CHANGE IN FIRM TECHNOLOGY STRATEGY

IN RESPONSE TO A DISRUPTIVE EVENT

By Denis G. Hamilton

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Written under the direction of

Professor Petra Christmann

And approved by:

Gordon Walker

John Cantwell

Brent Ruben

Sengun Yeniyurt

Newark, New Jersey

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ABSTRACT OF THE THESIS

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This dissertation examines change in firm technology strategy in response to an industry wide disruptive event. More specifically, this research focuses on how firm technology strategy changes (as measured by changes in technology investment levels) in response to a downward price shock in the industry. While economic theory would generally suggest that firms would likely reduce their technology investment levels in an industry experiencing significant declining price levels does this outcome occur in all cases? Under what circumstances might firms sustain or increase their technology investment levels in response to a disruptive event that creates significant downward price pressures? Two models are examined. The first evaluates overall industry behavior in response to this type of disruptive event. The second model then examines the association of a set of relevant factors to specific observed changes in firm technology investment levels following the disruptive event. A study was conducted to examine whether significant medical procedure reimbursement reform in the healthcare industry during the 1980s (a significant, disruptive event that created downward price pressure on the medical device industry) resulted in a change in technology strategy (increase or decrease in technology investment levels) of technology oriented medical device firms. To track changes in technology investment levels U.S. patent data for technology oriented medical device firms was collected for the period 1976 through 1990 (periods before, during, and after the period of the healthcare reimbursement reforms). The results of the study found that overall, contrary to general

economic theory and to the predictions of a government sponsored comprehensive research study, technology oriented medical device firms significantly increased their technology investment levels following this disruptive event. Further, firms with high technology intensity prior to the disruptive event were more likely to increase their technology investment levels post the disruptive event while small firms were less likely to increase their technology investment levels post the disruptive event. Firms that were not affiliated with a technology oriented parent firm were more likely to decrease their technology investment level post the disruptive event. Proposed explanations for these findings are presented. The research has potential implications for policy makers evaluating the likely impact of healthcare reforms on medical technology investment levels. Limitations of the study and recommendations for further research are also presented.

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I wish to thank my distinguished dissertation committee for their patience and support for my efforts in conducting this research. Their expert guidance and feedback have been instrumental in creating a more scholarly effort. Any shortcomings in that regard were clearly of my own making. I particularly wish to acknowledge Gordon Walker who I first met at Wharton in 1985. His course in strategic management there imbedded the seed that has continued to grow for many years since and eventually inspired my current career and research interests. John Cantwell endured my provocative (more likely naïve) questions through three Ph.D. courses in international business where I gained the utmost respect for his unique and masterful insights on business strategy. Brent Ruben has been a friend and business colleague for over 25 years and is largely responsible for my matriculation at Rutgers having introduced me to several members of the RBS faculty. His impressive academic achievements informed his wise counsel over those many years. He has never led me astray. Shen Yeniyurt was gracious in agreeing to participate on the committee bringing his wealth of strategic marketing knowledge and expertise in analytical methods. Please allow me, with no disrespect intended, to offer comment about Petra Christmann later in this section.

I was fortunate to have the assistance of Janet Czachura, a professional researcher with expertise in extracting patent data from the NBER database. Her knowledge of both the database and excel helped a novice researcher extract and build a dataset that could be readily adapted for coding, editing, evaluating, and ultimately used for testing the hypotheses presented in this dissertation.

Two fellow Ph.D. students were kind enough to assist me in finding additional reference material and to reacquaint me with proper use of regression models. I greatly appreciate the support of Wen Zhang and Rong Fu and thank them for their patience with my endless questions and for their valued feedback and comments on drafts of this research.

Most importantly, I wish to thank Petra Christmann, my academic advisor, committee chair, (and now supervisor), especially for her initial inspiration and encouragement. This occurred during my first semester in the Ph.D. program as I sought to take the lonely path of pursuing Strategy as a major focus area in my studies at RBS amidst a group of Ph.D. colleagues and faculty who were nearly all O.B. or O.T. focused. She has been a valuable and reliable source of support and guidance ever since that first meeting in 2009.

Finally, to my family. This late life journey to pursue a new career in academia and a Ph.D. has challenged them as much as me. Their support and encouragement were instrumental. I could have not made this journey without their love, patience and understanding.

Dissertation Committee

- Petra Christmann (Committee Chair & Faculty/Dissertation Advisor), Chair Department of Management & Global Business, Professor of Management & Global Business, Rutgers Business School
- Gordon Walker, Chairman of the Strategy and Entrepreneurship Department, David B. Miller Professor of Business, Cox School of Business, Southern Methodist University
- John Cantwell, Professor II (Distinguished Professor) of International Business, Rutgers Business School, Editor-in-Chief Journal of International Business Studies
- Brent Ruben, Distinguished Professor School of Communication and Information, Executive Director Rutgers Center for Organizational Development and Leadership, Member University Administrative Council, Rutgers University
- Sengun Yeniyurt, Associate Professor of Marketing – Supply Chain Management and Marketing Sciences Department, Rutgers Business School

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Chapter 1 - Introduction

Firms that rely on technology as a core element of their competitive strategy may face challenging strategic choices when their industry is confronted with a disruptive event. While technology oriented firms primarily rely on their technological capabilities to effectively serve their customers, will their technology strategy change when the criteria used by their customers to make supplier and product decisions is suddenly and significantly altered as a result of a disruptive event that creates substantial downward pressure on price levels in the industry and alters the decision criteria for evaluating new products from strictly product performance to a new emphasis on primarily product cost and value? Will firms continue to invest in technology at previous levels or will they adjust their technology investment levels to reflect potentially higher economic risks and lower likely returns on those investments?

To address these research questions two models are developed. Model 1 evaluates the overall impact of this type of disruptive event on the technology investment levels of firms in an industry. Model 2 evaluates the relationship between various firm attributes and a particular observed change in the technology investment levels (increase or decrease) of firms post the disruptive event. In building and examining these two models relevant theory is reviewed and evaluated drawing on strategy research in economics (Allison, 1971; Ben-Zion, 1984; Bowman, 1980; Ghemawat, 1991), innovation (Christensen, 1997; Foster, 1986; Henderson & Clark, 1990; Tushman & Anderson, 1986), and behavioral science (Cyert, Dill, & March, 1958; Fiegenbaum & Thomas, 1988; Kahneman & Tversky, 1979; Staw, Sandelands, & Dutton, 1981). These diverse theory areas were chosen because they provide alternative perspectives on the likely change in strategic behavior of technology oriented firms following this type of disruptive event.

In Model 1 hypotheses are developed based on the behavioral options of firms (either to sustain, increase, or decrease technology investment levels post the disruptive event). These hypotheses are linked to explanatory scenarios that are developed from the theories examined. The theories provide potential explanations for why a firm would likely behave in a specific manner post the disruptive event (i.e., sustain, decrease, or increase their technology investment levels). It is necessary to use these hypothetical scenarios as most of the theories do not specifically address how firms are likely to behave when faced with this type of disruptive event. However, it is possible to infer the likely firm behavior based on the tenets of each theory. Limitations of using this approach are discussed later in this dissertation.

In Model 2 various firm attributes are identified and examined to determine their potential association with the observed change in strategic behavior (either an increase or decrease of technology investment levels) of firms post the disruptive event.

Following this hypothesis and theory development section is a description of the research study that was conducted which specifically examines the impact of healthcare reimbursement reforms, implemented in late 1983, on the technology investment levels of medical device firms. These reforms were a disruptive event which caused a downward price shock on the medical device industry and changed the decision criteria and decision process used by healthcare providers in evaluating new, technology-oriented medical devices. The research study examines changes in technology investment levels of technology oriented medical device firms before and after this disruptive event and evaluates the association of various firm attributes to those changes. Data descriptions and summaries as well as data analysis methods are presented. This dissertation concludes with a summary of the results of the study, findings and conclusions, study limitations, and suggestions for further research.

Chapter 2 – Theory and Hypotheses

Disruptive Events –

Firms within an industry generally encounter changing environmental conditions as the industry progresses through its life cycle. Mostly such changes are considered the normal evolutionary pattern of the industry (Arrow, 1974; Klepper, 1997). In some instances, however, the changes are more dramatic and can be considered disruptive events (Bower & Christensen, 1995). These disruptive events can significantly impact on the firms in an industry and dramatically alter the industry's structure Prior research has focused mainly on disruptive technological events that drastically change the underlying technology platforms of an industry (See, for example, Tripsas, 1997). This previous research has identified how existing members of that industry respond to such technology changing events and the factors that predict whether they are likely to survive. There are also examples of research looking at the impact of disruptive events that are the result of changes in regulations (Walker, Madsen, & Carini, 2002). In that research the authors examined how significant changes in government regulations of airlines impacted on industry participants. Another type of disruptive event that has not been addressed directly in the strategy literature is when the disruptive event occurs in the industry of the firm's customers rather than directly in its own industry. The impact on the firm's customers can manifest in significant changes to traditional criteria used in supplier selection, product selection and pricing negotiations. When disruptive events occur in the industry of a firm's customers how do these events impact on the strategy of firms in the industry that serves those customers? More specifically, in the case of firms who have traditionally relied on technology as the basis for competition, how will the change in customer decision criteria with a significant increase in price

sensitivity impact on the firm's technology strategy as measured by changes in their level of technology investment? It is this latter type of disruptive event that is examined in this dissertation.

Technology Strategy -

Early discussion of technology strategy is found in the work of Schumpeter (1975 [Originally published 1942]) who described an innovation model that proceeds from invention to commercialization referred to as the "linear model" or "technology-push" model. Later, Schmookler (1966) challenged this view with his "demand-pull" model in which he argues that the market generates the incentive for firms to develop innovations in response to unmet market needs. Chandler (1990) observed the role of institutional factors in shaping the development activities of firms in the early 20th century. Each of these views shared the common perspective that the impetus for innovation was precipitated by forces outside of the firm. More recently these initial views of technology development have been complemented with the view that a combination of external as well as internal factors shape the development of innovations. This "evolutionary" perspective is described by Nelson (1991) who proposes that "Firms need to learn to get good at certain kinds of innovation, and at the things needed to take advantage of these" (p. 68). Cantwell and Fai (1999) describe this technological competence as the result of "…lengthy learning processes within production in the firm, in interaction with both the upstream elements of the scientific base and corporate R&D, and also downstream complementary or co-specialised assets and markets" (p. 338). This learning generates "tacit capabilities of a locally specific kind in each firm" (p. 339). Thus, it is these

internal capabilities combined with the influence of external factors that drive and enable technology based innovation.

Beyond the impetus for technological innovation (external & internal) is the discussion of whether technology development strategy within the firm is driven by a rational or emergent process (or combination of both). The rationalist view evolved from the "design school" scholars who wrote the initial textbooks for business strategy in the early 1970's. Christensen, Andrews, Bower, Hamermesh, and Porter in *Business Policy, Text and Cases* (1982) describe strategy formulation as a "*process of organization*" (p. 827). It is largely based on a rational, economically driven decision model. This is in contrast to Mintzberg (1990) and others (Nelson, 1991) who see strategy development as more of an "emergent" and evolutionary set of activities that often are the result of trial and error or serendipity as well as planned initiatives. As applied to technology strategy Nelson states, "One is suspicious of arguments to 'rationalize' production and innovation …, particularly when the winds of change are blowing from uncertain angles." (p. 72)

Regardless of the forces, or motivations, or processes, or capabilities, or detailed plans, or serendipity that precipitates the development of technology within a firm, ultimately it is the technological actions of firms that best describe the firm's technology strategy (intended or otherwise). What the firm wanted to do or was compelled to do by external forces may play a role in shaping these actions but what the firm actually does is determinative from a competitive strategy perspective.

Specifically this dissertation examines the firm's technology investment level (firm behavior) before and after a disruptive event in the industry in order to determine if there is a change in the firm's technology strategy following such an event.

Hypotheses & Scenarios

There are three possible post disruptive event technology investment level behaviors:

1. Firms can decrease their prior level of technology investment or
2. Firms can sustain prior technology investment levels or
3. Firms can increase prior technology investment levels.

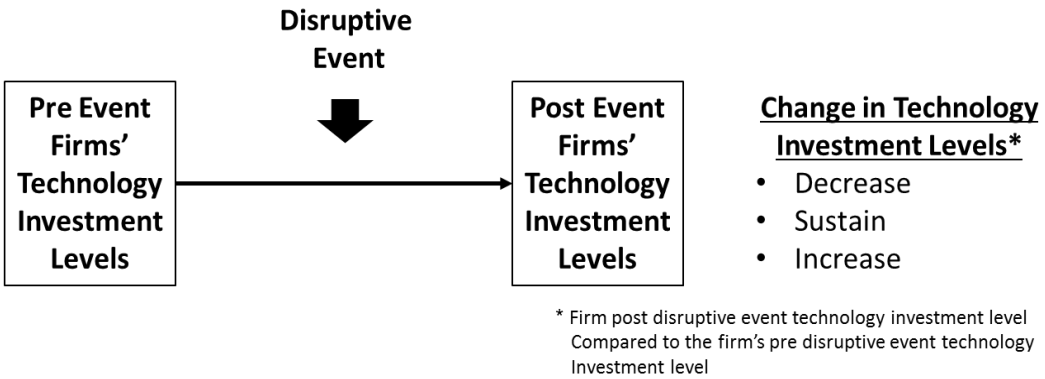
Overall it is not expected that all firms within an industry would maintain the same technology investment level post the disruptive event. It is more likely that some firms will decrease their technology investment levels while other firms might increase their technology investment levels. While allowing for this variation in individual firm behavior the question is whether, given the theories examined, is there likely to be a statistically significant overall change in the technology investment levels of firms in the industry post the disruptive event? If there is a change, is the likely change in overall behavior a decrease in technology investment level or an increase in technology investment level?

