed effect parameter α_i. One common method of doing this is to first difference the equation. If the effects are constant over time, the fixed effect parameter α_i will drop out of the equation. One advantage to Doyle's methodology is that equation 3.3 can be first-differenced easily. Doing so yields,

$$\Delta V_{i,t} = \beta_1 \, \Delta TA_{i,t} + \beta_2 \, \Delta MS_{i,t} + \beta_3 \, \Delta KS_{i,t} + \beta_4 \Delta beta_{i.t} + \Delta\gamma_t + v_{i,t}\,, \qquad [3.4]$$

where Δ refers to annual changes in each asset. In addition to the elimination of the fixed effect parameter α_i, first-differencing equation 3.3 has several other benefits. First, it alleviates problems pertaining to the creation of appropriate measures of intangible capital. In equation 3.3, because marketing and knowledge capital are measured as stocks, "the amount of knowledge (capital) held by the firm prior to a given point in time is unobservable, and therefore the total amount held an any particular time is therefore unobservable" (Doyle, p. 62). Therefore, using changes in knowledge and marketing stock in any given year, represented by the amount of R&D and advertising investment in that year, avoids this problem. In the absence of first-differencing, marketing and knowledge stocks would need to be constructed from current and past observations of advertising and R&D. This involves inferring depreciation and growth rates of intangible capital flows, which adds another level of complexity to the estimation process and introduces more opportunity for error.[33] A related issue involves the relatively short history of the dataset, which impairs the construction of reliable measures of the stock of intangible capital.[34] One drawback to first differencing is that it assumes the fixed effect is invariant over time. If there is a time element to α_i (such that it becomes $\alpha_{i,t}$) then first-differencing will not eliminate it from equation 3.3, and the coefficients will be biased.

Before proceeding, it is necessary to discuss the treatment of risk in equation 3.4. Risk is an important issue when valuing assets with the stock market. Although the beta coefficient is used as a proxy for systematic risk in equation 3.4, it is unavailable for estimation purposes. However, research has indicated that with regard to the beta, "the stability increases as the length of the estimation period increases – betas are relatively stable for periods of four or more years" (Doyle (1994) p. 62-3). This implies that over the course of 4 or more years, the average change in the beta is expected to be zero. For this reason, I make one further transformation to 3.3'. I average each differenced variable in the model over five years. This results in estimators β_j, sometimes referred to as

[33] For instance, one such method would be to assume knowledge stock equal to current R&D expenditures divided by the sum of the depreciation rate and growth rate; STOCK = R&D$_t$ /(δ+g). For more details on estimating capital stocks from intangible flow variables such as advertising and R&D, see Hall (1990).

b*etween estimators* (Wooldridge, 1995) that use only variation between the cross section observations. Essentially, it is the OLS estimator applied to time-averaged data:

$$\Delta V^*_i = \Delta\gamma^* + \beta_1\ \Delta TA^*_i + \beta_2\ \Delta MS^*_i + \beta_3\ \Delta KS^*_i + \beta_4 \Delta beta^*_i + v_i, \qquad [3.5]$$

where the '*' refers to 5-year averaged first-differences. The advantage to specification 3.5 is that the average change in the beta over five years is expected to be zero, and thus the beta drops out of the equation.[35] Furthermore, the averaged data may alleviate the impact of extreme values that are often associated with survey data. After dropping the beta from the equation, 3.5 becomes:

$$\Delta V^*_i = \Delta\gamma^* + \beta_1\ \Delta TA^*_i + \beta_2\ \Delta MS^*_i + \beta_3\ \Delta KS^*_i + v_i, \qquad [3.5']$$

Unfortunately, if beta is not stable over the 5 year period and it is omitted, then equation 3.5' will be misspecified, and to the extent that beta is correlated with the variables included in the model, the estimated coefficients of the included variables will be biased. One would expect the beta to be most correlated with R&D expenditures

[34] Another common treatment for unobserved heterogeneity is to use "fixed effects" estimation. This technique was employed by Ben Zion (1984), Hall (1993), and Johnson and Pazderka (1993). Instead of first-differencing, this method essentially demeans each cross section by estimating the difference of each variable from its cross section mean. The advantage to this method is that it effectively uses time series data and maximizes degrees of freedom in the regression. However, it still does not correct for time-dependent unobserved heterogeneity. Furthermore, it would be necessary to derive intangible capital stocks.

because they are subject to great uncertainty. However, as Doyle points out (p. 63), it is more likely that R&D intensity, as measured by R&D expenditures as a percentage of firm size, would be correlated with beta rather than the absolute level of R&D expenditures themselves. However, I find no evidence that the average change in R&D intensity is significantly different than zero.[36]

Because first-differencing the data redefines marketing and knowledge stock in terms of annual changes, I can use annual R&D expenditures and annual advertising expenditures as proxies. Substituting these into equation 3.5' yields

$$\Delta V^*_i = \Delta\gamma^* + \beta_1\, \Delta TA^*_i + \beta_2 ADV^*_i + \beta_3 RD^*_i + v_i\,. \qquad [3.6]$$

This is the basic equation used to estimate the returns to innovation. In this expression, ΔV^*_i represents the average annual change in market value over five years for firm i, ΔTA^*_i represents the average annual change in the book value of the firm over five years for firm i, ADV^*_i equals average annual advertising expenditures over 5 years for firm i, and RD^*_i represents average annual R&D expenditures over 5 years for firm i. As is customary, an intercept term is included.

The change in knowledge stock, or R&D expenditures, can be disaggregated further into various types of R&D investment. Let 'Process' represent process R&D,

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[35] Because the beta is omitted, fixed effects estimation would treat it as an omitted variable and add the variation of beta to the fixed effect parameter α_i. For comparison, Appendix C contains fixed effects estimates for each regression below.

'Product' represent product R&D, 'Applied' denote applied R&D, 'Basic' denote basic R&D, and 'Service' represent support service R&D. Equation 3.6 now can be expressed as:

$$\Delta V = \Delta\gamma^* + a_1\, \Delta TA^* + a_2 ADV^* + a_3\, Process^* + a_4\, Product^* \qquad [3.7]$$
$$+\, a_5\, Basic^* + a_6\, Applied^* + a_7\, Service^* + \varepsilon .$$

(The 'i' subscripts are dropped for convenience.) Again, each variable represents a five-year average annual change. In this expression, each coefficient represents the stock response, or the marginal value, of an additional unit of input.

The data includes firms from multiple industries, both manufacturing and nonmanufacturing. Compustat-provided SIC codes range from 1000 to 8700. Therefore, accounting for industry effects is an important issue. In the analysis below, industry dummy variables were included to account for industry effects. However, preliminary analysis indicated that industry terms were not significant, nor did they significantly alter the coefficients of other included variables. Therefore, to preserve degrees of freedom and alleviate collinearity, I omitted industry identifying variables from the final regressions .

Another issue often present in firm level cross sectional data is heteroskedasticity related to firm size. Heteroskedasticity occurs if there is a large disparity between the

[36] The average annual change in R&D intensity as a percent of the average R&D intensity is very close to zero (1.0%).

largest and smallest observations in the sample dataset. In this case, the error term in an ordinary least squares regression will have different variances associated with the different sizes of the observations. Firm size in the sample dataset summarized in Table 2a, as measured by sales revenue, ranges from $5.7 million to $63.5 billion, a significant disparity. Therefore, heteroskedasticity is likely to be present in the analysis. For each regression, a Park test was used to test for heteroskedasticity, which consists of first running an ordinary least squares regression, and then regressing the residuals against the suspected proportionality factor (either sales revenue or tangible asset value). If heteroskedasticity was detected, a weighting scheme was applied to correct for it. Then, the Park test was rerun on the weighted regression to validate the weighting scheme. The weighting scheme is described in detail in Appendix B.

2. *Preliminary Analysis*

Grabowski and Mueller (1978) estimated after tax returns on R&D expenditures of between 15 and 20 percent based on depreciation rates of between 5 and 20 percent. Research that is more recent has used a depreciation rate for R&D capital stock of 15 percent. Other research has estimated that R&D should be capitalized by the market at between 2.5 to 8 times the investment (Hall, 1998), with most estimates centered at 5 to 6. That is, a dollar invested in R&D should increase the market value of the firm by between \$2.5 and \$8. These figures are based on the use of flow-type variables to represent intangible capital, i.e., R&D expenditures per year. Alternatively, knowledge capital stocks can be constructed from current and past R&D expenditures and used in place of the flow variable. These knowledge capital stocks typically are 4-5 times higher in magnitude than the corresponding flow variable, and thus yield coefficient estimates approximately 4-5 times lower than the flow variable coefficients. This is consistent with an average annual return of 20 percent on R&D capital investment.[37] Another empirical result is that the stock of R&D is valued at between 0.5 to 2 times the value of tangible assets.

Before estimating the hypotheses derived in Chapter 2, estimation of equation 3.6 will provide a basis for comparing the returns to innovation using my sample to earlier results. The results of regressing equation 3.6,

$$\Delta V^*_i = \Delta\gamma^* + \beta_1\, \Delta TA^*_i + \beta_2 ADV^*_i + \beta_3 RD^*_i + v_i\,. \qquad [3.6]$$

are summarized in Table 3.

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[37] From Chapter 1, market value is defined as the net present value of current and future income. Therefore, net present value of a \$1 investment in R&D, assuming constant annual returns, is equal to $I/(1+k)+I/(1+k)^2+I/(1+k)^3+I/(1+k)^4+\ldots+I/(1+k)^T$, where I represents per period income (cash flow) generated from the R&D investment. In the limit, this simplifies to I/k. Therefore, $V(RD_S)=NPV=I(RD_S)/k$, where RD_S represents knowledge stock. A simple computation for knowledge stock used by Hall (1993) is $RD_S=RD_t/(\delta+g)$ where δ represents the R&D depreciation rate and g represents the R&D growth rate. This suggests $V(RD_S)=I(RD_t)/k(\delta+g)$. Following Hall, assume a 15% depreciation rate and a 5% growth rate. Also assume a required rate of return of 20%. Inserting V=\$5, k=.2, δ=.15 and g=.05 and solving for I yields an annual nominal cash flow/income of \$0.2 from a \$1 R&D investment, a reasonable cash flow. Note that a larger depreciation rate will result in a higher annual cash flow.