In this chapter various theories are examined and linked to a specific technology investment level behavior post the disruptive event in an attempt to predict and/or explain the behavior of firms. In addition, firm attributes are identified and hypotheses developed to associate these attributes with a specific change in technology investment level post the disruptive event.

To structure this discussion and analysis two models are developed. Model 1 is designed to examine which of the three strategic technology investment level behaviors is likely to occur overall in the industry post the disruptive event.

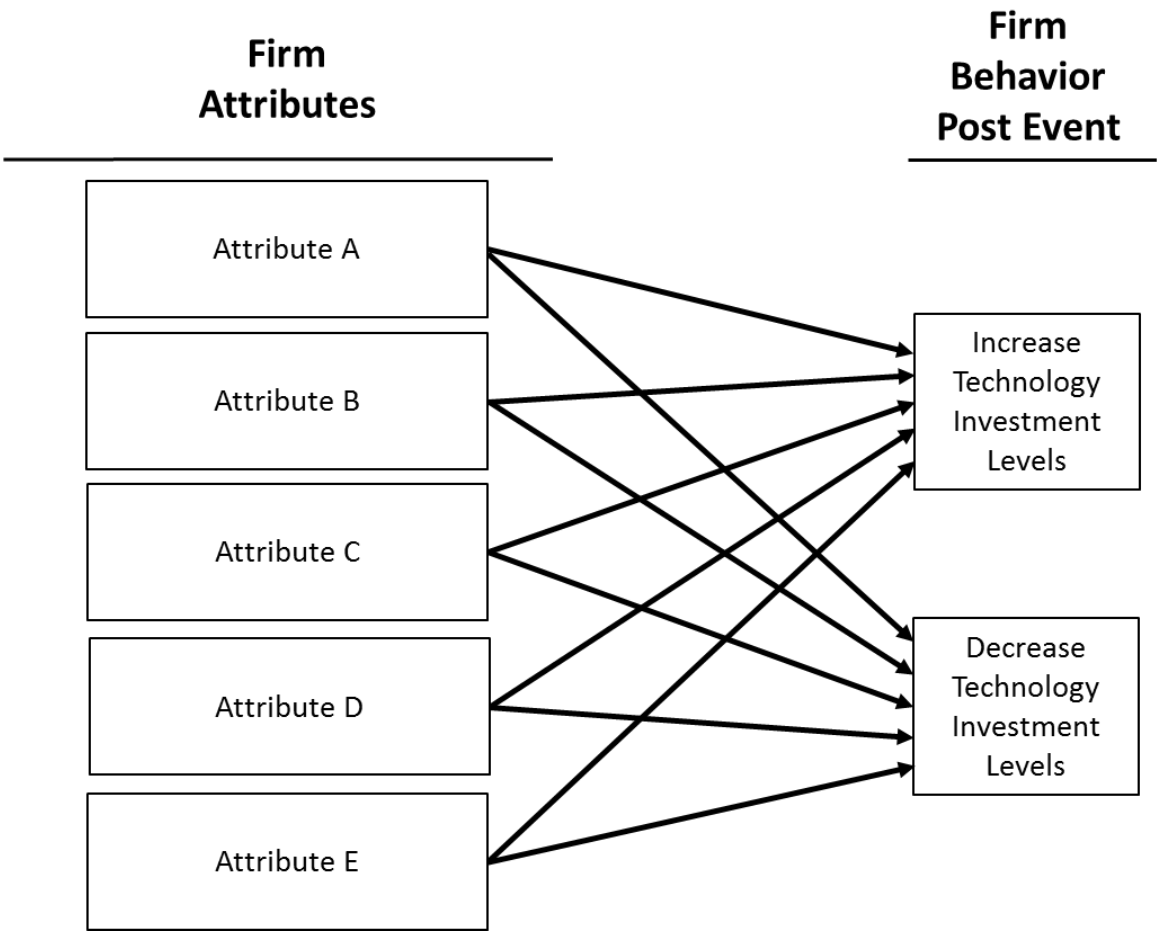
Model 1

Effect of Disruptive Event on average Firm Technology Investment Levels in the Industry



Model 2 is designed to evaluate the relationship between firm attributes and a firm-level change in technology investment level (increase or decrease) post the disruptive event.

Model 2
Potential Factors
Associated with Firm Behavior
Post Event



Model 1 - Theory and Hypotheses

In order to find guidance as to which behavior to expect post a disruptive event a review of strategy literature was conducted drawing on economic research, research addressing innovation, and research in behavioral science. The purpose was to consider alternative perspectives in order to be better informed of the likely behavior of firms confronted with the specific type of disruptive event being examined in this dissertation. Theories related to each behavioral outcome are examined.

Firm Behavior Post Disruptive Event: Decrease Technology Investment Level –

When faced with a disruptive event that results in a significant increase in customer pricing sensitivity as well as increased customer scrutiny for adopting new or updated products it is reasonable to assume that future technology investments would be perceived as less attractive for firms in that industry. This is the result of lower expected price levels and higher risks associated with the likelihood of new product adoption by customers. The combination of these factors would likely adversely impact the projected discounted cash flow estimates for such technology investments making those investments less attractive. This firm level theoretical perspective is supported by economics based research.

General economic theory as it relates to technology strategy finds its roots in basic financial risk/reward and return on investment models. "Economic theory suggests that R&D and investment are based on similar considerations, and that one could use the discounted present value of future income streams to evaluate the desirability of R&D investment" (Ben-Zion, 1984, p. 301). Bowman (1980) describes the risk aspect of these models as "the higher-risk project/investment will require a higher expected return…" (p. 17). This theory also requires the

assumption that firms are “rational actors” (Allison, 1971) who make the optimal decision after conducting a “search” for investment alternatives and then choosing the one that delivers the highest returns (as described by Cyert et al., 1958).

Another perspective on firm likely behavior in responding to a disruptive event is found in Tushman & Anderson (1986). They describe discontinuities created by changes in customer requirements. In some cases these discontinuities can be competency destroying rendering the firm’s existing technologies obsolete. In an industry that has not been historically subject to significant pricing pressure from customers the historical direction of firms’ technology activities are focused on developing technically superior products regardless of cost. It is reasonable to assume that a need to shift the technology focus to producing more cost-effective products from the prior focus of designing purely technologically superior products requires different competencies and thus the disruptive event is competency destroying as a result of the change in customer requirements. Combined with the uncertainty and lower levels of return expected as a result of the disruptive event it is unlikely that a firm would find it worthwhile to make the technology investments necessary to acquire new technologies or to retool their current technologies to meet these changing customer requirements. Consequently, based on this theory firms are likely to decrease their technology investment levels post the disruptive event.

Foster (1986) identified the “S-curve” effect which argues that return on technology investment is low initially then steadily increases then begins to taper off again as technologies mature. This return profile emulates an S-shaped curve. Disruptive events can accelerate this effect and move technologies into a mature state more quickly and into the declining return stage faster thus reducing the returns to be realized from continued investment in the technology. Firms going through this type of disruptive event would quickly realize that the prospects for

continued investment in current technologies are not likely to render the same level of returns enjoyed previously and as a consequence would reduce their technology investment levels following the disruptive event.

Kahneman and Tversky (1979) describe the effect that a history of successful investments has on the risk taking propensity of firms. They found that firms that have a history of realizing positive returns have a tendency to become more risk averse over time. In a technology oriented industry that has enjoyed the benefits of customers rewarding technology advancements with virtually unlimited pricing concessions, the likelihood that most technology oriented firms have experienced financial success is relatively high and would suggest that these firms have become increasingly more risk averse. Combining this theoretical perspective with the increased risks associated with the disruptive event, it is likely that firms would decrease their technology investment levels.

Cyert, Dill & March (1958) identified the role that expectations play in decision making. They found that firms tend to simplify investment decisions rather than use rigorous analytical methods. They also found that expectations about the outcome of investments are tied to hopes about those outcomes and the related search for information concerning the investment was not driven by a desire to obtain objective, rational data but rather by a desire to find support for the preferred outcome. When faced with an industry wide adverse disruptive event it seems reasonable to assume that a firm's expectations are adjusted downward and thus their perspective on the attractiveness of investment options would similarly be adjusted downward. Consequently, consistent with this theory firms would be expected to reduce their technology investment levels.

Thus there is broad support in strategy theory that firms that experience a disruptive event as defined in this dissertation would be likely to decrease their technology investment levels post the disruptive event.

Hypothesis 1 – Technology oriented firms will decrease their technology investment levels post the disruptive event.

Firm Behavior Post Disruptive Event: Sustain Current Technology Investment Level –

While strategy theory provides strong support for suggesting that firms will reduce their technology investments post the disruptive event there are some strategy theorists who might suggest that firms would likely sustain their technology investment levels post the disruptive event. For example, Christensen and others (Bower & Christensen, 1995; 1997) have published multiple literary articles and books on the impact of disruptive events on an industry. While the focus of Christensen's research was on the impact of new technologies on existing industry structures, the applicability of some of the rationale he provides for why firms find it difficult to make the changes necessary to adopt these new technologies seem equally applicable in the circumstances described in this research. For example, Christensen suggests that firms are often in a state of denial about the potential impact of new technologies and he argues they have a tendency to be locked-in to their current technologies. When experiencing a high level of success with the status quo it often is difficult for firms to recognize or accept that the status quo is going to change rapidly and decisively in a way that will be difficult for them to adopt. By the time they realize the changes are significant it is often too late for them to recover as new entrants have already established a foothold in the industry and those new entrants do not have

the baggage that incumbents must shed in order to adapt successfully. Thus, based on this theory, incumbent firms are likely to sustain their technology strategies post the disruptive event and thus likely to sustain their current technology investment levels at least until they are displaced by more forward thinking and technologically advanced new entrants.

Ghemawat (1991) challenged that firms will rationalize technology investment decisions purely on the basis of projected discounted cash flow and suggested that other factors enter into the overall considerations of the firm. He describes these additional consideration in his "Commitment Theory" which he defines as the "tendency of strategies to persist over time". This commitment effect is attributable to lock-in (commitment to previous investments in developing technological capabilities), lock-out (the high-cost of reinstituting an abandoned technology platform), lags (the time necessary to develop the capability to respond to an opportunity), and inertia (the propensity of a firm to sustain its prior course due to bias and other psychological/cultural factors) (p. 31). Ghemewat finds that firms in industries with significant sunk costs, significant opportunity costs, long lead times, and symbolism (i.e., the effect the choice has on the organization's culture) will be likely to make "commitment intense" choices (p. 51). Many technology oriented industries align with the characteristics described by Ghemawat. Technology oriented industries often require firms to invest in technologies long before there is any recovery of those costs (significant sunk costs). As with any large investment, the decision to pursue a given technology path is a decision not to pursue an alternative path that may turn out to be much more lucrative (significant opportunity costs). The development of technology in most technology oriented industries takes years (long lead times involved). Finally, many technology firms build identities around specific technology platforms and tend to prefer to build on those platforms over time (high levels of symbolism).

Thus overall, based on this theory, firms in technology oriented industries align with Ghemewat's parameters for firms likely to make commitment intense choices. Applying Ghemewat's commitment theory to technology oriented industries would suggest therefore that firms are likely to sustain their technology strategy post the disruptive event and thus sustain their technology investment levels in spite of the negative economic circumstances created by the disruptive event.

Tushman & Anderson (1986) in addition to describing discontinuities that are competency destroying as previously discussed, also describe discontinuities that are competency enhancing. An economically driven change in customer price sensitivity and new product adoption scrutiny could benefit some firms that possess technologies that can effectively respond to this new customer decision criteria by offering products that deliver comparable or better results at a lower cost. This doesn't necessarily argue for an increase in technology investment levels unless the technology platform for delivering comparable products at a lower cost has been underdeveloped and needs additional investment in order to deliver the more efficient product offerings. More likely existing technology investment levels would allow a firm to make the necessary adaptations of technology necessary to modify existing products to be less costly given new customer requirements while also funding the redirection of new technology investments to deliver more cost effective solutions. This approach allows firms to leverage the accumulated investment in the current technologies without increasing the overall technology investment level which would be unattractive given the less favorable economic forecast for the industry. Thus, based on this theory, firms would be likely to sustain their current technology investment levels post the disruptive event.

Staw, Sanderlands & Dutton (1981) found that when firms face a threatening situation such as a disruptive event there is a tendency for senior management to increase their control of decisions and that information sharing becomes more limited. These changes lead to less flexibility and less variation in current behavior compared to prior behavior. This condition would make it difficult for firms to make the changes necessary to fully respond to changing customer needs. This "Threat Rigidity Response" suggests that firms are likely to maintain their current technology strategy and most likely would not increase their current technology investment level but would more likely sustain that investment level.

These strategy based theoretical perspectives all support the second hypothesis:

Hypothesis 2 - Technology oriented firms will sustain their prior technology investment level post the disruptive event.

Firm Behavior Post Disruptive Event: Increase Technology Investment Level –

Under what circumstances might a firm actually consider increasing their technology investment levels post the disruptive event? There is less strategy literature that supports this type of behavior yet there are some extensions of strategy theory that could be argued in support of this option.

Consider a perspective that suggests that firms are able to realize a high level of return on technology investments by effectively responding to the customer's new requirements while not necessarily having to accept lower prices or incur higher risks. One concept consistent with this perspective is that firms focus on opportunities to develop products that overall reduce the cost-in-use that a customer experiences in using that product. The product itself may cost more

than prior products used by customers but offer benefits that actually reduce the customer's overall costs. This can be accomplished by creating products that require reduced labor or energy when used in their appropriate applications and thus can command a higher product price that is more than offset by the savings in payroll or utility costs experienced by the customer. This perspective is consistent with the discounted cash flow model previously presented (Ben-Zion, 1984), it just relies on a different set of assumptions then previously described for the firms that reduce their technology investment levels.

Another concept consistent with increasing technology investment levels is based on the fundamental strategy principle that customers will be willing to pay a premium for products that offer better benefits than competitive offerings (Porter, 1980). While overall these customers may need to lower their costs as a result of the disruptive event this does not necessarily preclude that customers still want and can afford some premium priced products with superior performance benefits and may find other ways to reduce costs rather than forego the opportunity to purchase such beneficial products. With the prospect that other technology oriented firms supplying these customers are likely to be reducing their technology investments this could actually create a potential opportunity to exploit the limited availability of unique products and provide an advantage for a firm willing to take a counter strategy by increasing their technology investment level and offering unique products during a time when there are fewer such offerings for customers to consider.

These perspectives supported by strategy theory support the third hypothesis:

Hypothesis 3 - Technology oriented firms will increase their technology investment level post the disruptive event.

Table 1 contains a summary of the 3 hypotheses for Model 1 and the related theories that support each hypothesis.

TABLE 1

Summary of Model 1 Theories and Hypotheses

#	Hypothesis	Theory	Authors	Theory Category	Post Disruptive Event Expected Behavior
1	**Technology oriented firms will decrease their technology investment levels post the disruptive event.**	Rational Actor, Financial Optimization (RADCF[1])	• Ben-Zion • Allison • Bowman	Economics	Decrease
		Competency destroying discontinuities	Tushman & Anderson	Innovation	Decrease
		"S-curve" life cycle of technologies	Foster	Innovation	Decrease
		Prospect Theory	Kahneman & Tversky	Innovation	Decrease
		The role of expectations in business decision making	Cyert, Dill, & March	Behavioral	Decrease
2	**Technology oriented firms will sustain their prior technology investment level post the disruptive event.**	Innovator's Dilemma	Christensen	Innovation	Sustain
		Commitment Theory	Ghemawat	Economics	Sustain
		Competency enhancing discontinuities	Tushman & Anderson	Innovation	Sustain
		Threat Rigidity Response	Staw, Sanderlands & Dutton	Behavioral	Sustain
3	**Technology oriented firms will increase their technology investment level post the disruptive event.**	Financial Optimization	Ben Zion	Economics	Increase
		Differentiation	Porter	Economics	Increase

Model 2 - Theory and Hypotheses

Assuming that firms change their technology investment levels post the disruptive event it is potentially worthwhile to examine the relationship between selected firm attributes and the observed change (increase or decrease) in technology investment levels of firms post the disruptive event to see if there is a statistically significant association between the attributes and a specific change in firm technology investment levels.

Key factors that could be associated with these changes include firm size, firm technology intensity, whether the industry experiencing the disruptive event is the core business of the firm, whether the firm has an affiliation with a technology oriented parent firm, and whether the firm's R&D activities are located in the country where the disruptive event occurs. Each of these factors will be further described and discussed in more depth and relevant hypotheses will be proposed based on the likely association with a specific change.

Firm Size – Strategy research frequently examines the effect of firm size on the results of research studies. Implicitly larger firms have more resources, more capabilities, larger networks, etc. that can be leveraged to deliver better outcomes. In this research study it is not clear what the "better" outcome may be (decrease, sustain, or increase technology investment levels post the disruptive event) or how firm size in itself might influence the likely "change" in technology investment levels of firms. Presumably the effect of being a large or small firm is already reflected in the current technology investment strategy of the firm. Presumptively larger firms might have more discretionary resources to invest in higher risk technology projects or may be more likely to experience positive results from their technology investments based on accumulated experience or may be able to enjoy economies of scale that allow for less costly development efforts or to pursue larger scale projects which may be beyond the limited means

of smaller competitors thus reducing the number of competitors pursuing similar projects, or may have access to alternative and more attractive industries in which to redirect their technology investments. It is not clear overall how these attributes of larger firms would likely associate more positively or negatively with a specific "change" in behavior (e.g., increase) vs. another (e.g., decrease) other than to suggest that larger firms would be more likely to be able to pursue either of the post disruptive event behavior change options they prefer which may not be the case with smaller firms who may be less able to increase their technology investments due to resource constraints created by the adverse impact of the disruptive event. Consequently, if the disruptive event adversely affects industry profits as is likely given the reduction in price levels for products in the industry then overall smaller firms are less likely to have the resources necessary to be able to increase their technology investment levels post the disruptive event than larger firms.

Hypotheses 4: Small firms are less likely to increase their technology investment levels post the disruptive event than non-small firms.

Firm Technology Intensity – Firms that have accumulated relatively more successful technology experience in the industry as evidenced by relatively higher technology investment levels than other industry participants (High Technology Intensity) prior to the disruptive event are more likely to have a track record of developing successful new products in the industry and are more likely to have a broader technological base that can be leveraged to address changing customer requirements. Consistent with Ghemawat's theory (1991) they are likely to be more "committed" to their prior strategic direction and have inertia to continue in that direction. On the other hand firms that have a relatively low technology intensity are less likely to have a broad technology base to draw upon for addressing changing customer requirements. They also

have fewer successful developments and likely more limited resources for pursuing new technologies. Being smaller, their survival is more at risk as a result of the disruptive event creating adverse effects on their current business.

Hypotheses 5: High Technology Intensity Firms are more likely to increase their technology investment levels post the disruptive event than non-High Technology Intensity Firms.

Hypotheses 6: Low Technology Intensity Firms are more likely to decrease their technology investment levels post the disruptive event than non-Low Technology Intensity Firms.

Disruptive Event is in the Industry that is the Core Business for the Firm – If a firm is primarily dependent on the industry in which the disruptive event occurs because that is where its core business is focused then it might be expected that such firms are less likely to reduce their technology investments, or put another way, firms that do not have their core business in the industry in which the disruptive event occurred are more likely to decrease their technology investment levels in the industry post the disruptive event than firms that do have their core business in that industry. This is presumably because firms that do not have their core business in the industry of the disruptive event have alternative and accessible options for their technology investments that are not as readily available to firms who have their core business in the industry.

Hypotheses 7: Technology oriented firms that do not have their core business in the industry in which the disruptive event occurred are more likely to decrease their technology investment levels in the industry post the disruptive event than firms that do have their core business in that industry.

Affiliation of the Firm with a Technology Oriented Parent Firm – Firms that are affiliated with a technology oriented parent firm likely have access to a broader range of technologies and expertise to address changing customer requirements. On the other hand, as part of their affiliation with a technology oriented parent firm, resource allocation decisions at the parent level likely span multiple industries (or at least product categories) and thus the reduced attractiveness of investment opportunities in the industry impacted by the disruptive event may result in a redirection of technology investments into other more attractive industries (products). Thus it is unclear which direction an affiliated firm would likely take post the disruptive event. A non-affiliated firm would more likely be subject to the unfavorable economic consequences of the disruptive event with more limited available resources derived from industries outside those impacted by the disruptive event. Consequently, it is more likely these non-affiliated firms would decrease their technology investment levels post the disruptive event.

Hypotheses 8: Firms not affiliated with a technology oriented parent firm are more likely to decrease their technology investment levels post the disruptive event than firms that are affiliated with a technology oriented parent firm.

Firm's R&D Located in the Same Country as the Disruptive Event - Firms whose R&D activities are located in the same country that is primarily impacted by the disruptive event are more likely due to proximity to have full awareness of the potential implications of that disruptive event on current technologies. It is also more likely that a major portion of such firms' business is dependent on sales in the country where the disruptive event occurs given that their R&D is located in the same country. While there may be exceptions to this generalization, it is expected that consequently, these firms are more likely to reduce their technology investment

levels than firms that have their R&D located elsewhere and are less aware and less directly economically impacted by the disruptive event.

Hypotheses 9: Firms with their primary R&D located in the same country that is primarily impacted by the disruptive event are more likely to decrease their technology investment levels post the disruptive event than firms that have their R&D activities located outside that country.

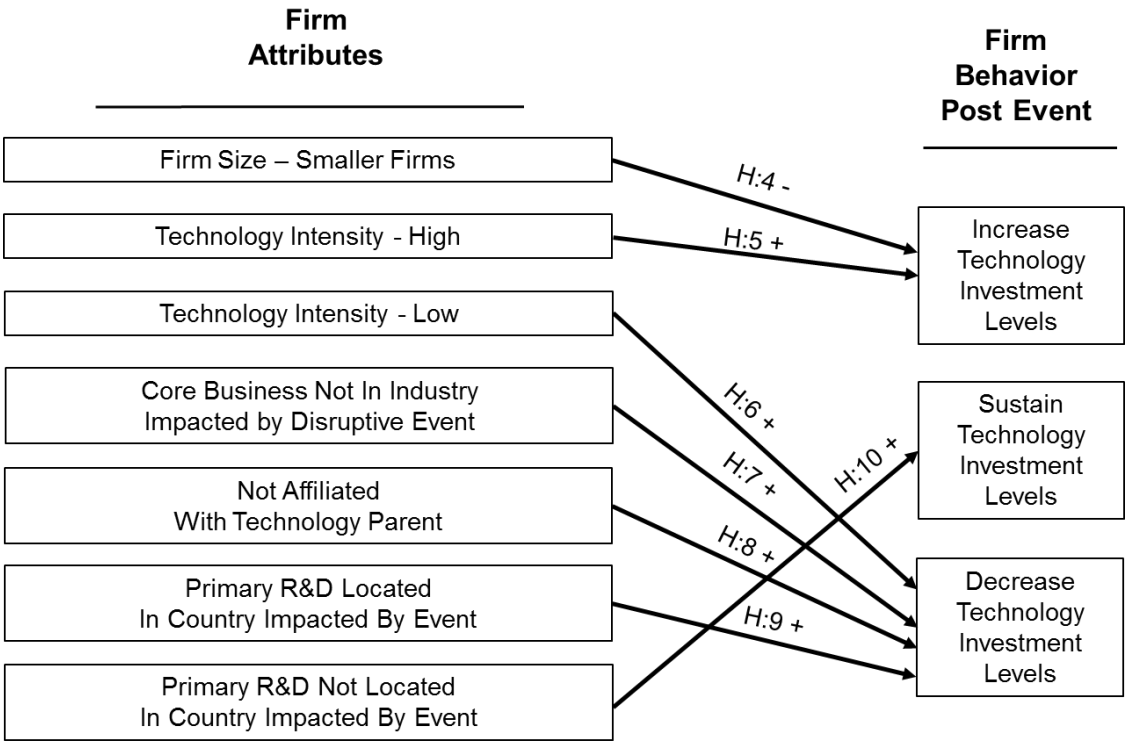
Hypotheses 10: Firms with their primary R&D located outside the country that is primarily impacted by the disruptive event are more likely to sustain their technology investment levels at levels consistent with the technology investment levels prior to the disruptive event.

Table 2 contains a summary of Model 2 hypothesized relationships between firm characteristics and technology investment levels post the disruptive event.

Table 2

Model 2

Hypothesized Relationships
Between Firm Characteristics and
Technology Investment Levels Post the Disruptive Event



Chapter 3 – Research Study - Medical Device Industry

To test the hypotheses presented in Chapter 2, a study was conducted to evaluate changes in technology strategy (as measured by changes in technology investment levels) of technology oriented medical device firms as a result of an adverse disruptive event that took place in that industry during the mid-1980s. This study focuses on a 13 year period (1978 – 1990) which straddled the implementation of significant, broad-based, healthcare reimbursement reforms starting in late 1983. These reforms resulted in significant downward price pressure on healthcare providers which led to commensurate downward price pressure on medical device companies. The following provides more background and description of the impact of this disruptive event on the medical device industry.

Healthcare Reform in the 1980s[1]

In the mid 1980's healthcare expenditures had been consistently rising faster than GNP (the measure of total economic activity used at that time) largely due to the enactment of Medicare and Medicaid. By 1985 healthcare expenditures accounted for almost 11% of GNP. Medicare expenditures for inpatient hospital services increased more than tenfold since its inception in 1967 to more than $33 billion in 1982. From 1979 to 1982 the average cost of a day in the hospital increased at an annual rate of 18 percent. This was more than three times the rate of inflation for the economy overall.