Table 3, regression ii, indicates that the stock response to R&D is 4.7, implying that a dollar invested in R&D is worth \$4.7 to the market value of the firm. This figure is well within the range of previous research. In addition, estimates of tangible assets between 1 and 2 are also within the expected range. A note of caution; the regression of equation 3.6 used the standard dataset of 71 observations. If I add back the observations excluded because of missing disaggregated R&D, I obtain an expanded dataset of 83 observations (the combination of survey data and Compustat data resulted in a fewer missing observations for total R&D than for disaggregated R&D).

The results of regressing equation 3.6 with this expanded dataset indicate a smaller stock response to R&D, approximately 3.8 (regression iv), although still within the range of previous research. The response to tangible assets is moderately higher than before, and the stock response to advertising expenditures is almost unchanged. These results add confidence to my chosen statistical methodology. For further comparison, I ran ordinary least squares estimates on first-differenced variables for individual years. The results of these regressions can be found in Appendix D.

Table 3. Value of Aggregate Assets				
Ordinary Least Squares Analysis				
Dependent Variable	Regression			
	Standard Data (# Obs=71)		Expanded Data (# Obs=83)	
	Unweighted i	Weighted ii	Unweighted iii	Weighted iv
Intercept	-400.55 265.78	-909.73 356.00	-390.92 266.80	-349.33 341.07
ΔTangible Assets	2.048 b 0.815	1.234 c 0.669	1.590 b (0.624)	1.448 a 0.513
Total R&D	5.577 a 0.589	4.663 b 0.557	4.845 a (0.515)	3.790 a 0.433
Adv. Expend.	1.395 a 0.495	2.338 a 0.226	1.707 a (0.398)	2.049 a 0.152
	F Value: 52.11[a] *Adj R^2: 0.687*	*F Value: 131.72 [a]* *Adj R^2: 0.740*	*F Value: 66.68 a* *Adj R^2: 0.706*	*F Value: 127.73 [a]* *Adj R^2: 0.823*

[a] Significant at the .01 confidence level.
[b] Significant at the .05 confidence level.
[c] Significant at the .10 confidence level.

Notes: Standard errors below coefficients. For each regression, the dependent variable is the 5-year average annual change in market value. Weighted statistics are heteroskedasticity-corrected.

Although numerous studies have examined the returns to aggregate R&D, to my knowledge no study has examined the stock value of disaggregated R&D. The results of regressing equation 3.7, both weighted and unweighted, are summarized in Table 4. The weighted results indicate that the stock response to product, applied, and basic R&D are significantly different from zero. However, the basic R&D response is negative. The stock responses to process R&D and technical service R&D are not significantly different from zero. Applied R&D appears to be valued the most by the market; a $1 expenditure indicates an increase in market value of approximately $15. In contrast, basic research is valued the lowest, with an expected change in market valuation of $-29 for each $1 invested in basic R&D.

These results paint a somewhat different picture than the results from regressing aggregate R&D. The expectation is that a rational firm will invest in each asset to the point where the marginal value of each investment is equivalent. However, this does not appear to be the case with regard to investment in different R&D types. It appears basic research and process R&D are not valued by the market, whereas product R&D and applied research are highly valued. What might explain these disparities? One possibility is that basic research is considered riskier than later stages of innovation and the market generally discounts basic research more than other types of intangible assets. This also raises the possibility that unobserved heterogeneity related to risk is much more correlated with basic research and process R&D than other variables, and thus the coefficients are biased. Therefore, it is possible that an omitted variable is causing bias. One candidate for an omitted variable is the growth rate of sales and industry specific indicators. However, the inclusion of these variable did not significantly alter the results.

Another possibility is that basic research is more characteristic of a public good, and therefore firms may have difficulty appropriating the returns from basic research.

Finally, reporting errors may by influencing the results. Public policy measures such as the R&D tax credit provide incentives for firms to report non-R&D investments as R&D, and many government contracts are associated with basic R&D. Therefore, it is quite possible that R&D expenditures are overstated, or the cost of investing in basic research is less than the cost of investing in other types of R&D because the government reimburses basic research expenditures.

Comparing process R&D and product R&D, it is evident that product R&D is valued more highly by the market. This is not surprising from the standpoint that the majority of firms invest more heavily in product R&D than process R&D. As Table 2a indicates, firms invest on average 4 times more in product R&D than process R&D. Applied R&D is the next most heavily invested type of R&D, and thus its high valuation is not surprising.

In summary, it appears the market values more highly those intangible assets that are closer to the "back-end" phase of the innovation process, such as applied R&D and product R&D, presumably because the returns from these types of R&D are more easily appropriated.

Although the statistics are corrected for heteroskedasticity, the regression does not explicitly control for firm size. Therefore, it does not test for the Schumpeter hypothesis; i.e., a relationship between firm size and R&D value. If the market incorporates firm size effects into their valuation, equation 3.7 would not capture it. In the next section, I test for size effects.

Table 4. Value of Disaggregated Intangible Assets		
Ordinary Least Squares Analysis -- # Observations = 71		
Independent Variable	Regression	
	Unweighted i	Weighted ii
Intercept	-338.913 [c] 183.143	-577.292 [b] 251.023
ΔTangible Assets	1.58385 [b] 0.65486	0.85815 0.65843
Process R&D	-14.81394 [b] 6.68049	-6.37705 6.81091
Product R&D	4.30335 [a] 1.21591	4.91704 [a] 1.33121
Applied R&D	19.18513 [a] 2.50408	15.00427 [a] 3.14081
Tech. Service R&D	3.91657 5.40542	7.34025 5.86822
Basic R&D	-14.22789 8.95988	-29.34434 [a] 10.57552
Adv. Expend.	2.04972 [a] 0.39300	2.06155 [a] 0.29935
	F Value: 58.57 [a] *Adj R^2: 0.852*	*F Value: 88.29* [a] *Adj R^2: 0.897*

[a] Significant at the .01 confidence level.
[b] Significant at the .05 confidence level.
[c] Significant at the .10 confidence level.

Notes: Standard errors below coefficients. The dependent variable is the average annual change in market value, $\Delta V_{i,t}$. Weighted statistics are heteroskedasticity-corrected.

3. Appropriability Effect

In this section, I test for the existence of the appropriability effect. According to hypothesis 2, process innovations should generate more net revenue than product innovations as the sales of the firm increase. This should translate to higher valuations for process R&D than product R&D as sales increase. In order to test for this effect, it is necessary to estimate the impact of R&D on firm value at different levels of firm sales. If the stock response to process R&D is larger than the stock response to product R&D, *as sales increase*, then I will have evidence to reject the null hypothesis that the appropriability effect does not exist.

To accomplish this empirically, I incorporate sales-intangible asset interaction terms into equation 3.7 for each intangible asset variable. This yields,

$$\begin{aligned} \Delta V = \Delta\gamma + \alpha_1\, \Delta TA + \alpha_2\, ADV + \beta_2\, Sales{*}ADV + \alpha_3\, Process \quad & [3.8] \\ + \beta_3\, Sales{*}Process + \alpha_4\, Product + \beta_4\, Sales{*}Product + \alpha_5\, Basic & \\ + \beta_5\, Sales{*}Basic + \alpha_6\, Applied + \beta_6\, Sales{*}Applied + \alpha_7\, Service & \\ + \beta_7\, Sales{*}Service + \varepsilon . & \end{aligned}$$

This methodology is based on Doyle (1994), with the difference that I am using disaggregated R&D data. The use of interaction terms allows me to determine the influence of sales on each intangible asset variable by examining the cross partial derivative of the market value change with respect to sales and the intangible asset of interest:

$$\frac{\partial^2 E(\Delta V)}{\partial(Sales)\partial j} = \beta_j, \qquad [3.9]$$

where j represents a particular intangible asset, and β_j its sales interaction coefficient. The parameter β_j represents the stock response to an intangible asset controlling for firm size. In other words, it represents the change in the value of an intangible asset in response to an increase in sales. For example, if j represents process R&D, then the impact of an increase in sales on the value of process R&D would be represented by the coefficient β_3. A positive value of β_3 implies that the value of process R&D increases with firm size, while a negative coefficient implies firm value declines with firm size.

The results of regressing equation 3.8 with ordinary least squares are summarized in Table 5. They indicate that the addition of sales interaction terms changes the interpretation of several intangible asset relationships. For example, the sales-process R&D interaction is positive; as sales increases, the value of process R&D increases. The coefficient is significant, so I can reject the hypothesis of no relationship between sales and process R&D. In contrast, the sales-product R&D interaction term is negative, although insignificant. Therefore, I cannot reject the hypothesis that there is no relationship between firm size and product R&D. Taking these two results together implies that the value of process R&D increases with firm sales at a higher rate than product R&D, exactly as the appropriability effect predicted. Based on this result, I can reject the null hypothesis that the appropriability effect does not exist.

However, the large negative coefficient for process R&D implies investment in process R&D may not be rational for all firms, depending upon their size. The responses to process R&D investment and other types of intangible investments at the mean of firm size are depicted in Table 5b. The Table indicates that both process and basic R&D have negative responses at the mean. In the case of process R&D, firms with sales below $12,403 million will not see positive returns to their investment. For basic R&D, firms with sales greater than $503 million will not see a return on their investment.

Examining the other coefficients, with the exception of advertising expenditures, the value of all other assets decline as sales increases. This implies that, in general, there are decreasing returns to R&D with regard to firm size. This contradicts the Schumpeter Hypothesis. Previous research on the Schumpeter hypothesis has been inconclusive. For example, Doyle found evidence in support of Schumpeter's hypothesis in some industries but not in others. One explanation for these findings is that Schumpeter is supported only for some types of R&D, but not for every type. Therefore, research that has used aggregate R&D to test for the Schumpeter hypothesis were dependent on the composition of R&D in the sample used.