[1] The synopsis of the changes to the reimbursement system and related impact on medical technology in the mid-1980s is primarily based on information contained in: ***Diagnosis Related Groups (DRGs) and the Medicare Program: Implications for Medical Technology – A Technical Memorandum*** (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-TM-H-17, July 1983). In addition, the author of this dissertation was employed by two different medical device companies during the 1980s with responsibility for strategic planning and business development including R&D. Some of the descriptions of the impact on medical device companies are based on his direct experience with the implementation of DRGs and his routine interactions with industry experts and industry peers.

Many critics cited the “cost plus” retrospective system of reimbursement to health care providers as the primary cause for out of control inflation in healthcare spending. Under this system hospitals and other medical care providers were reimbursed for the actual costs they incurred plus a profit for the services they rendered. They had little incentive to control costs. Combined with full coverage insurance plans that covered nearly all employees and their families as well as Medicare and Medicaid which covered nearly everyone else there was little pressure on the healthcare delivery system to control costs. In response to these rising costs many private insurance plans began to offer prospective payment plans where rates were set prior to the period in which they apply. This transferred some of the cost risk to hospitals and other healthcare providers. It took the form of “per-case” payment and the hospital was paid a specific amount based on the type of diagnosis regardless of what they actually spent to treat a patient. This new system of reimbursement was called Diagnostic Related Groups or DRGs. Starting in October 1983 this new reimbursement system began to be phased in for Medicare reimbursement. Other providers of reimbursement including Medicaid instituted similar reimbursement systems.

According to the Office of Technology Assessment (1983), the DRG payment incentives implemented in 1983 were expected to affect technology use in the following ways:

> “Overall, the number and intensity of ancillary procedures provided to inpatients can be expected to decrease, but the use of procedures that can be shown to lower the cost per case will increase.

> The settings of technology use are likely to be influenced by DRG payment, but the incentives work in conflicting directions and are sensitive to the key features of program design. It remains to be seen which incentive will dominate for which procedures. DRG payment will encourage the movement of technologies into the home, particularly those
> for post-hospital care.
>
> DRG payment is likely to influence the specialization of services, but the magnitude and direction of these effects is unknown. The incentives to reduce costs encourage concentration
> of capital-intensive technologies in fewer institutions. Conversely, the increasing competition among hospitals for physicians and patients will create incentives for the widespread acquisition of some technologies.
>
> A change in technology product mix is likely to result from downward pressure on the price and quantity of supplies and, if capital is included in the DRG rate, capital equipment.
> Greater product standardization can be expected as more expensive models and procedures are eased out of the market through competition." (1983, p.5)

The report on Diagnosis Related Groups (DRGs) and the Medicare Program: Implications for Medical Technology (1983) summarized the findings as follows: "The implications are obvious: with limited resources, hospitals will need to assess new technologies more closely and ration

resources more carefully" (p. 41). The expectation was for an overall reduction in the demand for technology based products in the delivery of healthcare as a result of this new reimbursement system. Emphasis was now on treatment modalities that provided good outcomes at the least cost. The prior principle of the best possible treatment at any cost was no longer viable for healthcare providers. The reimbursement organizations were no longer willing to fund this approach. The continuation of the previous trend towards the use of more costly and sophisticated treatments was deemed irresponsible in a cost conscious system focused on managing rising healthcare costs to a more reasonable level. Medical device companies now needed to demonstrate not only clinical outcome effectiveness but also cost effectiveness for all new and existing products. Healthcare providers intended to transfer these industry cost pressures to the medical device suppliers through tougher negotiations and fewer sole source contracts resulting in more competitive pricing. This new cost orientation by healthcare providers was expected to lead to a lower level of financial return for medical device companies. In fact, many hospitals hired experienced purchasing managers from industry to help them negotiate contracts with medical device companies. In the past, purchasing departments in hospitals were mainly clerical functions simply processing the orders that the nurses and doctors sent to them. The sole decision maker in many cases was the medical professional and it was considered interference in the delivery of healthcare for the finance or materials management departments to question in any way the decisions of medical practitioners regarding which products were required to perform their professional services. Medical companies with knowledge of this decision process were able to exploit the purchasing departments when it came to price negotiations. In many cases the products that were used were not even standardized within one hospital. Each surgeon might specify a particular instrument from a particular supplier requiring the hospital to maintain multiple products in inventory for

performing the exact same procedure. The purchasing department's job was to merely fulfill orders and make sure the products were available when needed for each medical professional.

With increased cost pressures the Chief Financial Officer of the hospitals became more interested and involved in the purchasing process and increased pressure was put on medical staff by hospital administration to identify at least two qualified suppliers for any particular device to allow for a competitive negotiation process between suppliers. In addition, hospitals formed product review committees to attempt to standardize more product selections. Hospitals also formed buying groups to combine their purchasing power with other hospitals in order to further leverage the medical device companies for lower pricing. Concurrently, private hospital ownership was increasing and through horizontal integration these privately owned hospitals were becoming large groups of hospitals with common ownership and management. Examples include Hospital Corporation of America (HCA) and Humana which collectively owned several hundred hospitals. These organizations consolidated their purchasing of medical devices by using product selection and standardization committees comprised of medical professionals from across their institutions, as well as finance executives, and materials managers. This further increased their ability to leverage medical device firms for lower pricing based on the considerable size of the purchasing contracts. Consequently this new legislation designed to control costs caused significant changes to the healthcare industry. It can be characterized as a significant "disruptive event" that was having significant impact on the healthcare provider industry in terms of the way it managed its operations and the way it interacted with its suppliers including medical device companies. The healthcare delivery industry, faced with considerable cost control pressures, turned to its suppliers and fully expected them to help

participate in relieving the cost pressures. They understood that their medical device suppliers had enjoyed large profit margins for years and could afford to contribute in the form of lower pricing to help them address the new economic model they were forced to adopt.

As a result of these changes medical device firms needed to reconsider their strategies. This included reevaluating their technology investment strategies, specifically in regard to the spending level and focus of technology investments. They no longer could rely on open ended pricing to recover the investment in any technology that offered potentially better treatment. They could not depend solely on their influence over the medical professional in order to close the sale. The product decisions were more complex (combining both product performance with value in use) and involved more members of the healthcare provider organization (medical professionals, finance executives, and professional purchasing managers). Senior management in medical device firms recognized these changes and as a result were forced to rethink the strategies they had been using to compete. In particular, technology investment strategy which had been the cornerstone of most technology oriented medical device firms required immediate attention. It was no longer possible to pass the considerable costs of developing new, innovative products through to the healthcare providers without a very sound economic and clinical rationale to support the sales proposal.

Medical device firms also needed to understand the new breed of customers they would have to convince. These included the finance executives and professional purchasing managers in addition to the medical practitioners. These new customers were less enamored with the latest technology and were not interested in the relationship building approach that most medical device sales organizations had been trained to practice in managing customer relationships with

medical professionals. These “new” customers wanted data to support claims regarding performance and cost-in-use and they expected discounts and new payment terms in return for commitments to buy the products, particularly when large volume contracts were in play. Golf outings and honorariums for speaking engagements often offered to the medical professionals were considered unethical inducements by those implementing the reforms. In addition, Medicare began to implement more restrictive rules on what practices were deemed acceptable for interactions between health care providers and their suppliers. These changes in the purchasing process used by healthcare provider organizations, largely precipitated by this disruptive event, were having a significant impact on medical device companies. The successful medical device company business model that had provided significant growth and profitability for decades was now obsolete. For technology oriented medical device companies the outlook was bleak as they no longer were able to pass through their development costs unimpeded. It clearly made technology development a riskier proposition and the previous criteria for funding a technology development project needed revision to reflect the new purchasing criteria and purchasing process of the customers.

Critics of the changes in reimbursement policy expected that medical device companies would significantly cut back on their technology investments in response to these new, stringent cost control initiatives. These critics argued that for-profit research entities would stop pursuing breakthrough technologies altogether due to implementation of these economically unattractive reimbursement rules that resulted in higher risks and lower rewards for technology research investment projects[1].

Medical Device Industry and Related Technology in the 1980s -

The total market for medical supplies and devices in 1984 (shortly after implementation of DRGs) was nearly $9 billion. IV solutions and related supplies was the largest single segment of this market. The next largest segments in order of size were: x-ray supplies, orthopedic supplies, general medical supplies, pacemakers, cardiovascular devices, garments & textiles, sutures, surgical instruments, syringes and needles, disposable procedure kits and trays, catheters/tubes, respiratory therapy devices/supplies, radiological catheters, biological products, surgical packs and parts, ophthalmic related products/devices, cardiopulmonary products/devices, chemicals and soaps, sponges, dietary supplies, sterilizer supplies, paper products, gases, diagnostic instruments, dialysis supplies, blood collection devices/supplies, electrosurgical devices, grafts & mesh, underpads, utensils, identification supplies, thermometers, elastic goods, maternity products, bandages, ostomy products, rubber goods, and surgeon needles.[2]

[2] From IMS Data contained in an unpublished paper prepared by the author in 1986 for Harbir Singh at the Wharton School, University of Pennsylvania.

The most active technology oriented medical device supplier firms based on patent application activity during the period 1978 – 1990 are listed in order of total patents applied for in Table 3. The primary areas of product focus (if available) for these firms is also included in this table.

TABLE 3

Patent Application Production and Key Products
Top 50 Technology Oriented Medical Device Firms
Based on Total Medical Device Patent Applications 1978 – 1990

	Firm Name	Total Patents	Key Products
1	OLYMPUS OPTICAL CO., LTD.	369	Imaging equipment
2	MEDTRONIC INC.	305	cardiology products
3	BAXTER INTERNATIONAL INC.	282	IV solutions
4	CORDIS CORPORATION	250	stents
5	SIEMENS AKTIENGESELLSCHAFT	242	multiple products
6	MINNESOTA MINING AND MANUFACTURING COMPANY	220	multiple products
7	KENDALL COMPANY	216	dressings, feeding pumps, needles
8	KIMBERLY-CLARK CORPORATION	192	textiles
9	BECTON, DICKINSON AND COMPANY	168	syringes
10	TOSHIBA CORPORATION	166	
11	C. R. BARD, INC.	141	fluid collection, packaging, catheters
12	TERUMO KABUSHIKI KAISHA (TERUMO CORPORATION)	140	Syringes, needles
13	ALZA CORPORATION	139	
14	DRAGERWERK AKTIENGESELLSCHAFT	136	respirators
15	ABBOTT LABORATORIES	120	IV solution
16	PROCTER + GAMBLE COMPANY	119	
17	ETHICON, INC.	119	sutures
18	BRISTOL-MYERS SQUIBB COMPANY	116	
19	AMERICAN HOSPITAL SUPPLY CORPORATION	108	Largest distributor of medical products
20	SHERWOOD MEDICAL COMPANY	102	syringes
21	RICHARD WOLF GMBH	90	
22	HEWLETT-PACKARD COMPANY	83	patient monitoring
23	ADVANCED CARDIOVASCULAR SYSTEMS, INC.	74	cardiovascular products

TABLE 3 (Continued)

Patent Application Production and Key Products
Top 50 Technology Oriented Medical Device Firms
Based on Total Medical Device Patent Applications 1978 – 1990

	Firm Name	Total Patents	Key Products
25	UNITED STATES SURGICAL CORPORATION	68	surgical instruments, sutures
26	BOEHRINGER MANNHEIM G.M.B.H.	67	
27	GENERAL ELECTRIC COMPANY	67	body scanning equipment
28	MERCK + CO., INC.	60	drug related infusion
29	INTERMEDICS, INC.	58	
30	MILES INC.	58	
31	CARDIAC PACEMAKERS, INC.	55	pacemakers
32	EASTMAN KODAK COMPANY	54	film
33	AMERICAN CYANAMID COMPANY	53	sutures
34	CRITIKON, INC.	52	patient monitoring
35	HABLEY MEDICAL TECHNOLOGY CORPORATION	51	R&D lab
36	PFIZER HOSPITAL PRODUCTS GROUP, INC.	50	
37	ZIMMER, INC.	50	orthopedics
38	JOHNSON + JOHNSON	50	multiple supplies/instruments
39	SULZER BROTHERS LTD.	45	bone implant anchor
40	U.S. PHILIPS CORPORATION	44	
41	PERSONAL PRODUCTS COMPANY	43	bandages
42	BIORESEARCH, INC.	41	sutures
43	HOLLISTER INCORPORATED	40	
44	E. I. DU PONT DE NEMOURS AND COMPANY	38	
45	WELCH ALLYN INC.	37	multiple supplies/instruments
46	ELI LILLY AND COMPANY	37	
47	CANON KABUSHIKI KAISHA	37	imaging equipment
48	MONSANTO COMPANY, INC.	35	
49	HITACHI, LTD	34	
50	HOFFMANN-LA ROCHE INC.	34	

Summary Healthcare Reforms and the Medical Device Industry –

The implementation of healthcare reimbursement reforms was a major event in 1983. The adoption of the DRG model by all payors (reimbursers of healthcare costs) was swift and had a significant impact on healthcare provider organizations and their traditional model of operation. They turned quickly to their suppliers to seek relief from the significant cost control pressures that were being exerted on them. Medical device firms had no choice but to be responsive to these changing customer requirements. This response included price concessions and recognition of a different perspective on the criteria that would be used by healthcare providers to evaluate new products developed my medical device firms. Clearly, the implementation of healthcare reforms was a disruptive event for the healthcare provider industry and as discussed in this chapter it was a disruptive event for the medical device industry as well.

This research study will now examine how that disruptive event impacted on the technology strategy of medical device firms.

Chapter 4 – Data and Methods

Data Requirements –

The primary data requirement for Model 1 and Model 2 is to obtain measures of the level of technology investment of technology oriented medical device firms before and after the disruptive event (implementation of healthcare reforms). Additional data was collected to evaluate the firm attributes identified in Model 2. These additional data included: the size of the firm, the primary location of technology development activities, whether a firm had an ownership affiliation with a diversified technology oriented firm, whether medical devices was a core business for a firm or not, and whether a firm was a high technology intensity firm or low technology intensity firm.

Use of Patent Data as Proxy for Technology Investment Levels –

Patent data is used in this study as a proxy measure of technology investment levels of technology oriented medical device firms. Using patent data to measure technological activity and investment has a long history dating back to Schmookler (1966) and Scherer (1965). Basberg (1987) identified several studies that used patent data to measure the <u>outputs</u> of research activity. "Most models relate patenting to the development phase as an output indicator of R&D activity, and a positive relationship between R&D and patenting is … empirically well documented." (Basberg, 1987, p. 133). Schmookler (1966) and Griliches (1990) suggest that patents may also be good indicators of <u>inputs</u> of inventive activity. Alternative measures of inputs such as R&D spending or technically trained labor force statistics are difficult to obtain and can be more difficult to allocate to specific segments of the business such as

medical devices. As Griliches points out “Even today, with data much more plentiful, the available detail in the published R&D statistics is still quite limited” (1990, p. 1670).

The limitations of using patent data are also well documented in the literature. Archibugi (1992) noted the following disadvantages of patent data: not all inventions are patented; not all innovations are patentable; the propensity to patent can vary across firms and industries; many patents are never used; and some are used simply to block competitors. Griliches (1990) distilled patent data limitations into two major problems: The issues created by classification of patents into various categories which can make it difficult to see all the innovative activity that applies to a specific industry, and: The intrinsic variability of patents in terms of their value as well as issues with making valid comparisons of patent activity over time. These identification and variability problems can further cause difficulty in linking patent activity of an individual firm to specific financial outcomes for the firm. Griliches (1990) also raises the question of whether patents are a measure of technological input versus output. In some cases patented technology is used as the foundation of creating a group of innovative technologies over a period of time - more of an input (see also Cantwell & Fai, 1999) as compared to patents that relate to a specific product - more of an output. Griliches also argues that difficulties arise from the “…large ‘noise’ component in patents as indicators of R&D output in the short-run within-firm dimension.” (Griliches, 1990, p. 1686). This “noise” in patent count data is primarily related to the relatively small percentage of patents that actually provide significant value to the firm. Consequently, it is difficult to assess the true value of individual patents or to rank them effectively in a hierarchy of value.

Most of the issues with patent data relate to their use as measures of output of technological activity. As measures of input, i.e., measures of technology investment levels, several researchers find significant value in using patent data. Acs and Audretsch (1989) find that the "empirical evidence suggests that patents provide a fairly reliable measure of innovative activity." (Acs & Audretsch, 1989, p. 177). Pavitt (1988) concludes that "patent statistics broken down by patent class can help evaluate and explain the patterns of relative technological strength and weakness of firms…" (Pavitt, 1988, p. 528). Griliches (1990) suggests, that while there are no good measures of technical or scientific progress, patent data has the following benefits: it is available, by definition it relates to inventiveness, and it appears to be based on an objective and slowly changing standard. He concludes from his extensive analysis of several authors' work on the validity of using patent data; "… the evidence is quite strong that when a firm changes its R&D expenditures, parallel changes occur also in its patent numbers" (Griliches, 1990, p. 1674). The conclusions of these authors thus clearly supports the use of patent data as a proxy measure of the level of technology investment (input) of technology oriented firms.

In addition to being a proxy for the level of technology investment, the patent database also provides other key information including the primary names and geographic location of the firms filing for the patent. This data is used as a proxy for identifying the location of the technology development headquarters of a firm.

Data Categorization

The concept of collecting data before and after a disruptive event to assess the impact of that event has been used previously (Walker et al., 2002). The timeframe to be used for evaluating

technology investment pre the disruptive event is the six year period 1978 to 1983. The implementation of healthcare reimbursement reforms takes place in late 1983 (October) and was not likely to impact the momentum of technology investments undertaken up until that time (even allowing for anticipation of the upcoming event) nor was it likely to impact on purchase agreements for medical devices in 1983 as most purchase agreements are for one year periods and would have been negotiated prior to the enactment of DRGs in October 1983. A six year period is selected to provide a sufficient period of time to establish a level of technology investment for the firm prior to the healthcare reimbursement reforms and to observe any significant change in that level of technology investment following the event. In choosing the six year pre-event period of technology investment levels consideration was given to the period of time that would be used to measure the post-event technology investment levels and the importance of having these two periods be of equal duration to provide a comparable period of investment activity for comparison purposes. A couple of considerations warranted the selection of a six year period. First, adding additional years to the pre or post event period would cause those additional years to be further removed from the actual date of the disruptive event raising a question as to whether they were truly indicative of the investment level of the firm in a period reasonably proximate to the event. Further, adding one additional year to an already six year base pre and post the event would not likely significantly change the total investment level pre and post the event unless those additional years were significantly different than the other six years. If they were significantly different it would raise again the question of their relevance to the disruptive event given their distance from the event as opposed to other potential or unidentified relational factors. On the other hand, choosing a time period of more than one or two years is done to recognize the period of time necessary to develop technology suitable for patenting a medical device. These patentable technology

development timeframes would typically span more than a single year and thus it is necessary to view the technology investment levels over at least a couple of years to establish an understanding of any significant change in the investment level pre and post the event.

The six year period of 1985 – 1990 is chosen as the post event period for similar reasons to those discussed above with the additional consideration that the year 1984 is viewed as a transition year. Key activities taking place in the transition year include technology oriented medical device supplier firms completing existing technology investments started prior to the event. Concurrently, the healthcare provider organizations, are implementing their new purchase criteria and purchase process for medical devices during 1984 as medical device product purchase contracts come up for renewal. By choosing to start this post event period in 1985 rather than 1984 the objective is to establish that the year 1985 clearly reflects activity **after** the disruptive event and **after** the implementation of more cost oriented criteria into the customer decision and purchase process. In addition, medical device firms are now fully aware of how their customers are reacting to the disruptive event and at this point the technology oriented medical device firms have gone through a budget cycle to reflect that awareness in their level of technology investments. The year 1984 would likely be a mix of activity that reflects reaction by some medical device firms and not by others and it would be difficult to isolate which firms had incorporated awareness of the changes in their technology investments and which firms had not. In addition, the momentum of investment decisions made prior to full awareness of the impact on their customers has mostly worked its way through the development cycle of technology oriented medical device supplier firms by the end of 1984. By 1985 most, if not all, of these firms are operating in accordance with their customer's new

decision criteria and purchasing process and are likely to have incorporated these new realities into their strategies including their technology investment strategy.

Data Description -

Patent data for patent applications for the sub category (category 32 – Surgery and Medical Instruments in the US patent office) for the period 1978 through 1990 has been collected and formatted for further evaluation. Preliminary analysis of the data indicates that a total of 19,575 patents were applied for in this sub category during the thirteen year period under examination. Medical device firms with five or more patent applications during the thirteen year period account for 8,871 (45.3%) of the total patent applications. These 361 medical device firms are considered the technology oriented medical device firms based on this minimum level of patent application during the period under review. Firms with fewer than 5 patents over the 13 year period are not considered to be technology oriented medical device firms at least in relation to the rest of the industry. The remaining patents (10,704 or 54.7%) not issued to technology oriented medical device firms were issued to firms or individuals with fewer than 5 total patent applications during the thirteen year period or to universities, government institutions, or hospitals. Since this research focuses on technology oriented medical device supplier firms, the patent applications for the 361 firms with 5 or more patents during the thirteen year examination period are included as the initial dataset in this research. Table 4 provides a summary of concentration of patent activity across the 361 firms.

TABLE 4

Summary of Patent Application Statistics for Technology Oriented Medical Device Firms 1978 – 1990 (All Medical Device Firms with at least 5 Patent Applications) N = 361

Number of Patents Applied for during the period 1978 - 1990	Number of Firms	% of Total Technology Oriented Medical Device Firms	Cumulative % of Firms	Cumulative % of Total Patent Applications
200 or more	7	1.9%	1.9%	21.2%
100 – 199	13	3.6%	5.5%	41.2%
50 – 99	18	5.0%	10.5%	53.7%
25 - 49	36	10.0%	20.5%	66.6%
10 – 24	124	34.4%	54.9%	87.9%
5 - 10	163	45.2%	100.0%	100.0%
Total	361	100.0%		

Further analysis of the data was made to adjust the dataset to eliminate new entrants, exiting firms, and firms with less than 5 patent applications pre-disruptive event. These adjustments were made to allow for better pre/post comparisons. Including firms in the dataset with less than 5 pre disruptive event patent applications may introduce a bias in the data due to the relatively low level of base period patent applications used to make the comparison to patent applications in the post disruptive event period. A simple comparison of the data for firms with less than 5 pre-event patent applications supports the likely existence of this bias. Analysis of

these low base period firms found that 76.9% of the 203 firms with less than 5 patent applications in the pre disruptive event period had increases in their patent applications post the disruptive event as compared to only 50% of the 158 firms with 5 or more patent applications pre the disruptive event. To control for this potential bias in the data those firms with less than five patents in the pre disruptive event period were removed from the dataset. In addition firms that entered the industry after 1980 or exited the industry after 1988 were also removed from the dataset to avoid making comparisons of two significantly different numbers of years between pre and post event. These adjustments were intended to produce a dataset that allowed for testing the comparisons between periods with fewer validity issues.

Table 5 summarizes the number of new entrants and exits during the 13 year period 1978 – 1990.

TABLE 5
New Entrants and Exits
N = 361

Category	Number of Firms	% of Total
New Entrants (Firms entering the industry in 1983 or later years as evidenced by no patent activity prior to 1983)	34	9.4%
Exits (Firms leaving the industry in 1986 or later years as evidenced by no patent activity after 1985)	16	4.4%

Table 6 summarizes patent application statistics for the 147 firms in the adjusted dataset.

TABLE 6
Summary of Patent Application Statistics for
Technology Oriented Medical Device Firms
1978 – 1990
(All Medical Device Firms with at least 5 Patent Applications
Excluding new entrant, exit firms, and firms with less than 5 pre-event applications)[1]
n = 147 firms, n_2 = 6,734 patents

Number of Patents Applied for during the period 1978 - 1990	Number of Firms	% of Total Technology Oriented Medical Device Firms	Cumulative % of Firms	Cumulative % of Total Patent Applications
200 or more	7	4.8%	4.8%	28.0%
100 – 199	13	13.6%	18.4%	54.7%
50 – 99	16	10.9%	24.5%	69.7%
25 - 49	29	19.7%	44.2%	83.8%
10 – 24	60	40.8%	85.0%	97.9%
5 - 10	22	14.5%	100.0%	100.0%
Total	147	100.0%		

[1]Technology oriented medical device firms who applied for 5 or more patents during the period 1978 – 1990 excluding firms that did not apply for any patents during the first five years 1978 – 1982 (considered new entrants) or the last five years 1986 – 1990 (considered exits) or had less than 5 pre-disruptive event (pre 1984) patents (considered low base year bias firms)

METHODS -

Model 1:

Disruptive Event (X_1) → Change in Technology Strategy (Y_1)

Variable Descriptions –

Y_1 = A **Change in Technology Strategy** has occurred if there is a significant change in the technology investment level post the disruptive event compared to technology investment levels pre the disruptive event:

- Technology Investment Level = the cumulative number of patents applied for by a firm in years 1985 – 1990 (post disruptive event technology investment level) and the cumulative number of patents applied for by a firm in years 1978 – 1983 (pre disruptive event technology investment level). See supporting discussion and citations in the previous section for the use of patent applications as a proxy for technology investment levels.

X_1 = The **Disruptive Event** was the significant change in reimbursement policy of healthcare funders which was implemented in late 1983 that resulted in significant cost reduction pressures on healthcare providers and their suppliers. Activities prior to 1984 are considered pre the disruptive event and activities after 1984 are considered post the disruptive event. 1984 is considered a transition year between pre and post disruptive event.

Summary of Hypotheses to be tested in Model 1:

H1: Technology oriented firms facing a disruptive event in their industry will decrease their technology investment level post the disruptive event.

H2: Technology oriented firms facing a disruptive event in their industry will sustain their technology investment level post the disruptive event.

H3: Technology oriented firms facing a disruptive event in their industry will increase their technology investment level post the disruptive event.

To test these hypotheses first a test is conducted to determine if there is a statistically significant difference between post event technology investment levels and pre event technology investment levels.

If that difference is significant and it indicates that technology investment levels decreased then hypotheses H1 is supported and hypotheses H2 and H3 are rejected as overall these are mutually exclusive outcomes.