My results also may be influenced by the period I am examining. The 1990's saw high valuations for small and growing high tech firms, which may have increased the value of intangible assets for smaller firms. However, another explanation is likely. Notice that, with the exception of basic research, the stock response to process R&D, at just under $8.4, is lower than other R&D responses. Therefore, the fact that

Schumpeter's hypothesis is not supported is not surprising given that, as firm size increases, the only R&D type that benefits is the type with the lowest valued R&D.

Table 5. Value of Disaggregated Assets Controlling for Firm Size		
Ordinary Least Squares Analysis: # Observations = 71		
Independent Variable	Regression	
	Unweighted i	Weighted ii
Intercept	-134.378 240.522	174.329 255.637
ΔTangible Assets	0.49951 0.61662	-0.02059 0.61325
Process R&D	-27.36846 [b] 12.86930	-56.30779 [a] 13.61608
(Process R&D)*(Sales)	0.00212 [c] 0.00114	0.00454 [a] 0.00101
Product R&D	7.03864 [a] 2.30467	8.80636 [a] 2.38091
(Product R&D)*(Sales)	-0.00016280 0.00017931	0.00021794 0.00014485
Applied R&D	28.45565 [a] 6.53458	36.20305 [a] 6.10977
(Applied R&D)*(Sales)	-0.00150 [c] 0.00076931	-0.00243 [a] 0.00063824
Tech. Service R&D	11.48587 8.03501	18.61951 [b] 8.31112
(Tech. Serv. R&D)*(Sales)	-0.00021191 0.00064738	-0.00102 [c] 0.00051577
Basic R&D	22.92503 18.51254	0.92995 18.11130
(Basic R&D)*(Sales)	-0.00370 [b] 0.00182	-0.00185 0.00159
Adv. Expend.	0.61250 0.80866	0.02385 0.74316
(Adv. Expend)*(Sales)	0.00004772 0.00003486	0.00005227 [b] 0.00002584
	F Value: 49.49 [a] *Adj* R^2*: 0.900*	*F Value: 88.09* [a] *Adj* R^2*: 0.941*

[a] Significant at the .01 confidence level. [c] Significant at the .10 confidence level.
[b] Significant at the .05 confidence level.

Notes: Standard errors below coefficients. The dependent variable is the average annual change in market value, $\Delta V_{i,t}$.

Table 5b. Stock Response at the Mean – Weighted Regression		
Independent Variable	Mean Response	Sales Level at which response = 0*
Process R&D	-20.03	12,403
Product R&D	10.55	
Applied R&D	16.78	
Tech. Service R&D	10.47	
Basic R&D	-13.85	503
Adv. Expend.	0.44	

* If mean response less than zero.

Notes:

I also ran a similar specification using total R&D rather than R&D types to test whether the Schumpeter hypothesis is supported with regard to total R&D. Table 6 summarizes the results for the standard and expanded datasets. Regardless of the data included or weighting, the results indicate that for this sample Schumpeter is not supported. The sales-total R&D interaction term is negative and significantly different from zero.

Table 6b indicates the stock response to aggregate R&D at the mean of firm size is just over $6.6, and that of advertising is closer to $2.

In summary, process R&D is of increasing value relative to product R&D as firm size increases, and therefore I can reject the null hypothesis that the appropriability effect does not exist. The next section investigates the interaction between product and process innovation.

Table 6. Value of Aggregate Assets, Controlling for Firm Size				
Ordinary Least Squares Analysis				
Independent Variable	Regression			
	Standard Data (# Obs=71)		Expanded Data (# Obs=83)	
	Unweighted i	Weighted ii	Unweighted iii	Weighted iv
Intercept	-972.478 a 332.395	-1323.900 a 415.110	-797.435 b 328.577	-1029.773 a 337.330
ΔTangible Assets	1.389 c 0.726	0.995 0.741	2.558 a 0.604	2.562 a 0.568
Total R&D	11.354 a 1.330	8.350 a 1.516	8.709 a 0.971	8.398 a 1.014
Total*Sales	-0.0005 a 0.0001	-0.00025 b 0.00010	-0.00024 a 0.00005	-0.00022 a 0.00005
Adv. Expend.	2.426 b 1.019	3.252 a 0.809	1.749 c 0.985	2.209 a 0.690
Adv*Sales	0.00006 a 0.00002	0.00002 c 0.00001	0.00003 0.00002	0.00002 0.00001
	F Value: *45.53* [a] *Adj* R^2*: 0.761*	*F Value:* *71.08* [a] *Adj* R^2*: 0.834*	*F Value:* *53.49* [a] *Adj* R^2*: 0.762*	*F Value:* *76.26* [a] *Adj* R^2*: 0.821*

[a] Significant at the .01 confidence level.
[b] Significant at the .05 confidence level.
[c] Significant at the .10 confidence level.

Notes: Standard errors below coefficients. For all regressions, the dependent variable is the 5-year average annual change in market value. Weighted statistics are heteroskedasticity-corrected.

Table 6b. Stock Response at the Mean – Weighted Regression		
Independent Variable	Mean Response (Standard Data)	Mean Response (Expanded Data)
Aggregate R&D	6.35	6.64
Adv. Expend.	3.41	2.37

Notes: Mean response computed at a mean sales value of $7,991 MM.

4. *Interaction Between Product and Process R&D*

So far, I have found evidence to support the existence of an appropriability effect. The first hypothesis in Chapter 2, derived from equation 2.3', states:

Hypothesis 1: The efficiency of product (process) R&D influences the efficiency (and revenue) of process (product) R&D according to the sign of the interaction terms.

Essentially, this hypothesis rests on the idea that there are interactions between product and process innovation such that an increase in the efficiency of one will have spillover effects on the value of the other.

To test for an interaction between product and process innovation, I can adapt equation 3.7 as follows:

$$\Delta V = \Delta\gamma + a_1\, \Delta TA + a_2 ADV + a_3\, Process + a_4\, Product \qquad [3.10]$$

$$+\ \sigma(Process * Product) + a_6\, Basic + a_7\, Applied + a_8\, Service + \varepsilon.$$

The difference between this expression and expression 3.7 is the interaction term, Product*Process. The interaction term serves a purpose similar to the sales-intangible asset interaction terms I used before -- it allows me to determine the influence of product R&D on process R&D (and vice versa) by examining the cross partial derivative of the market value change with respect to product and process R&D:

$$Z = \frac{\partial^2 E(\Delta V)}{\partial(Product)\ \partial(Product)} = \sigma, \qquad [3.11]$$

where σ is the interaction coefficient. Z (or σ) signifies the stock response to process (product) R&D controlling for product (process) R&D. In other words, it represents the change in the value of process R&D in response to an increase in product R&D. Or, the change in the value of product R&D in response to an increase in process R&D. A positive value of Z implies that the value of process R&D increases as the value of product R&D increases, and complementarities exist between them. Likewise, a negative coefficient implies a trade-off between product and process innovation. An implicit assumption in this methodology is that the interactions on the efficiency parameters for process and product innovation, θ and λ, *are symmetric. In other words, positive spillovers from product to process innovation are mirrored by positive, and equal, spillovers from process to product innovation.* Although this may be a strong assumption, it is necessary because there are no direct measures of the interaction terms.

The results for equation 3.10 are summarized in Table 7a. The coefficient on the product/process interaction term is positive and significant. This suggests that there are complementarities between product and process innovation, as Athey and Schmutzler (1998) and Cohen and Klepper (1996) suggest. Investment in product R&D would seem to induce benefits to process R&D, and vice versa. The coefficient on the interaction term suggests that, for every dollar invested in product or process R&D, the complementarity between product and process R&D increases firm value by an additional $0.05 beyond the direct effect.

However, the large negative coefficient for process R&D implies investment in process R&D may not be rational for all firms, depending upon their size. The response to process R&D investment and product R&D investment at the mean of firm size are depicted in Table 7b. The Table indicates that process R&D has a negative response at the mean. Firms with sales below $608 million will not see positive returns to process R&D investment.

Table 7a. Interaction Between Product R&D and Process R&D		
Ordinary Least Squares Analysis -- # Observations = 71		
Independent Variable	Regression	
	Unweighted i	Weighted ii
Intercept	-80.233 181.458	-151.883 244.322
ΔTangible Assets	1.511 b 0.598	0.726 0.607
Process R&D	-28.788 a 7.188	-25.768 a 7.913
Product R&D	0.313 1.552	0.709 1.638
Product*Process	0.034 a 0.010	0.041 a 0.011
Applied R&D	18.833 a 2.289	15.820 a 2.792
Tech. Service R&D	11.952 b 5.399	15.609 b 5.888
Basic R&D	-13.828 c 8.184	-28.786 a 9.511
Adv. Expend.	2.068 a 0.359	2.096 a 0.280
	F Value: 63.13 [a] *Adj R^2: 0.877*	*F Value: 89.55* [a] *Adj R^2: 0.910*

[a] Significant at the .01 confidence level.
[b] Significant at the .05 confidence level.
[c] Significant at the .10 confidence level.

Notes: Standard errors below coefficients. For each regression, the dependent variable is the 5-year average annual change in market value. Weighted statistics are heteroskedasticity-corrected.

Table 7b. Stock Response at the Mean – Weighted Regression		
Independent Variable	Mean Response	Sales Level at which response = 0*
Process R&D	-20.68	628
Product R&D	2.06	

* If mean response less than zero.
Notes:

Next, I respecified equation 3.10 to control for firm size, much as I did in the appropriability effect section. Equation 3.10 becomes:

$$\Delta V = \Delta\gamma + \alpha_1\, \Delta TA + \alpha_2\, ADV + \beta_2\, Sales{*}ADV + \alpha_3\, Process \qquad [3.12]$$
$$+ \beta_3\, Sales{*}Process + \alpha_4\, Product + \beta_4\, Sales{*}Product$$
$$+ \sigma_1\, (Process{*}Product) + \sigma_2\, (Sales{*}Process{*}Product)$$
$$+\alpha_5\, Basic + \beta_5\, Sales{*}Basic + \alpha_6\, Applied + \beta_6\, Sales{*}Applied$$
$$+ \alpha_7\, Service + \beta_7\, Sales{*}Service + \varepsilon.$$

The addition of the sales-intangible assets interaction terms serves the same purpose they did before; they control for firm size. Of particular interest in this equation are the interaction terms for product and process R&D. With this specification, I can determine the effect of firm size on the product-process interaction:

$$\frac{\partial Z}{\partial Sales} = \sigma_2 . \qquad [3.13]$$

The parameter σ_2 represents the stock response to process (product) R&D controlling for product (process) R&D and sales. In other words, it represents the change in the value of the interaction between product and process R&D as firm sales increase. A positive value of σ_2 implies that the value of the interaction increases with firm size, and a negative coefficient implies higher firm sales has adverse consequences for the interaction.

The results of regressing equation 3.12 are summarized in Table 7c. The coefficient on the sales/product/process interaction term is negative, but not significant. This suggests that sales plays no significant role in the interaction between product and process innovation.

However, the negative coefficients for several intangible assets imply investment in these assets may not be rational for all firms, depending upon their size. The responses to intangible investments at the mean of firm size are depicted in Table 7d.

Table 7c. Interaction Between Product R&D and Process R&D, Controlling for Firm Size		
Weighted Least Squares Analysis -- # Observations = 71		
Independent Variable	Regression	
	Unweighted	Weighted
Intercept	78.974253 227.226	542.077503 c 273.821
ΔTangible Assets	0.736 0.552	0.127 0.588
Process R&D	-20.686 13.655	-61.728 a 15.636
(Process R&D)*(Sales)	0.0001 0.0015	0.004 b 0.002
Product R&D	-1.818 4.725	-1.382 5.887
(Product R&D)*(Sales)	0.00013 0.00031	0.000234 0.000372
Product*Process	0.043 0.028	0.059 c 0.034
(Process*Product)*(Sales)	-2.58171E-7 0.00000216	-0.0000021 0.0000024
Applied R&D	19.166 a 6.389	30.088 a 6.635
(Applied R&D)*(Sales)	-0.00043 0.00078	-0.004 b 0.002
Tech. Service R&D	18.154 b 9.468	27.035 b 10.875
(Tech. Service R&D) *(Sales)	0.00034 0.00079	-0.0017 0.0008
Basic R&D	49.167 a 18.261	24.668 19.059
(Basic R&D)*(Sales)	-0.006 a 0.002	-0.000968 b 0.000828
Adv. Expend.	0.550 0.726	-0.369 0.724
(Adv. Expend)*(Sales)	0.000036 0.000031	0.000040 0.000025

Table 7c (cont'd).		
	F Value: 55.21 [a] *Adj R^2: 0.921*	*F Value: 86.28 [a]* *Adj R^2: 0.948*
[a] Significant at the .01 confidence level. [b] Significant at the .05 confidence level.	[c] Significant at the .10 confidence level.	

Notes: Standard errors below coefficients. For each regression, the dependent variable is the 5-year average annual change in market value. Weighted statistics are heteroskedasticity-corrected.

Table 7d. Stock Response at the Mean – Weighted Regression

Independent Variable	Mean Response	Sales Level at which response = 0*	
Process R&D	-24.53	14,550	(+)
Product R&D	-0.07	8,391	(+)
Applied R&D	-1.88	7,522	(-)
Tech. Service R&D	13.45		
Basic R&D	16.93		
Adv. Expend.	-0.05	9,225	(+)

* If mean response less than zero. Positive sign indicates larger firms benefit from R&D, negative sign indicates smaller firms benefit.

5. Unobserved Heterogeneity

As discussed in the empirical framework section, the possibility that unobserved heterogeneity, or fixed effects, are driving the results is important to consider when drawing conclusions. Unobserved heterogeneity arises from two primary sources: sample selection bias and omitted variables. In my specification, the parameter α_i represents potential unobserved heterogeneity that may result from variables conceivably omitted from the model, and can be considered an individual effect for each firm cross section, and thus represents potential unobserved heterogeneity. There are several methods for dealing with unobserved heterogeneity. My preferred method was to eliminate the fixed effects parameter, α_i, by first-differencing equation 3.3. This method had the additional benefit of transforming intangible stocks from levels to changes, and thus avoided the problem of estimating intangible stocks.

However, another common technique for eliminating α_i is to use fixed effects regression. In fixed effects regression, instead of first-differencing, one eliminates α_i by using the difference of each variable from its cross section mean as the unit of observation. The advantage to this method is that it maximizes degrees of freedom in the regression because one avoids dropping the initial observation, and it may provide a better treatment for risk. Since the beta is omitted, fixed effects estimation would treat it as an omitted variable and add the variation of beta to the fixed effect parameter α_i. Therefore, because fixed effects regression provides potential benefits versus first-differencing, Appendix C contains fixed effects estimates for each regression performed above. To accommodate the fixed effects methodology, specifications for each regression are slightly different than those specified above. In particular, the dependent variable is the year-end market value of the firm, rather than the annual change in market value. This will imply somewhat different interpretations of the coefficients than those estimated using first differenced observations. The estimated coefficients for R&D and advertising should be larger because they are being regressed against the level of market value rather than a change in the level. However, one should expect signs and significance levels of the coefficients to be similar to those obtained above. Significant differences will indicate evidence that unobserved heterogeneity is driving the results obtained above.

Because of the exploratory nature of this research, several permutations of fixed effects were run for each hypothesis. These include weighted and unweighted regressions, regressions with and without firm intercepts, and regressions with and without a first order autoregressive variance structure (to correct for serial correlation). In general, the fixed effects yielded similar results to those obtained above. Examination of Tables C1 and C2 indicates that, compared to first differencing, fixed effects estimation yields similar estimates for tangible assets, with stock responses between 1 and 2 depending upon the particular specification. Intangible assets are highly valued regardless of the fixed effects specification. The inclusion of firm intercept parameters appears to increase the coefficients on intangible assets and decrease the coefficients on tangible assets, which may indicate firm or industry effects are important to the specification.

Table C3 contains the results of fixed effects estimates testing the Schumpeter Hypothesis. Again, results were similar to those obtained using first differencing. In general, the sales-R&D interaction was negative. Table C4 depicts results for disaggregated R&D expenditures. Like those above, coefficients for product R&D and applied R&D were greater than those for other types of R&D. Table C5 indicates that fixed effects supports the idea that the appropriability effect is positive, and Table C6 yields a positive interaction between product and process R&D.

In summary, fixed effects estimation yielded similar results to those obtained using first differencing. The results of each major hypothesis tested above were corroborated by the fixed effects regressions.

SUMMARY AND CONCLUSIONS

Public policies towards innovation related activities have met with no small amount of controversy. For instance, many have argued that accelerated capital depreciation rules unduly favored investment in physical capital to the detriment of investment in intangible capital (CED, 1986). Another controversial policy was the research and experimentation tax credit, instituted in 1981. Critics of the credit argued that it was not nearly as effective as proponents contended because of various loopholes that existed in the law. They argued the credit had its largest impact in how firms categorized their expenditures for tax purposes; after the credit was introduced, many expenditures previously not considered R&D suddenly and not so mysteriously appeared in the R&D expenditures column on corporate tax forms. Therefore, instead of stimulating R&D, as was its intent, the credit merely induced firms to rename pre-existing investment in other assets as R&D (Mansfield, 1986).

The rationale for government sponsored innovation incentives stems from the belief that the public good aspect of innovation knowledge leads to below-optimal investment in R&D. Supporters of policies such as the R&D tax credit argue that despite the problems, these types of policies push investment in innovative related activities closer to their optimal levels.

One issue often overlooked in these discussions is the relative importance of different types of innovative activity. For example, Japan's economic emergence has been attributed in large part to its focus on process innovation, in contrast to the United State's focus on product innovation (Mansfield, 1988). However, it also is argued that product innovations are the basis for the creation of new markets and thus policies should favor product R&D over other types of R&D. The lesson is that the composition of R&D related activities plays an important role in the performance of the economy, but many aspect of innovation remain poorly understood. This point is equally true from a microeconomic standpoint; the composition of intangible assets likely plays as large a role in a firm's success as the amount of R&D itself.

This paper examines the market value of disaggregated intangible assets. Specifically, it measures the stock response to advertising, physical capital, and various classes of R&D, with a focus on product R&D and process R&D. Previous research in this area has focused on the value of total R&D and its relation to industry or firm specific conditions, particularly firm size, but has not examined the value of different types of R&D. Awareness that the composition of R&D is important to firm value is growing. Recent studies have indicated that some degree of success in both product and process innovation is necessary for a firm to be successful over the long term (Capon et. al., 1992).

I first develop a profit maximizing model that determines the optimal levels of product R&D and process R&D. The results of the model suggest that at equal levels of expenditures, the marginal values of different types of R&D can vary, suggesting different levels of optimal R&D once the profit-maximizing condition of marginal revenue equals marginal cost is imposed. This implication is supported by the actual behavior of R&D producing firms -- product R&D expenditures are on average 4 times greater than process R&D expenditures. Another implication of the model is that the value and/or efficiency of product (process) innovation can influence the returns from process (product) innovation. Finally, the model suggests a variation on the familiar Schumpeterian hypothesis of a positive relationship between firm size and R&D profitability. Rather than aggregate R&D, firm size plays an important role in the relative valuations of process and product R&D. The returns to process R&D should increase relative to the returns to product R&D as firm size increases.