If that difference is significant and it indicates that technology investment levels increased then hypotheses H3 is supported and hypotheses H1 and H2 are rejected as overall these are mutually exclusive outcomes.

If there is not a statistically significant difference between pre event technology investment levels and post event levels then hypotheses H2 is supported and hypotheses H1, H3 are rejected as they are mutually exclusive outcomes.

Preliminary evaluation of the data using SPSS software indicated that the data for pre event and post event technology investment levels is not normally distributed so a one-sample t-test could

not be utilized for this evaluation. Instead a Wilcoxon signed-rank test is utilized to compare the medians of the pre event technology investment levels and the post event technology investment levels of medical device firms. Required assumptions for using this test are met (i.e. use of continuous variable, related groups, and symmetry of the differences between the related groups). This test allows determination of the direction of differences and the size of the difference along with confirmation of the statistical significance of any differences. Support for using this test to compare the significance in differences of outcomes for related groups is found in Conover (1999) and Daniel (1990).

Model 2:

Tests to be completed -

Small Firm Size (X_2) association with increase in Post Event Technology Investment Level (Y_2)

High Technology Intensity (X_3) association with increase in Post Event Technology Investment Level (Y_2)

Low Technology Intensity (X_4) association with decrease in Post Event Technology Investment Level (Y_4)

Not Core Business (X_5) association with decrease in Post Event Technology Investment Level (Y_4)

Not Technology Affiliated (X_6) association with decrease in Post Event Technology Investment Level (Y_4)

R&D Located in U.S. (X_7) association with decrease in Post Event Technology Investment Level (Y_4)

R&D Not Located in U.S. (X_8) association with Sustained Post Event Technology Investment Level (Y_3)

Dependent Variables

$\mathbf{Y_2}$ = A firm **Increased Post Event Technology Investment Level** if the number of patent applications in the post event period is greater than the number of patent applications in the pre event period;

1 = increased, 0 = decreased or no change

$\mathbf{Y_3}$ = A firm **Sustained Post Event Technology Investment Level** if the number of patent applications in the post event period is within plus or minus 20% of the number of patents in the pre event period;

1 = sustained, 0 = increased or decreased

$\mathbf{Y_4}$ = A firm **Decreased Post Event Technology Investment Level** if the number of patent applications in the post event period is less than the number of patent applications in the pre event period;

1 = decreased, 0 = increased or no change

Independent Variables

$\mathbf{X_2}$ = A firm is **Small** in size if the total number of patent applications of the firm in the period 1978 – 1983 is less than 6 and the firm is not affiliated with a technology oriented parent firm; If small it is coded 1, if not small it is coded as 0

$\mathbf{X_3}$ = A firm is **High Technology Intensity** if the total number of patent applications of the firm in the period 1978 – 1983 is greater than 12; If high technology intensity it is coded 1, if not high technology intensity it is coded as 0

$\mathbf{X_4}$ = A firm is **Low Technology Intensity** if the total number of patent applications of the firm in the period 1978 – 1983 is less than 7; If low technology intensity it is coded 1, if not low technology intensity it is coded as 0

$\mathbf{X_5}$ = If a firm's primary business is not in medical devices then medical devices is a **Not Core Business** for the firm; if medical devices is not core then coded 1, if medical devices is core then coded 0

$\mathbf{X_6}$ = If a firm is not affiliated with a technology oriented parent firm the firm is considered **Not Technology Affiliated**; if not technology affiliated it is coded as 1, if technology affiliated it is coded as 0

$\mathbf{X_7}$ = A firm is considered to have its primary **R&D Located in the U.S.** if that firm's patent applications in the patent database are identified as submitted from the U.S.; if located in the U.S. then coded 1, if R&D is not located in the U.S. then coded 0

$\mathbf{X_8}$ = A firm is considered to have its primary **R&D Not Located in the U.S.** if that firm's patent applications in the patent database are identified as submitted from any geographic location other than the U.S.; if not located in the U.S. then coded 1, if R&D is located in the U.S. then coded 0

Hypotheses Tests:

In order to test hypotheses 4 through 10, logistic regression is used. Logistic regression is the preferred method for testing when the dependent variable is binary or dichotomous as is the case with $\mathbf{Y_2}$ and $\mathbf{Y_3}$ in Model 2. Logistic regression uses the formula:

$$\boldsymbol{P} = \frac{\boldsymbol{e}^{\propto+\boldsymbol{\beta x}}}{\mathbf{1}+\boldsymbol{e}^{\propto+\boldsymbol{\beta x}}}$$

Where $\boldsymbol{P}$ is the probability of a 1 (for a 1,0 variable), $\boldsymbol{e}$ is the base of the natural logarithm (about 2.718) and $\propto$ and $\boldsymbol{\beta}$are the parameters of the model (as in their normal linear regression). The value of $\propto$ yields $\boldsymbol{P}$ when x is zero, and $\boldsymbol{\beta}$ indicates how the probability of a 1 changes (the outcome can only be either 1 or 0) when x changes by a single unit. Because the relation between x and $\boldsymbol{P}$ is nonlinear, $\boldsymbol{\beta}$ does not have as straightforward an interpretation in this model as it would in ordinary linear regression.

From a logistic regression an odds ratio can be determined. The odds ratio is the ratio of the odds of an event occurring to it not occurring overall or under the influence of various independent variables. This generally is expressed as a logit or log of odds as follows:

$$\boldsymbol{logit}\ (\boldsymbol{P}) = \mathbf{ln}(\frac{\boldsymbol{P}}{\mathbf{1}-\boldsymbol{P}})$$

SPSS was used to run the logistic regressions and to measure 95% confidence intervals of the odds ratios. This is ultimately expressed as likelihood consistent with the hypotheses statement. An example, a High Technology Intensity firm (X_3) is N.Nx times more likely to increase their technology investment (Y_2 = 1) than a firm that is not a High Technology Intensity firm.

Model 2 is evaluated using the dataset that includes 147 firms adjusted to eliminate the low base year firms and new entrants and exits in order for the comparisons used in determining $\mathbf{Y_2}$ and $\mathbf{Y_3}$ to be valid (see discussion in data description section of this paper for more information about this dataset).

Summary of hypotheses to be tested in Model 2:

Small Firm –

Hypothesis 4: Small firms are less likely to increase their technology investment levels post the disruptive event

High Technology Intensity Firm–

Hypothesis 5: High Technology Intensity Firms are more likely to increase their technology investment levels post the disruptive event than non-High Technology Intensity Firms.

Low Technology Intensity Firm–

Hypothesis 6: Low Technology Intensity Firms are more likely to decrease their technology investment levels post the disruptive event than non-Low Technology Intensity Firms.

Medical Devices Not Core Business Firm –

Hypothesis 7: Technology oriented firms that do not have their core business in the industry in which the disruptive event occurred are more likely to decrease their technology investment levels in the industry post the disruptive event than firms that do have their core business in that industry.

Not Affiliated with Technology Oriented Parent Firm –

Hypothesis 8: Firms not affiliated with a technology oriented parent firm are more likely to decrease their technology investment levels post the disruptive event than firms that are affiliated with a technology oriented parent firm.

Firm with primary R &D located in the same geographic market impacted by the disruptive event –

Hypothesis 9: Firms with their primary R&D located in the same country that is primarily impacted by the disruptive event are more likely to decrease their technology investment levels post the disruptive event than firms that have their R&D activities located outside that country.

Firm with primary R &D not located in the same geographic market impacted by the disruptive event –

Hypothesis 10: Firms with their primary R&D located outside the country that is primarily impacted by the disruptive event are more likely to sustain their technology investment levels at levels consistent with the technology investment levels prior to the disruptive event.

Chapter 5, Results and Analysis

Results –

Model 1 Results –

Comparison of post event technology investment levels to pre event technology investment levels for the 147 technology oriented medical device firms included in this study was conducted to determine if a significant difference in technology investment levels was observed post the disruptive event as compared to pre the disruptive event. A Wilcoxon signed-rank test determined that there was a statistically significant median increase in the technology investment levels post the disruptive event as compared to pre the disruptive event for the 147 firms, $z=2.596$, $p < .01$

The median level of patents applied for pre the disruptive event was 9 and the median level after the disruptive event was 10.

The results of tests of the first three hypotheses is shown in Table 7.

TABLE 7

Model 1 – Results

Hypothesis	Supported?
H1: Technology oriented firms facing a disruptive event in their industry will **decrease** their technology investment level post the disruptive event.	No
H2: Technology oriented firms facing a disruptive event in their industry will **sustain** their technology investment level post the disruptive event.	No
H3: Technology oriented firms facing a disruptive event in their industry will **increase** their technology investment level post the disruptive event.	**Yes**

Table 8 provides summary comparisons for the modified dataset excluding the new entrants, exits, and low base period firms

TABLE 8

Comparison of % Change in Patent Applications Post Disruptive Event (1985 – 1990) to Patent Applications Pre Disruptive Event (1978 – 1983) for Technology Oriented Medical Device Firms (Excluding new entrant, exit firms, and firms with less than 5 pre-event applications)[1] n = 147

% Change in Number of Patent Applications Post Event as Compared to Pre-Event	% of Firms[1]
Increased 100% or more	**24.5%**
+20% to +99%	**23.1%**
1% to +19%	**5.4%**
0% to -20%	**8.8%**
-21% to -50%	**15.7%**
-51% to -99%	**22.5%**

[1]Technology oriented medical device firms who applied for 5 or more patents during the period 1978 – 1990 excluding firms that did not apply for any patents during the first five years 1978 – 1982 (considered new entrants) or the last five years 1986 – 1990 (considered exits) or had less than 5 pre-disruptive event (pre 1984) patents (considered low base year bias firms)

Model 2 Results –

Table 9 shows the results of the logistic regressions for hypotheses 5 through 9

Table 9
Model 2
Hypotheses Test Results (Logistic Regressions)
Hypotheses 4 through 10
Dataset n = 147

Hypothesis	Y_i	X_i	Odds Ratio Exp. (β)	Significance	Supported?
H4: Small firms are less likely to increase their technology investment levels post the disruptive event.	Y_2	X_2	**N/A 100% of small Firms decreased**	**<.05**	**Yes**
H5: High Technology Intensity Firms are more likely to increase their technology investment levels post the disruptive event than non-High Technology Intensity Firms.	Y_2	X_3	**1.937**	**.033**	**Yes**
H6: Low Technology Intensity Firms are more likely to decrease their technology investment levels post the disruptive event than non-Low Technology Intensity Firms.	Y_4	X_4	**1.278**	**.092**	No
H7: Technology oriented firms that do not have their core business in the industry in which the disruptive event occurred are more likely to decrease their technology investment levels in the industry post the disruptive event than firms that do have their core business in that industry.	Y_4	X_5	**.804**	**.929**	No
H8: Firms not affiliated with a technology oriented parent firm are more likely to decrease their technology investment levels post the disruptive event than	Y_4	X_6	**1.50**	**.026**	**Yes**

firms that are affiliated with a technology oriented parent firm.					
Hypothesis	**Y_i**	**X_i**	**Odds Ratio Exp. (β)**	**Significance**	**Supported?**
H9: Firms with their primary R&D located in the same country that is primarily impacted by the disruptive event are more likely to decrease their technology investment levels post the disruptive event than firms that have their R&D activities located outside that country.	**Y_4**	**X_7**	**.882**	**.509**	No
H10: Firms with their primary R&D located outside the country that is primarily impacted by the disruptive event are more likely to sustain their technology investment levels at levels consistent with the technology investment levels prior to the disruptive event.	**Y_3**	**X_8**	**.244**	**.434**	No

Table 10 provides descriptive summary data for the 147 firms categorized by independent variable**.** The attributes that were evaluated were: firm size, high technology intensity firms, low technology intensity firms, firms that do not have their core business in medical devices, firms not affiliated with a technology parent firm, firms with their primary R&D located in the U.S., firms with their primary R&D not located in the U.S.

TABLE 10

Summary of Data/Results for Key Firm Attributes
(Excluding New Entrants, Exits, and low base year firms)
n = 147

Firm Attribute	Number of Firms	% of Firms that Increased their Level of Technology Investment Post the Event	% of Firms that Decreased Their Level of Technology Investment Post the Event
Small Firms	**19**	**0.0%**	**100.0%**
Firms with High Technology Intensity	**47**	**66.0%**	**34.0%**
Firms with Low Technology Intensity	**41**	**41.5%**	**56.1%**
Medical devices is Not Core Business for firm	**83**	**53.0%**	**44.6%**
Firm is Not Technology Affiliated with a parent firm	**40**	**40.0%**	**60.0%**
Firms with primary R&D located in the U.S.	**96**	**51.0%**	**46.9%**
Firm Attribute	**Number of Firms**	**% of Firms that Sustained their Level of Technology Investment Post the Event**	**% of Firms that Significantly Increased or Decreased Their Level of Technology Investment Post the Event**
Firms with primary R&D located outside the U.S.	**51**	**19.6%**	**80.4%**

Table 11 provides a complete list of the 147 technology oriented, medical device firms (excluding new entrants and exit firms, and firms with less than 5 patents in the pre-disruptive event period). The table provides each firm's total number of patent applications during the thirteen year period (1978 – 1990) as well as the number of patent applications in the pre-disruptive event period (1978 – 1983) and the number of patent applications in the post disruptive event period (1985 – 1990). These latter two numbers do not equal total patents as the total also includes patent applications from the transition year, 1984.