To estimate these implications empirically, I employ a stock market valuation model of the firm. I first estimate the value of tangible and intangible assets. The stock response to total R&D is estimated to be between 3.7 and 4.7 for each $1 invested, a response consistent with a required rate of return of approximately 20%, and well within the range of previous research. Intangible investments closer to the end of the innovation process, such as applied and product R&D, generally are valued more highly than investments at the beginning of the innovation process. However, the stock responses to disaggregated R&D expenditures vary more widely than expected, from a high of 15 for applied research to a low of –29 for basic research. The disparity in estimates may be a function of different rates of depreciation for the intangible assets and/or differences in the ability to appropriate the returns from each type of R&D. However, the most likely explanation is misreported R&D expenditures for basic research and support services R&D. Government contracts for R&D support basic research much more extensively than other types of R&D, and therefore the costs associated with basic research are likely lower than the costs of other types of R&D. Furthermore, incentives derived from the R&D tax credit and similar policy instruments provide an incentive to misallocate non R&D-related investments as R&D. In any case, further research into the returns to disaggregated R&D is called for.

Next, I test the Schumpeter hypothesis that firm size and R&D profitability are positively correlated. In testing this hypothesis, I use firm size-R&D interaction terms and examine the mixed partial derivative of the change in market valuation with respect to both firm size and R&D. The results indicate that Schumpeter is not supported. Firm size is not a positive and significant determinant of R&D profitability. In fact, firm size is estimated to have a negative impact on R&D profitability. I extend this specification to examine the relationship between firm size and different types of R&D. The results tend to support the idea of a positive appropriability effect; i.e., the profitability of process R&D increases with firm size at a greater rate than the profitability of product R&D. Because process R&D expenditures generally are smaller than product R&D expenditures, this may explain the lack of support for the traditional Schumpeter hypothesis.

Finally, I employ interaction terms between product and process R&D to test whether there is a relationship between the two, and how this relationship affects the market value of the firm. I find that product and process R&D are complementary, supporting much of the recent economics literature, but contradicting some strands of management literature.

The stock market value of the firm is dependent upon many factors. Therefore, the potential that unobserved heterogeneity, arising from variables omitted from the model, is driving the results is a valid concern. Fixed effects regression of each major hypothesis provided similar results to those obtained in Chapter 3, and thus fixed effects does not appear to be a significant factor in the analysis.

The opportunities for further research are plentiful. First, the results of this paper should be viewed with caution. It has been shown that the value of intangible assets is not constant over time. The reasons for this may be several: first, variations in the value of ordinary assets may affect the value of intangible assets. Second, declines in the value of R&D assets may occur in high-tech industries where the returns to R&D are short-lived. Finally, changes in the composition of R&D over time may contribute to changes in the measured value of total R&D. Therefore, the possibility that financial markets value different types of R&D at different levels may affect the returns to intangible assets over time. The period examined here, 1992-1997, was a time of very high growth rates for the value of common stocks. Therefore, additional research should be conducted in this area covering different periods. In addition, several implications regarding the appropriability effect were derived from the theoretical model that the data did not allow me to test: (1) a positive appropriability effect is less likely to exist when the firm retains a high proportion of its ex ante sales, (2) a positive appropriability effect is less likely to exist in the presence of high sales growth, and (3) a positive appropriability effect is more likely to exist in the presence of trade-offs between product and process R&D than in the presence of complementarities.

In summary, the ability to measure the returns to different types of R&D will provide new insights into how the allocation of innovative resources affect an organization's profits and equity values, and how outside factors may influence these choices. The results of these inquiries can lead to improved R&D allocations by improving the information upon which the organization bases its R&D decisions. The results also will be a step forward in the quest to improve public policy towards R&D by providing policy makers with a better understanding of the determinants of firm innovativeness. A better understanding of the relative value of different types of R&D and the different conditions favoring each type may lead to a more efficient structure for the R&D tax credit or other innovation related public policies.

APPENDICES

APPENDIX A

APPENDIX A

DERIVATION OF CONDITION 2.15

The derivative with respect to q of expression 2.13,

$$P = \frac{[\delta(1+\theta)A_R m_R q]^{1/(1-\delta(1+\theta))}}{[\alpha(1+\lambda)A_D m_D(hq+Z)]^{1/(1-\alpha(1+\lambda))}} \qquad [2.13]$$

is:

$$\frac{\partial P}{\partial q} = \frac{[(1/1-\delta(1+\theta))(\delta(1+\theta)A_R m_R)\,(\delta(1+\theta)A_R m_R q)^{[1/(1-\delta(1+\theta))]-1}]\,[\alpha(1+\lambda)A_D m_D(hq+Z)]^{1/(1-\alpha(1+\lambda))}}{[\alpha(1+\lambda)A_D m_D(hq+Z)]^{[1/(1-\alpha(1+\lambda))]+1}}$$

$$- \frac{[(h/(1-\alpha(1+\lambda)))(\alpha(1+\lambda)A_D m_D)(\alpha(1+\lambda)A_D m_D(hq+Z))^{[1/(1-\alpha(1+\lambda))]-1}][\delta(1+\theta)A_R m_R q]^{1/(1-\delta(1+\theta))}}{[\alpha(1+\lambda)A_D m_D(hq+Z)]^{[1/(1-\alpha(1+\lambda))]+1}}$$

This sign of this expression is determined by the numerator. Therefore, setting the left term in the numerator as greater than the right term and simplifying yields expression 2.14:

$$(1 + Z/hq) > (1-\delta(1+\theta)) / (1-\alpha(1+\lambda)). \qquad [2.14]$$

APPENDIX B

APPENDIX B

HETEROSKEDASTICITY CORRECTION AND TEST

To control for heteroskedasticity, I used one of the following two weighting schemes, each assuming that sales is the proportionality factor. One scheme uses log transformations and the other does not. I assume an additive form of heteroskedasticity in which the estimated variance of the disturbance, σ^2_i, takes the form:

$$\sigma^2_i(a) = a_o + a_1 \text{ SALES}_i + a_2\text{SALES}^2_i \tag{B1}$$

or

$$\sigma^2_i(b) = b_o + b_1 \log(\text{SALES}_i) + b_2\log(\text{SALES}^2_i) \tag{B2}$$

where a_o, a_1, a_2, b_o, b_1, and b_2 are constants to be estimated. In some cases, $a_2 = b_2 = 0$. In each of the analyses above, I estimated the least squares equations, then apply the least squares method to the following equations:

$$e^2_i(a) = c_o + c_1 \text{ SALES}_i + c_2\text{SALES}^2_i + v_i \tag{B3}$$

if I assume B1, or

$$e^2_i(b) = d_o + d_1 \log(\text{SALES}_i) + d_2\log(\text{SALES}^2_i) + v_i \tag{B4}$$

if I assume B2. $e^2{}_i(a)$ and $e^2{}_i(b)$ are the ordinary least squares residuals obtained from equation B1 and B2, respectively. This yields initial estimates of σ^2_i:

$$\sigma^2{}_i(a) = c_o + c_1 \text{ SALES}_i + c_2\text{SALES}^2{}_i \qquad [B1']$$

$$\sigma^2{}_i(b) = d_o + d_1 \log(\text{SALES}_i) + d_2\log(\text{SALES}^2{}_i) \ . \qquad [B2']$$

These initial estimates of c_o, c_1, c_2, d_o, d_1, and d_2 are not asymptotically efficient because v_i is heteroskedastistic. Therefore, another round of estimators are obtained by applying least squares to:

$$\frac{e^2{}_i(a)}{\sigma^2{}_i(a)} = \frac{c_o}{\sigma^2{}_i(a)} + c_1 \frac{\text{SALES}_i}{\sigma^2{}_i(a)} + c_2\frac{\text{SALES}^2{}_i}{\sigma^2{}_i} + v^*{}_i \ (a) \qquad [B5]$$

and

$$\frac{e^2{}_i(b)}{\sigma^2{}_i(b)} = \frac{c_o}{\sigma^2{}_i(b)} + c_1 \log\frac{(\text{SALES}_i)}{\sigma^2{}_i(b)} + c_2\frac{\log(\text{SALES}^2{}_i)}{\sigma^2{}_i(b)} + v^*{}_i \ . \qquad [B6]$$

These estimators are asymptotically efficient. Thus, the 'second round' estimators of $\sigma^2{}_i$ is:

$$\sigma^2{}_i(a) = c'_o + c'_1 \text{ SALES}_i + c'_2\text{SALES}^2{}_i \qquad [B1']$$

and

$$\sigma^2_i(b) = d'_0 + d'_1 \log(SALES_i) + d'_2 \log(SALES^2_i) \quad . \qquad [B2']$$

Asymptotically efficient coefficients for the specifications in each hypothesis are estimated using $\sigma^2_i(a)$ or $\sigma^2_i(b)$ as weights.

After each hypothesis was estimated using the weighted least squares approach, I tested for any remaining heteroskedasticity using a Park test. This entails regressing the residuals obtained from the weighted least squares estimate against sales:

$$\omega^2_i = \beta_0 + \beta_1 \, SALES_i + \varepsilon_i \qquad [B7]$$

where ω^2_i are the weighted least squares residuals. A significant β_1 indicates the presence of heteroskedasticity. In each regression specified in each hypotheses in Chapter 3, little or no heteroskedasticity was detected after the weighting scheme was applied.

APPENDIX C

APPENDIX C

FIXED EFFECTS REGRESSIONS

Table C1. Fixed Effects Regressions – Expanded Firms
Firms=83; Obs=489

Independent Variable	Options:	Regression 1	2	3	4	5	6	7	8	9	10	11
	Weighted						X	X	X	X	X	X
	Firm Intercept		X		X			X		X		X
	Annual Dummies			X	X	X			X	X	X	X
	Serial Correl. Correction					X					X	X
Intercept		-1954.645 546.208					-2685.688 1206.703					
TA		1.631 0.182	1.2604 0.4479	1.6958 0.1788	1.3047 0.4371	0.8686 0.2919	1.160 0.176	3.5939 0.4874	1.0990 0.1634	1.8536 0.4549	1.1104 0.2917	1.1189 0.4278
TOTAL R&D		14.819 1.095	23.723 2.636	14.533 1.072	23.658 2.581	17.735 1.776	13.771 1.163	14.535 2.970	2.970 1.079	16.133 2.620	14.731 1.784	11.892 2.713
ADV		8.904 1.135	1.115 2.819	8.165 1.120	13.311 3.426	12.906 2.083	12.838 0.983	17.551 2.575	2.554 0.911	8.622 2.507	11.519 1.676	4.726 2.341
Year92				-3169.43 1014.64	9610.47 4238.63	-3308.17 1348.37			-6485.05 1779.75	7291.63 4050.69	-6879.30 2545.71	14912 11911
Year93				-3336.85 1023.62	9211.44 4242.44	-3600.53 1360.31			-6458.97 1788.99	7147.51 4021.51	-7056.31 2549.20	14650 11910
Year94				-3752.04 1029.67	8736.40 4339.70	-4028.77 1387.39			-7012.00 1777.34	6260.05 4200.08	-7672.76 2580.36	14310 11974
Year95				-1931.08 1060.18	10306 4460.68	-2299.37 1441.48			-1897.03 1759.96	12221 4362.20	-1903.06 2601.80	21085 12034

Table C1. (Cont'd)

Independent Variable		Regression										
		1	2	3	4	5	6	7	8	9	10	11
Year96				-687.35 1055.98	10988 4547.86	-1234.03 1481.78			1531.23 1750.84	14867 4551.69	1361.33 2684.75	24592 12097
Year97				2413.63 1070.84	13808 4588.89	1768.32 1511.13			8788.02 1784.99	21425 4674.54	8519.20 2749.31	31871 12141

Notes: The dependent variable is the year-end market value of the firm. Standard errors below coefficient. Shaded cells indicate significance at the 0.1 level.

Table C2. Fixed Effects Regressions – Standard Firms
Firms=71; Obs=417

In-dependent Variable		Regression										
	Options:	1	2	3	4	5	6	7	8	9	10	11
	Weighted						X	X	X	X	X	X
	Firm Intercepts		X		X			X		X		X
	Annual Dummies			X	X	X			X	X	X	X
	Serial Correl. Correction					X					X	X
Intercept		-1049.092 457.935					-1399.945 935.522					
TA		1.496 0.148	0.660 0.505	0.582 0.143	1.093 0.496	0.731 0.268	1.424 0.138	2.370 0.519	1.440 0.119	1.631 0.454	0.764 0.237	0.0719 0.383
TOTAL R&D		17.194 1.010	23.860 2.946	17.116 0.968	26.596 2.923	8.292 1.682	15.875 1.209	13.690 3.259	6.191 1.047	19.596 2.880	16.187 1.712	9.073 2.355
ADV		5.763 1.070	21.875 3.254	4.688 1.041	6.710 4.455	0.835 2.107	6.651 0.961	25.362 3.531	5.914 0.835	5.412 3.693	0.406 1.672	12.763 2.952
Year92				-2671.64 822.90	15736 4380.67	-2668.02 1132.50			-7127.96 1280.22	9796.06 3836.61	-6607.49 1922.56	18030 12083
Year93				-2457.92 830.44	15708 4370.35	-2629.55 1140.46			-5252.71 1292.01	11484 3808.40	-4977.17 1926.78	19611 12086
Year94				-2516.10 833.24	15818 4452.51	-2692.93 1156.1			-4738.80 1279.90	12015 3902.37	-4343.99 1917.76	20358 12114
Year95				-939.75 860.87	17466 4585.80	-1348.14 1205.8			-696.60 1250.96	16546 4046.46	-294.03 1904.84	24065 12174
Year96				365.48 857.22	18445 4704.30	-217.27 1245.0			2229.09 1239.32	18991 4293.32	2521.21 1961.63	26860 12255
Year97				3283.40 869.50	21211 4749.88	2590.08 1268.9			8043.98 1255.44	24458 4381.61	8518.24 1994.54	33176 12275

Notes: The dependent variable is the year-end market value of the firm. Standard errors below coefficient. Shaded cells indicate significance at the 0.1 level.

Table C3. Fixed Effects Regressions – Standard Firms
Firms=71; Obs=417

In-dependent Variable		Regression										
	Options:	1	2	3	4	5	6	7	8	9	10	11
	Weight						X	X	X	X	X	X
	Firm Intercept		X		X			X		X		X
	Annual Dum			X	X	X			X	X	X	X
	Serial Correl. Correcn					X					X	X
Intercept		-2562.579					-5436.995					
		618.007					1119.688					
TA		1.309	0.400	1.368	0.890	0.691	1.444	2.300	1.462	1.540	0.831	0.086
		0.165	0.509	0.160	0.481	0.275	0.155	0.518	0.139	0.443	0.241	0.386
TOTAL R&D		28.775	29.631	26.951	28.066	19.816	30.837	25.655	24.933	26.184	20.222	7.091
		2.529	5.839	2.470	5.454	3.647	2.721	6.017	2.514	5.008	3.338	4.080
TOTAL R&D* SALES		-0.00088	-0.00027	-0.00073	0.00011	-0.00009	-0.00101	-0.00051	-0.00060	-0.00008	-0.00024	0.00009
		0.00017	0.00027	0.00016	0.00026	0.00022	0.00015	0.00021	0.00014	0.00017	0.00016	0.00017
ADV		10.306	15.551	7.633	-15.734	9.3235	14.364	25.858	10.795	-13.632	13.093	15.971
		1.797	4.015	1.813	5.866	3.5209	1.639	5.512	1.504	5.665	2.792	4.998
ADV* SALES		0.00006	0.00026	0.00007	0.00052	0.00005	-0.000003	0.00001	-7.28E-6	0.00031	-0.00002	-0.00005
		0.00004	0.00009	0.00004	0.00009	0.00006	0.000031	0.00007	0.00002	0.00006	0.00003	0.00005
Year92				-3374.86	25474	-2453.37			-9040.44	19605.17	-7886.57	16102
				872.09	4535.57	1276.87			1354.51	4382.26	2089.06	12343
Year93				-3293.84	25689	-2412.52			-7071.86	21445.82	-6231.09	17635
				888.03	4546.20	1309.07			1361.95	4376.22	2091.45	12351
Year94				-3357.87	26489	-2417.91			-6779.26	22745.30	-5740.78	18299
				910.13	4665.33	1362.65			1383.90	4547.27	2135.53	12410
Year95				-2038.40	29089	-1026.64			-3437.61	27647.95	-1931.12	21958
				968.13	4854.84	1478.34			1398.82	4731.62	2178.90	12510

Table C3. (Cont'd)

Independent Variable		Regression 1	2	3	4	5	6	7	8	9	10	11
Year96				-948.85	30355	105.61			-989.95	29661.60	773.31	24792
				983.36	4983.04	1543.19			1423.34	4898.76	2241.46	12599
Year97				1960.32	33685	2957.53			4793.72	36359.08	6615.84	30925
				1010.98	5066.28	1603.85			1464.05	5115.80	2344.69	12674

Notes: The dependent variable is the year-end market value of the firm. Standard errors below coefficient. Shaded cells indicate significance at the 0.1 level.

Table C4. Fixed Effects Regressions – Standard Firms
Firms=71; Obs=235

In-dependent Variable	Options:	Regression 1	2	3	4	5	6	7	8	9	10	11
	Weight						X	X	X	X	X	X
	Firm Intercept		X		X			X		X		X
	Annual Dum			X	X	X			X	X	X	X
	Serial Correl. Correcn					X					X	X
Intercept		-1540.591 601.604					-2780.950 1176.932					
TA		1.583 0.230	1.922 0.610	1.649 0.229	1.978 0.624	0.789 0.326	1.418 0.224	2.694 0.686	1.648 0.213	2.506 0.676	0.709 0.297	1.924 0.576
Process		-19.720 12.746	-5.396 11.298	-14.534 12.770	-1.471 11.775	-6.460 9.795	-28.394 14.798	14.540 14.282	-9.394 14.206	19.448 14.081	8.792 11.835	15.613 13.107
Product		14.813 3.052	9.006 4.313	14.813 3.034	7.844 4.406	16.601 2.905	16.523 3.628	6.399 5.555	17.345 3.401	6.866 5.351	17.466 3.512	4.877 4.939
Applied		55.323 8.131	67.101 13.317	50.340 8.306	67.312 13.442	58.595 7.562	58.760 9.783	75.994 15.638	36.457 9.875	70.627 14.860	52.251 9.262	35.328 13.882
Service		-65.331 14.504	-21.748 16.882	-57.104 14.698	-15.624 18.214	-21.666 12.610	-70.656 15.915	7.423 19.749	-50.861 15.291	10.410 19.764	-6.917 13.811	21.347 17.053
Basic		71.849 22.582	30.161 20.676	58.936 22.841	29.061 21.011	48.898 17.415	81.180 27.981	-46.426 29.719	53.211 26.566	-44.089 28.545	13.062 23.821	-45.887 27.217
ADV		10.086 1.378	19.358 3.580	9.198 1.397	15.303 5.288	12.774 2.433	11.958 1.298	27.658 4.442	10.312 1.251	22.992 5.362	12.608 2.057	24.719 5.377
Year92				-1798.36 1163.24	8774.41 4941.94	-2774.75 1214.59			-6222.67 1809.33	-4738.02 5315.83	-8222.92 2149.02	-4274.90 9805.22
Year93				-3149.03 1198.25	9329.65 4922.62	-2528.10 1201.41			-8222.44 1851.85	-1506.94 5160.20	-6168.65 2090.34	-1446.20 9718.45
Year94				-2118.17 1041.74	9582.22 5090.63	-1971.49 1194.85			-4521.71 1662.09	-621.07 5427.17	-4442.00 2056.88	-893.03 9855.20

Table C4. (Cont'd)

Independent Variable		Regression 1	2	3	4	5	6	7	8	9	10	11
Year95				-2037.69	9248.04	-1817.32			-3040.87	-1738.22	-2948.04	-550.00
				1041.10	5320.87	1248.78			1549.35	5720.82	2019.19	10098
Year96				-984.33	9789.95	-1356.22			-1141.07	-1634.90	-1924.91	-502.88
				1118.11	5421.32	1309.22			1799.87	5907.47	2146.15	10304
Year97				1725.79	10874	95.2738			5663.71	2063.05	3340.29	4048.52
				1232.08	5541.94	1380.22			1894.65	6075.96	2223.37	10349

Notes: The dependent variable is the year-end market value of the firm. Standard errors below coefficient. Shaded cells indicate significance at the 0.1 level.