TABLE 11

Technology Oriented Medical Device Firms
Total Patent Applications (1978 – 1990),
Patent Applications Pre-Disruptive Event (1978 – 1983),
Patent Applications Post Disruptive Event (1985 – 1990), and
Percent Change in Patent Applications Post Event Period compared to Pre-Event Period
(Excluding New Entrants, Exits, and low base year bias firms = < 5 patents pre)

n = 147

Ranked from Highest % Change to Lowest % Change

	Name of Firm	Total	Total Pre	Total Post	% Change Post vs Pre
1	ADVANCED CARDIOVASCULAR SYSTEMS, INC.	74	8	63	687.5%
2	SHERWOOD MEDICAL COMPANY	102	13	81	523.1%
3	INTERMEDICS, INC.	58	9	49	444.4%
4	ASAHI KOGAKU KOGYO KABUSHIKI KAISHA	32	5	27	440.0%
5	TERUMO KABUSHIKI KAISHA (TERUMO CORPORATION)	140	25	111	344.0%
6	TOSHIBA CORPORATION	166	29	126	334.5%
7	MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.	27	5	20	300.0%

8	MOLNLYCKE AB	27	5	19	280.0%
9	CARDIAC PACEMAKERS, INC.	55	11	41	272.7%
10	ZIMMER, INC.	50	11	38	245.5%
11	UNITED STATES SURGICAL CORPORATION	68	14	48	242.9%
12	CONCEPT, INC.	23	5	17	240.0%
13	U.S. PHILIPS CORPORATION	44	10	34	240.0%
14	HEWLETT-PACKARD COMPANY	83	19	60	215.8%
15	WELCH ALLYN INC.	37	9	28	211.1%
16	SULZER BROTHERS LTD.	45	11	34	209.1%
17	RICHARD WOLF GMBH	90	21	63	200.0%
18	C. R. BARD, INC.	141	34	101	197.1%
19	EASTMAN KODAK COMPANY	54	14	40	185.7%
20	FUJI PHOTO OPTICAL CO. LTD.	22	5	14	180.0%
21	BRISTOL-MYERS SQUIBB COMPANY	116	29	80	175.9%
22	COOK INC.	33	8	21	162.5%
23	AMERICAN CYANAMID COMPANY	53	13	34	161.5%
24	E. I. DU PONT DE NEMOURS AND COMPANY	38	10	26	160.0%
25	BOEHRINGER MANNHEIM G.M.B.H.	67	19	48	152.6%
26	PROCTER + GAMBLE COMPANY	119	33	82	148.5%
27	ADVANCED TECHNOLOGY LABORATORIES, INC.	21	5	12	140.0%
28	MINNESOTA MINING AND MANUFACTURING COMPANY	220	61	146	139.3%
29	SIEMENS AKTIENGESELLSCHAFT	242	69	165	139.1%
30	TAKEDA CHEMICAL INDUSTRIES LTD.	23	7	16	128.6%
31	GENERAL ELECTRIC COMPANY	67	18	41	127.8%
32	AJINOMOTO COMPANY INCORPORATED	29	9	20	122.2%
33	AMERICAN MEDICAL SYSTEMS, INC.	29	9	20	122.2%
34	KIMBERLY-CLARK CORPORATION	192	57	118	107.0%
35	BECTON, DICKINSON AND COMPANY	168	52	104	100.0%
36	STRYKER CORPORATION	16	5	10	100.0%
37	MONSANTO COMPANY, INC.	35	12	23	91.7%
38	CORDIS CORPORATION	250	72	136	88.9%
39	CRITIKON, INC.	52	17	32	88.2%
40	OLYMPUS OPTICAL CO., LTD.	369	119	224	88.2%
41	EMPI, INC.	26	8	15	87.5%
42	ELI LILLY AND COMPANY	37	13	24	84.6%
43	KUREHA CHEMICAL INDUSTRY CO., LTD.	14	5	9	80.0%
44	TRUTEK RESEARCH, INC.	17	5	9	80.0%
45	PHILLIPS PETROLEUM COMPANY	16	6	10	66.7%
46	CANON KABUSHIKI KAISHA	37	14	23	64.3%
47	BAYER AKTIENGESELLSCHAFT	22	8	13	62.5%

48	WARNER-LAMBERT COMPANY	15	5	8	60.0%
49	HOLLISTER INCORPORATED	40	15	23	53.3%
50	CARL ZEISS STIFTUNG	23	8	12	50.0%
51	ESSILOR INTERNATIONAL COMPAGNIE GENERALE D OPTIQUE	15	6	9	50.0%
52	HOECHST AKTIENGESELLSCHAFT	30	12	18	50.0%
53	ALZA CORPORATION	139	52	74	42.3%
54	MINE SAFETY APPLIANCES CO.	12	5	7	40.0%
55	SCHERING CORP.	19	8	11	37.5%
56	SRI INTERNATIONAL	19	8	11	37.5%
57	ELECTRO-BIOLOGY, INC.	15	6	8	33.3%
58	KYOWA HAKKO KOGYO CO., LTD	21	9	12	33.3%
59	SMITH AND NEPHEW ASSOCIATED COMPANIES P.L.C.	26	10	13	30.0%
60	SHILEY INCORPORATED	17	7	9	28.6%
61	SURVIVAL TECHNOLOGY, INC.	27	11	14	27.3%
62	SYNTEX (U.S.A) INC.	29	12	15	25.0%
63	TOKYO KOGAKU KIKAI KABUSHIKI KAISHA	18	8	10	25.0%
64	MEDICAL ENGINEERING CORP.	73	30	37	23.3%
65	BAXTER INTERNATIONAL INC.	282	122	150	23.0%
66	IVAC CORPORATION	21	9	11	22.2%
67	MALLINCKRODT, INC.	21	9	11	22.2%
68	KURARAY CO., LTD.	12	5	6	20.0%
69	PERSONAL PRODUCTS COMPANY	43	15	18	20.0%
70	RESPITRACE CORPORATION	12	5	6	20.0%
71	SHARP KABUSHIKI KAISHA (SHARP CORPORATION)	27	11	13	18.2%
72	HELLIGE GMBH	13	6	7	16.7%
73	DRAGERWERK AKTIENGESELLSCHAFT	136	58	67	15.5%
74	JOHNSON & JOHNSON PRODUCTS, INC.	17	7	8	14.3%
75	MERCK + CO., INC.	60	28	32	14.3%
76	HOFFMANN-LA ROCHE INC.	34	16	18	12.5%
77	VALLEYLAB INC.	19	8	9	12.5%
78	MILES INC.	58	26	28	7.7%
79	AESCULAP-WERKE AKTIENGESELLSCHAFT VORMALS JETTER + SCHEERER	15	9	9	0.0%
80	PFIZER INC.	24	12	12	0.0%
81	RCA CORPORATION	13	6	6	0.0%
82	ETHICON, INC.	119	53	51	-3.8%
83	AMERICAN HOME PRODUCTS CORPORATION	29	14	13	-7.1%
84	SUMITOMO ELECTRIC INDUSTRIES CO., LTD.	31	14	13	-7.1%
85	ABBOTT LABORATORIES	120	60	54	-10.0%

86	CETUS CORPORATION	11	6	5	-16.7%
87	LASERSCOPE, INC.	11	6	5	-16.7%
88	HENKEL KOMMANDITGESELLSCHAFT AUF AKTIEN(HENKEL KGAA)	11	5	4	-20.0%
89	MEDICAL DESIGNS, INC.	9	5	4	-20.0%
90	NOVAMETRIX MEDICAL SYSTEMS, INC.	9	5	4	-20.0%
91	SUMITOMO CHEMICAL COMPANY, LIMITED	9	5	4	-20.0%
92	FIGGIE INTERNATIONAL INC.	16	8	6	-25.0%
93	KENDALL COMPANY	216	116	87	-25.0%
94	VITATRON MEDICAL B.V.	14	8	6	-25.0%
95	AUERGESELLSCHAFT GMBH	12	7	5	-28.6%
96	MEDTRONIC INC.	305	175	118	-32.6%
97	TELEDYNE INDUSTRIES, INC.	11	6	4	-33.3%
98	UOP	10	6	4	-33.3%
99	MATSUSHITA ELECTRIC WORKS, LTD.	26	13	8	-38.5%
100	BIORESEARCH, INC.	41	23	14	-39.1%
101	BEIERSDORF AKTIENGESELLSCHAFT	8	5	3	-40.0%
102	CARL FREUDENBERG	8	5	3	-40.0%
103	DAIG CORPORATION	8	5	3	-40.0%
104	SNYDER LABORATORIES, INC.	18	10	6	-40.0%
105	UPJOHN COMPANY	24	15	9	-40.0%
106	AIR-SHIELDS, INC.	11	7	4	-42.9%
107	BIOTRONIK MESS- UND THERAPIEGERATE GMBH & CO., INGENIERBURO BERLIN	22	14	8	-42.9%
108	CARBOMEDICS, INC.	12	7	4	-42.9%
109	SCHERING AKTIENGESELLSCHAFT	11	7	4	-42.9%
110	DOW CORNING CORPORATION	18	11	6	-45.5%
111	DUPHAR INTERNATIONAL RESEARCH B.V.	17	11	6	-45.5%
112	L'OREAL S.A.	17	11	6	-45.5%
113	CODMAN + SHURTLEFF, INC.	30	18	9	-50.0%
114	MICRO-MEGA SA	18	12	6	-50.0%
115	DATASCOPE CORPORATION	14	9	4	-55.6%
116	IMED CORPORATION	13	9	4	-55.6%
117	BEAR MEDICAL SYSTEMS, INC.	9	5	2	-60.0%
118	KALTENBACH & VOIGT GMBH	14	10	4	-60.0%
119	KARL OTTO BRAUN KG	7	5	2	-60.0%
120	METATECH CORPORATION	7	5	2	-60.0%
121	VARIAN ASSOCIATES, INC.	8	5	2	-60.0%
122	DEL MAR AVIONICS	12	8	3	-62.5%
123	HAEMONETICS CORPORATION	8	6	2	-66.7%
124	INTERMEDICAT GMBH	19	12	4	-66.7%

125	MINOLTA CAMERA CO., LTD.	12	9	3	-66.7%
126	STERLING DRUG INC.	8	6	2	-66.7%
127	AMERICAN HOSPITAL SUPPLY CORPORATION	108	71	23	-67.6%
128	HUDSON OXYGEN THERAPY SALES COMPANY	10	7	2	-71.4%
129	AMERICAN OPTICAL CORPORATION	20	15	4	-73.3%
130	COLGATE-PALMOLIVE COMPANY	28	22	5	-77.3%
131	JOHNSON + JOHNSON	50	40	9	-77.5%
132	MACHIDA ENDOSCOPE CO., LTD.	11	9	2	-77.8%
133	HOWMEDICA, INC.	29	24	5	-79.2%
134	ILLINOIS TOOL WORKS INC.	6	5	1	-80.0%
135	SENKO MEDICAL INSTRUMENTS MFG. CO., LTD.	7	5	1	-80.0%
136	DOW CHEMICAL COMPANY	7	6	1	-83.3%
137	JOBST INSTITUTE, INC.	7	6	1	-83.3%
138	MARQUEST MEDICAL PRODUCTS, INC.	7	6	1	-83.3%
139	UNION CARBIDE CORPORATION	7	6	1	-83.3%
140	BURROUGHS WELLCOME CO.	8	7	1	-85.7%
141	KINGSDOWN MEDICAL CONSULTANTS, LTD.	9	7	1	-85.7%
142	SMITHKLINE BECKMAN CORPORATION	9	8	1	-87.5%
143	TECHNICON INSTRUMENTS CORPORATION	9	8	1	-87.5%
144	HUGHES AIRCRAFT COMPANY	10	9	1	-88.9%
145	IPCO CORPORATION	13	11	1	-90.9%
146	SYVA COMPANY	12	11	1	-90.9%
147	KABUSHIKI KAISHA MORITA SEISAKUSHO	13	12	1	-91.7%

The detailed summary of the results by hypotheses and theory is in Table 12:

TABLE 12
Research Results by Theory/Hypotheses

H:#	Hypothesis	Theory	Author(s)	Supported ?
1.	Decrease	Rational Actor, Financial Optimization (RADCF[1]) [1] Risk Adjusted Discounted Cash Flow	• Ben-Zion • Allison • Bowman	No
		Competency destroying discontinuities	Tushman & Anderson	No
		"S-curve" life cycle of technologies	Foster	No
		Prospect Theory	Kahneman & Tversky	No
		The role of expectations in business decision making	Cyert, Dill, & March	No
2.	Sustain	Innovator's Dilemma	Christensen	No
		Commitment Theory	Ghemawat	No
		Competency enhancing discontinuities	Tushman & Anderson	No
		Threat Rigidity Response	Staw, Sanderlands & Dutton	No
3.	Increase	Rational Actor, Financial Optimization (RADCF[1])	• Ben-Zion • Allison • Bowman	**Yes**
		Differentiation	Porter	**Yes**

Analysis –

Model 1 results statistically confirms with significant reliability that firms changed their technology strategy post the disruptive event. Comparison of the medians of technology investment levels for post the disruptive event vs. pre the disruptive event demonstrates that overall, for the technology oriented firms in the medical device industry, there is a statistically significant increase in the technology investment levels post the disruptive event.