Table C5. Fixed Effects Regressions – Standard Firms
Firms=71; Obs=235

In-dependent Variable		Regression										
	Options:	1	2	3	4	5	6	7	8	9	10	11
	Weight						X	X	X	X	X	X
	Firm Intercept		X		X			X		X		X
	Annual Dum			X	X	X			X	X	X	X
	Serial Correl. Correcn					X					X	X
Intercept		-2004.350 912.978					-5058.339 1617.702					
TA		1.859 0.262	1.137 0.546	1.935 0.260	1.331 0.516	0.652 0.346	2.205 0.285	1.690 0.726	2.298 0.269	1.496 0.658	0.848 0.340	1.747 0.693
Process		34.346 28.174	12.945 24.583	31.293 27.886	18.521 23.220	-9.912 25.131	41.469 35.292	11.153 32.015	34.449 34.090	20.402 29.265	-6.419 31.091	-7.650 32.502
Process* Sales		-0.00348 0.00181	0.00178 0.00161	-0.00293 0.00181	0.00150 0.00152	0.00131 0.00156	-0.00386 0.00182	0.00277 0.00189	-0.00262 0.00181	0.00218 0.00173	0.00149 0.00164	0.00320 0.00187
Product		4.800 8.746	-9.040 8.863	4.231 8.629	-20.289 8.654	7.368 8.015	-1.916 10.388	-12.654 11.597	0.454 9.921	-27.366 11.254	9.580 9.560	-13.760 11.884
Product* Sales		0.00052 0.00060	0.00026 0.00060	0.00057 0.00059	0.00085 0.00058	0.00046 0.00055	0.00100 0.00063	0.00036 0.00074	0.00091 0.00060	0.00116 0.00070	0.00042 0.00058	0.00057 0.00073
Applied		42.389 16.367	-23.968 25.636	43.058 16.148	-9.425 24.491	55.506 14.910	40.813 20.242	-33.765 37.900	40.274 19.079	-41.665 34.702	58.107 18.587	-9.727 34.749
Applied* Sales		0.00059 0.00116	0.00426 0.00138	0.00015 0.00116	0.00270 0.00135	0.00057 0.00095	0.00069 0.00112	0.00485 0.00179	-0.00039 0.00109	0.00387 0.00166	-6.68E-6 0.00094	0.00242 0.00156
Service		-3.570 28.322	35.176 36.682	7.605 28.161	27.552 34.866	-32.630 28.295	-33.838 35.431	33.825 51.483	-1.206 33.876	17.730 47.307	-47.355 36.351	-19.889 47.013
Service* Sales		-0.00377 0.00168	0.00143 0.00192	-0.00416 0.00166	0.00220 0.00181	0.00195 0.00151	-0.00222 0.00174	0.00253 0.00225	-0.00296 0.00164	0.00349 0.00204	0.00281 0.00165	0.00470 0.00201

Table C5. (Cont'd)

Independent Variable		Regression 1	2	3	4	5	6	7	8	9	10	11
Basic		93.732	197.930	80.454	154.970	128.040	168.173	227.070	122.520	118.590	128.960	108.620
		51.517	36.7106	50.997	36.014	37.707	62.417	54.403	59.182	52.016	53.363	54.579
Basic* Sales		-0.00068	-0.01813	-0.00035	-0.01289	-0.00768	-0.00468	-0.02236	-0.00358	-0.01200	-0.00845	-0.01148
		0.00376	0.00324	0.00370	0.00326	0.00308	0.00371	0.00392	0.00349	0.00397	0.00344	0.00399
ADV		6.136	9.798	3.344	-17.073	9.611	9.068	18.535	5.661	-14.620	13.182	-4.227
		2.999	3.966	3.110	6.998	4.190	3.714	7.301	3.552	9.733	4.334	10.040
ADV* Sales		0.00024	0.00021	0.00030	0.00057	-0.00005	0.00010	-0.00006	0.00017	0.00031	-0.00017	0.00019
		0.00011	0.00018	0.00011	0.00019	0.00014	0.00012	0.00024	0.00011	0.00023	0.00014	0.00023
Year92				-1843.99	31317	-1542.65			-7400.82	30467	-7943.94	21132
				1290.43	4681.42	1477.65			2080.91	6630.85	2697.31	7679.36
Year93				-3097.35	31844	-1418.50			-7830.66	33564	-6143.73	24387
				1279.37	4719.71	1481.50			1998.87	6611.95	2651.65	7649.14
Year94				-2189.19	32680	-814.57			-6317.61	34464	-4572.81	25159
				1224.62	4863.15	1528.97			1980.99	6758.75	2621.55	7790.14
Year95				-2206.11	34164	-533.46			-5147.11	36135	-3150.22	26363
				1309.01	5173.63	1669.30			2015.17	7345.35	2676.72	8349.10
Year96				-851.42	35362	-92.9073			-3090.13	36274	-2365.27	26372
				1357.67	5303.48	1766.33			2064.48	7530.83	2754.69	8619.81
Year97				1914.13	37548	1468.38			4052.55	42071	2833.50	31731
				1493.37	5476.76	1873.52			2203.76	7905.09	2898.86	8939.04

Notes: The dependent variable is the year-end market value of the firm. Standard errors below coefficient. Shaded cells indicate significance at the 0.1 level.

Table C6. Fixed Effects Regressions – Standard Firms
Firms=71; Obs=235

In-dependent Variable		Regression										
	Options:	1	2	3	4	5	6	7	8	9	10	11
	Weight						X	X	X	X	X	X
	Firm Intercept		X		X			X		X		X
	Annual Dum			X	X	X			X	X	X	X
	Serial Correl. Correcn					X					X	X
Intercept		-572.099 610.617					-692.161 1174.158					
TA		1.865 0.228	2.1400 0.6101	1.9224 0.2273	2.1927 0.6230	0.8297 0.3280	1.641 0.215	2.9234 0.6841	1.8156 0.2064	2.7831 0.6793	0.7409 0.2918	1.9933 0.5802
Process		-79.018 17.493	-39.9396 18.7694	-72.3623 17.4657	-37.6710 19.6126	-16.4030 15.2832	-104.259 19.741	-20.5303 20.6959	-75.7148 19.3420	-16.1291 21.2349	-10.7706 17.4806	-1.1856 20.5159
Product		2.291 3.942	-3.2488 6.8418	2.6360 3.9158	-4.6259 6.9665	13.7513 4.5925	0.385 4.530	-5.7742 7.5973	3.5237 4.3361	-5.3166 7.6243	12.1838 5.1577	-0.9945 7.3996
Process* Product		0.12567 0.02659	0.06306 0.02756	0.12210 0.02635	0.06445 0.02814	0.01846 0.02205	0.16759 0.03086	0.06943 0.03001	0.1410 0.02935	0.06665 0.03007	0.03783 0.02573	0.03121 0.02924
Applied		60.812 7.860	60.3831 13.4660	56.0214 8.0422	59.8672 13.6511	60.0411 7.7197	64.537 9.283	66.9552 15.9132	44.3573 9.5606	61.7783 15.2063	54.3178 9.3348	33.4601 14.0293
Service		-55.403 14.026	-18.3116 16.7272	-48.3749 14.1903	-14.2182 17.9753	-21.2389 12.6984	-59.663 15.138	2.6480 19.5903	-44.4034 14.6452	3.8446 19.7387	-9.3146 13.8101	19.2068 17.1835
Basic		84.360 21.752	34.4068 20.4877	72.5258 22.0518	32.8654 20.7904	51.5989 17.6768	94.576 26.490	-35.1420 29.7192	68.3718 25.5315	-35.5636 28.4459	21.0904 24.2254	-42.1442 27.4480
ADV		9.198 1.331	19.7896 3.5384	8.3982 1.3487	17.0155 5.2693	12.8298 2.4179	11.107 1.234	27.9032 4.3831	9.7716 1.1987	24.9221 5.3656	12.7030 2.0115	25.4891 5.4189

Table C6. (Cont'd)

Independent Variable		Regression 1	2	3	4	5	6	7	8	9	10	11
Year92				-657.32	8803.10	-2558.94			-3709.94	-5065.03	-7060.86	-4168.77
				1139.96	4874.34	1233.15			1803.05	5250.77	2224.79	9555.24
Year93				-2321.33	9265.92	-2321.82			-5929.21	-1886.71	-5020.51	-1327.78
				1160.39	4855.35	1218.90			1829.45	5097.91	2174.49	9466.53
Year94				-1149.84	9422.71	-1767.80			-2532.40	-1344.66	-3391.82	-918.80
				1018.47	5021.46	1209.33			1638.30	5368.56	2113.15	9607.39
Year95				-1069.24	8857.15	-1667.96			-1561.68	-2993.45	-2195.75	-861.72
				1017.87	5250.84	1250.31			1509.33	5676.88	2018.87	9861.94
Year96				10.6770	9398.35	-1214.25			541.80	-2847.14	-1198.75	-845.22
				1091.21	5349.87	1308.16			1751.89	5858.45	2138.11	10073
Year97				2340.35	10555	250.14			6525.70	986.43	4126.09	3738.71
				1186.36	5467.89	1380.61			1815.79	6018.85	2219.99	10119

Notes: The dependent variable is the year-end market value of the firm. Standard errors below coefficient. Shaded cells indicate significance at the 0.1 level.

Table C7. Fixed Effects Regressions – Standard Firms
Firms=71; Obs=235

		Regression										
	Options:	1	2	3	4	5	6	7	8	9	10	11
	Weight						X	X	X	X	X	X
	Firm Intercept		X		X			X		X		X
	Annual Dum			X	X	X			X	X	X	X
In-dependent Variable	Serial Correl. Correcn					X					X	X
Intercept		-743.922 832.367					-2056.066 1501.287					
TA		3.351 0.293	1.0032 0.5155	3.3957 0.2897	1.1933 0.4915	1.1786 0.3311	3.727 0.293	1.6459 0.6689	3.7472 0.2810	1.4930 0.6039	1.7214 0.3104	1.5123 0.5800
Process		-26.792 27.416	18.2298 35.8091	-28.6091 27.0553	18.9126 33.8414	-2.4090 30.8532	-100.005 39.237	-32.2279 59.0570	-85.4217 37.8488	-19.5531 52.8342	-37.2183 42.9558	-17.4979 51.2689
Process* Sales		-0.00639 0.00168	-0.00081 0.001756	-0.00586 0.001680	-0.00066 0.001664	-0.00148 0.001588	-0.00296 0.00175	0.002101 0.002418	-0.00266 0.001768	0.001585 0.002176	-0.00034 0.001764	0.001344 0.002100
Product		14.819 11.468	21.8738 13.0260	13.7432 11.2898	7.3742 12.7391	51.7671 11.3853	24.449 14.083	41.9575 19.4474	25.7169 13.3067	22.3880 18.3172	79.3198 14.6215	15.2659 17.3769
Product* Sales		-0.00132 0.00074	-0.00165 0.000718	-0.00122 0.000730	-0.00089 0.000700	-0.00253 0.000714	-0.00195 0.00083	-0.00303 0.000973	-0.00190 0.000792	-0.00197 0.000918	-0.00442 0.000831	-0.00167 0.000870
Process* Product		-0.17355 0.07002	-0.2187 0.05876	-0.1686 0.06932	-0.1892 0.05594	-0.2842 0.05431	-0.22100 0.08267	-0.2850 0.08568	-0.2263 0.07906	-0.2517 0.07673	-0.3996 0.06942	-0.2393 0.07224
Process* Product* Sales	!	0.02700 0.00510	0.01881 0.003942	0.02641 0.005056	0.01660 0.003775	0.02303 0.003790	0.03169 0.00533	0.02496 0.004794	0.03071 0.005127	0.02235 0.004319	0.03271 0.004235	0.02201 0.004036
Applied		75.424 14.889	14.3071 25.2204	75.2145 14.6509	21.0835 24.0588	77.1695 14.5504	110.223 18.533	40.9440 36.8744	104.07 17.47	21.6261 33.5249	97.5706 17.8093	13.0269 33.0858
Applied* Sales		-0.00186 0.00107	0.002146 0.001373	-0.00220 0.001068	0.001082 0.001327	-0.00109 0.000932	-0.00390 0.00107	0.001389 0.001735	-0.00437 0.001027	0.001150 0.001581	-0.00249 0.000899	0.001465 0.001607

Table C7. (Cont'd)

Independent Variable		Regression										
		1	2	3	4	5	6	7	8	9	10	11
Service		-41.607	6.6158	-29.8845	4.4489	-86.1789	-78.786	-54.9252	-53.1939	-58.9491	-138.45	-43.3525
		28.645	35.7362	28.3375	34.1878	28.1389	34.047	50.5585	32.6565	46.5753	34.4222	45.2437
Service*		-0.00247	0.000783	-0.00287	0.001465	0.003476	-0.00094	0.004320	-0.00147	0.004837	0.005662	0.004014
Sales		0.00158	0.001850	0.001562	0.001760	0.001455	0.00161	0.002103	0.001530	0.001908	0.001518	0.001883
Basic		56.118	178.26	44.2115	140.85	94.3311	72.804	210.16	38.4303	121.46	82.4535	121.94
		46.991	34.8126	46.5108	34.2924	35.8444	55.506	49.6771	52.6836	47.3173	47.4967	45.7177
Basic*		0.00443	-0.01509	0.004656	-0.01078	-0.00433	0.00394	-0.01863	0.004457	-0.01069	-0.00415	-0.01039
Sales		0.00342	0.003147	0.003372	0.003148	0.002945	0.00336	0.003670	0.003170	0.003641	0.003084	0.003580
ADV		0.279	11.8924	-2.1129	-11.1466	9.3734	2.961	22.9294	0.8358	-2.6363	12.1122	-5.5525
		2.691	3.7606	2.7695	6.7426	3.8408	3.205	6.7739	3.0611	9.1433	3.7710	8.8050
EXADV*		0.00018	0.000128	0.000241	0.000436	-0.00005	0.00001	-0.00028	0.000070	0.000024	-0.00020	0.000051
Sales		0.00010	0.000175	0.000101	0.000184	0.000132	0.00010	0.000239	0.000101	0.000230	0.000130	0.000224
Year92				-694.86	32676	-2183.89				30609	-6248.11	32928
				1155.77	4436.69	1349.49				6056.19	2433.40	5660.74
Year93				-1471.18	33309	-1749.99				33330	-4173.75	35408
				1129.64	4473.00	1348.62				6031.61	2390.04	5636.01
Year94				-1169.33	33896	-1568.66				33839	-3833.70	35970
				1090.30	4602.85	1389.46				6157.93	2343.45	5757.97
Year95				-940.68	35189	-1452.62				34874	-3348.17	37321
				1163.48	4891.85	1510.80				6698.66	2373.08	6291.99
Year96				316.49	36020	-1262.87				34369	-3153.69	36778
				1206.91	5009.51	1597.99				6862.05	2418.08	6420.39
Year97				2793.97	38202	422.42				40159	2358.04	42716
				1311.45	5175.71	1696.47				7209.42	2548.67	6780.70

Notes: The dependent variable is the year-end market value of the firm. Standard errors below coefficient. Shaded cells indicate significance at the 0.1 level.

!: Values multiplied by 1000.

APPENDIX D

APPENDIX D

INDIVIDUAL YEAR RESULTS

Table D. Ordinary Least Squares Regressions for Each Year – Standard Firms

	Regression									
	92-93		93-94		94-95		95-96		96-97	
In-dependent Variable	Un-weighted Obs=70	Weighted Obs=70	Un-weighted Obs=70	Weighted Obs=70	Un-weighted Obs=67	Weighted Obs=67	Un-weighted Obs=69	Weighted Obs=69	Un-weighted Obs=69	Weighted Obs=69
Intercept	-209.793 307.943	-322.755 454.818	-79.498 170.599	-169.262 303.939	-530.754 321.229	-258.397 528.061	-390.996 266.665	-101.291 424.630	-1728.446 954.147	-3103.825 1045.403
TA	0.144 0.478	1.284 0.309	-0.145 0.512	-1.241 0.323	-1.674 0.417	-1.687 0.432	0.940 0.477	1.892 0.573	0.734 1.240	0.352 0.836
TOTAL R&D	-0.691 0.703	0.335 0.832	0.651 0.457	1.402 0.581	6.970 0.805	1.647 0.823	5.349 0.572	5.742 0.657	13.592 1.567	14.258 1.508
ADV	2.372 0.537	2.715 0.250	0.324 0.318	0.615 0.182	3.132 0.525	5.188 0.320	1.682 0.458	0.572 0.317	3.021 1.398	3.860 0.801

Notes: The dependent variable is the year-end market value of the firm. Standard errors below coefficient. Shaded cells indicate significance at the 0.1 level.

APPENDIX E

Table 1. Summary Statistics-Responders and Non-responders ($MM)							
	All Years	1992	1993	1994	1995	1996	1997
The following variables were supplied by both the IRI survey and Compustat							
Avg. R&D Exp.							
Survey Resp.	326.5	219.0	354.3	334.6	195.8	386.8	449.2
(# Firms)		(46)	(46)	(58)	(60)	(67)	(57)
Non-Resp	483.5	437.0	376.7	436.9	785.9	473.1	417.4
(# Firms)		(56)	(54)	(44)	(41)	(36)	(41)
Advertising							
Survey Resp	180.3	150.5	202.0	119.9	76.8	279.8	240.1
(# Firms)		(46)	(46)	(58)	(60)	(67)	(57)
Non-Resp	223.0	213.1	187.7	242.1	383.2	115.7	194.5
(#Firms)		(60)	(60)	(48)	(46)	(39)	(49)
Market Value							
Survey Resp	11878	9048	9174	8949	8393	14279	20352
(#Firms)		(40)	(42)	(53)	(54)	(61)	(50)
Non-Resp	11795	8397	9062	9710	16714	14069	15133
(#Firms)		(54)	(53)	(42)	(41)	(34)	(41)
Firm Size ($Sales)							
Survey Resp	11369	8960	11742	11865	7923	13632	13474
(#Firms)		(46)	(46)	(58)	(60)	(67)	(57)
Non-Resp	12262	11912	9999	1089	18463	11399	11474
(#Firms)		(56)	(55)	(45)	(44)	(37)	(45)
Ratio R&D/Sales							
Survey Resp	4.4%	3.3%	3.2%	3.0%	3.3%	8.3%	4.1%
(#Firms)		(46)	(46)	(58)	(60)	(67)	(57)
Non-Resp	11.1%	8.1%	8.2%	23.6%	14.8%	4.7%	7.3%
(#Firms)		(56)	(54)	(44)	(41)	(36)	(41)
The following variables were not available from Compustat							
	All Years	1992	1993	1994	1995	1996	1997
Product R&D	161.9	107.8	241.5	171.2	88.1	106.2	265.2
Process R&D	47.1	27.2	46.0	80.4	27.4	36.6	61.0
Basic Research R&D	10.7	8.5	10.7	10.2	8.5	11.1	15.0
Applied Research R&D	46.2	34.2	34.6	46.8	44.3	47.2	68.3
Technical Service R&D	40.3	34.0	36.7	42.8	26.1	53.2	48.5

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