Further review of the data indicates that over 88% of firms either increased or decreased their technology investment levels by 20% or more post the disruptive event as compared to pre the disruptive event.

In examining factors that relate (could explain) increases or decreases in technology investment levels for firms post the disruptive event as compared to pre the disruptive event support was found in the logistic regression analysis performed in Model 2 for the following: **High Technology Intensity** firms were more likely to increase their technology investment levels post the disruptive event than non-High Technology Intensity Firms and also were more likely to increase their technology investment level than Low Technology Intensity Firms; **Small Firms** were less likely to increase their technology investment levels post the disruptive event than non-small firms; and Firms N**ot Affiliated with a Technology Oriented Parent** firm were more likely to decrease their technology investment levels post the disruptive event than firms with affiliations with technology oriented parent firms. There was no support for an association between: **Low Technology Intensity** firms and a decrease in technology investment levels; Technology Oriented Firms that do **not have their Core Business in the industry impacted by the disruptive event** and a decrease in technology investment levels; firms with their **R&D Located in the Same Country as the disruptive event** and a decrease in technology investment

levels; and firms with their **R&D located outside the country of the disruptive event** and sustaining their technology investment levels. Implications of each of these results is discussed in the following paragraphs.

High Technology Intensity Firms (firms that had more than 12 pre-event patent applications) were 1.9x more likely to increase their technology investment levels post the disruptive event than firms that were not high intensity. Sixty-six percent (66.0%) of High Technology Intensity firms increased their technology investment levels compared to only 41.5% of Low Technology Intensity Firms (firms that had less than 7 pre-event patent applications). Given that **small firms** (firms with less than 6 pre-event patents and **no affiliation with a technology oriented parent** firm) were more likely to decrease their technology investment levels as well suggests that overall the firms with a smaller level of technological investments pre the disruptive event were more likely to decrease their technology investment levels post the disruptive event compared to the firms with larger levels of pre disruptive event technology investment. As previously discussed the larger firms may have had more technologies to draw from in order to respond to changing customer requirements, have more resources to invest particularly compared to small firms with no affiliation to a technology oriented parent, have more bargaining power with healthcare providers due to their size, and have more patent protected proprietary products to resist price pressures from customers. These factors may explain the differences in technology investment behaviors between larger and smaller firms.

The reasons for the lack of statistically significant relationships between the other variables and the technology investment levels post the disruptive event are more difficult to explain without more information. The rationale for expecting these relationships to exist were presented with

the introduction of these variables. There was no new data discovered in the research or results to challenge those expectations.

Chapter 6 - Findings, Discussion and Conclusions

Contrary to the outcome suggested by most theoretical frameworks and contrary to a major research study conducted by the Office of Technology Assessment of the U.S. Government, overall, firms in the medical device industry statistically significantly increased their technology investment levels post medical reimbursement reform (a disruptive event).

These results have significant implications for strategy theory. While the specific reasons for this unexpected outcome cannot be conclusively determined in this study without further data and analysis, clearly these results were inconsistent with the outcome that was expected based on the analysis of several theoretical models. Do disruptive events lead to less predictable behavior? Are these theoretical models better predictors in the absence of turmoil in an industry? Why are these results different than expected? It would be most presumptuous in a dissertation to suggest that so many noted authors have theories that are suspect in their application. As noted in the limitations section of this dissertation it is inconsistent with the development of those theories to so narrowly apply them to this specific case. The value of incorporating these theories into this research was in providing reasoning that would support a specific technology investment behavior post the disruptive event and in fact some firms did behave consistent with the predicted outcome that was suggested by these theories. There is also value in examining why several of the theories did not apply generally in this case and to suggest what aspects of the theories did apply. While these endeavors cannot necessarily be completely answered using the data in this research there are some observations and proposals that can be offered.

What can be observed is that assumptions play a key role in predicting firm behavior in this case. By changing the assumptions that were implicit in theories suggesting that firms will decrease their technology investments post the disruptive event it is possible to see how the predicted outcome might be different. One key assumption is that firms will experience a decrease in prices because their customers need to reduce costs. If this assumption is challenged, a different outcome is then suggested. This was demonstrated by introducing the cost-in-use perspective in support of hypothesis 3 (increase). This approach would allow firms to actually increase prices for new products (earn a good return on technology investment) provided their products could help customers lower their overall costs. This was accomplished by developing products that reduced labor costs or energy costs or allowed a reduction in the time necessary to do a procedure which would allow better leverage of fixed costs as well as expand the use of limited facilities. Such products might also allow procedures to be done in an out-patient setting at a much lower cost with no overnight stay required for the patient. Thus firms can command a premium for products that offer these cost-saving benefits in helping the healthcare provider to lower their overall costs.

The second key assumption that needs to be challenged is assuming that because customers increase their scrutiny of new products and are more cost conscious that they will be unwilling to pay a premium for clinically superior products. While they cannot afford to pay a premium for all products, it is reasonable to assume that products which truly offer superior clinical benefits can still command a premium price and that customers will exert price pressure on the more commodity like products in order to be able to afford products that deliver superior clinical outcomes. Providing superior clinical outcomes is consistent with nearly all healthcare

provider missions and thus it would be difficult for them to eschew these new technologies for cost reasons.

Other factors may also have influenced medical device companies' technology investment behavior including the sunk costs previously invested in their R&D and in their marketing capabilities combined with the vulnerable nature of some of their existing products that might not be protected by patents or may be over priced relative to the market. Leveraging these sunk costs and investing in technology to create more proprietary products would make these firms less susceptible to price pressures and could be rationalized both in terms of return on incremental investment and be more favorable in terms of comparisons to exit costs or when considering barriers to exit.

Another perspective would be to assume that the behavior was not necessarily totally rational and/or that it was the result of decisions that were influenced by other factors. Strategy researchers have written about bias in decision making (Eisenhardt & Zbaracki, 1992; Schwenk, 1984), and the inability of firms to seek or accept data that is inconsistent with preconceived perspectives (Staw et al., 1981). Others have written about inertia and the difficulty that firms have in making changes (Amit & Schoemaker, 1993; Chen & Hambrick, 1995). These factors could also help explain why medical device firms increased their technology investment levels post the disruptive event in spite of potential negative consequences. These factors could also have influenced key assumptions that were foundational in making economic based assessments for technology investment decisions.

It is possible that the industry may simply have discovered several new technologies that offered significant promise and determined the potential benefits in further developing those new technologies outweighed the risks, even with considering the impact of healthcare reimbursement reform on the industry. As technology oriented firms the allure of new technologies would likely be too compelling to abandon even in the face of some economic adversity.

A final perspective is that while returns would decrease following the disruptive event those returns were still well above the required cost of capital to deliver new technology based products and better than other investment options available to these firms, thus continued investment in medical device technology was a sound financial decision albeit potentially not as lucrative as before the disruptive event.

In summary, both economics based and other factors could have influenced firms to increase their technology investments post the disruptive event. While the proposals presented here offer some potential explanations, which of these factors (or combination thereof) were determinative in influencing medical device firm behavior is left for future research.

Finally, focusing on medical device firms in this study is particularly important because a large portion of the cost increases in the delivery of medical care leading up to the disruptive event were the result of new, expensive, technology based products developed by technology oriented medical device firms. Many of these technology based products were instrumental for developing and performing advanced healthcare delivery procedures and advancing treatments with better outcomes for patients albeit at a much higher cost. During the healthcare reforms

of the 1980's there was significant concern that the new, cost-control demands from the entities that were funding healthcare delivery would significantly discourage technology oriented medical device firms from continuing their search for important new treatments for patients. The results of this study suggest that these concerns were unfounded and the exact opposite occurred - technology investments overall by medical device firms actually increased and in some specific cases these increases were dramatic. This finding may be quite relevant and timely given the current discussion of whether medical device firms might reduce their technology investments in the event of a significant increase in government intervention in U.S. healthcare such as implementing a government funded national healthcare system that includes a tax on medical devices as is currently being implemented under the Affordable Care Act.

Chapter 7 - Study Limitations and Future Research Opportunities

Study Limitations –

Some limitations of this study include building theoretical scenarios based on only a generalization of theories rather than also validating those scenarios by collecting qualitative data obtained from interviews with employees of medical device firms who are familiar with the industry events that took place during the period under examination to determine which theoretical scenario was most applicable to the firm. Thus the scenarios are more speculative in their design and may be too firm specific to be used to predict overall industry behavior. There applicability could be enhanced if they were developed from actual case studies of medical device firms, healthcare providers, and healthcare reimbursers.

Hypotheses are generated from the scenarios but it would be incorrect to assume a validated causal relationship between a scenario and the behaviors observed and tested in the data and analysis. These causal relationships are proposed in this research and not observed or tested directly. There is also the likely possibility of inappropriate use, or biased extension, of theory to create incomplete or inaccurate scenarios of how technology oriented firms would likely behave in response to a disruptive event based on that theory. There is also the risk of over-simplifying those scenarios by assuming that any specific, single rationale can be used to explain complex strategic behavior. As discussed in the conclusions, it is more likely that multiple factors/rationale would influence such behavior.

There are several other limitations in this research including: working with a relatively small dataset, examining data that is 25+ years old and making any assumptions about its applicability to firm behavior today, making observations in a single industry, limiting the dataset to firms that had five or more patents in total for the 13 year period or in the pre disruptive event period (potential selection bias), using a proxy (number of patents) for determining technology investment levels without validation with R&D spending levels or number of R&D employees, inability to link most of the technology investment data to financial results data such as profits or sales in order to control for the impact that profitability may have had on growth in technology investment levels, and lack of multivariate logistics regression analysis to examine the interactive effects of the independent variables, and use of a single coder to code firm attributes.

It must also be considered that there may be better explanations for the results obtained in this study. These more beneficial explanations were either not identified, overlooked, or not addressed in this research. The strategy literature continues to grow and practically it is becoming more and more difficult to address all the relevant theory in a single study. While several scenarios were developed from three bodies of strategy research, clearly there are more theories within each of those bodies that could have been examined and developed in this research and there are very likely other streams of research with valuable applicability to this topic that were not considered here including organizational behavior, decision making models, and institutional theories, for example.

Future Research Opportunities –

There may be opportunities to expand this research model for further validation to other technology oriented industries that have experienced disruptive events. Those industries may have more complete data on technology investment levels, financial performance, and may also have qualitative data regarding decision criteria that may have been used in making alternative technology investment decisions post a disruptive event that could be used to build better, more realistic scenarios or actual case studies at the firm level.

The use of more sophisticated regression models to test for interactions with the independent variables may provide further insight into potential drivers of firm behavior.

The issue of conflicting theoretical explanations each with compelling rationale raises questions about how firm behavior evolves in such situations. The proposals presented in this study suggest that there may be a hierarchy of factors that influence firm behavior and that the elements of that hierarchy relies on factors derived from multiple theoretical perspectives. Research that more fully integrates the interactions and potential hierarchies of these perspectives may prove particularly useful while recognizing the likely challenges that developing and testing such complex models will likely create.

REFERENCES

1983. Diagnosis Related Groups (DRGs) and the Medicare Program: Implications for Medical Technology. In O. o. T. A. US Congress (Ed.). Washington, D.C.: U.S. Government Printing Office.

Acs, Z. J., & Audretsch, D. B. 1989. Patents as a Measure of Innovative Activity. ***KYKLOS***, 42(2): 171-180.

Allison, G. T. 1971. ***Essence of decision***. Boston, MA: Little, Brown & Co.

Amit, R., & Schoemaker, P. J. H. 1993. Strategic assets and organizational rent. ***Strategic Management Journal***, 14(1): 33-46.

Archibugi, D. 1992. Patenting as an indicator of technological innovation: a review. ***Science & Public Policy (SPP)***, 19(6): 357-368.

Arrow, K. 1974. ***The Limits of Organization***. New York: Norton.

Basberg, B. L. 1987. Patents and the measurement of technological change: A survey of the literature. ***Research Policy***, 16(2–4): 131-141.

Ben-Zion, U. 1984. The R&D and Investment Decision and Its Relationship to the Firm's Market Value: Some Preliminary Results. In Z. Griliches (Ed.), ***R&D, Patents, and Productivity***. Chicago, IL: University of Chicago Press.

Bower, J. L., & Christensen, C. M. 1995. Disruptive Technologies: Catching the Wave. ***Harvard Business Review***, 73(1): 43-53.

Bowman, E. H. 1980. A Risk/Return Paradox for Strategic Management. ***Sloan Management Review***, 21(3): 17.

Cantwell, J. A., & Fai, F. M. 1999. Firms as thesource of innovation and growth: the evolution of technological competence. ***Journal of Evolutionary Economics***, 9(3): 331-366.

Chandler, A. D. J. 1990. ***Scale and Scope: The Dynamics of Industrial Capitalism***. Cambridge, MA: Harvard University Press.

Chen, M.-J., & Hambrick, D. C. 1995. Speed, Stealth, and Selective Attack: How Small Firms Differ From Large Firms in Competitive Behavior. ***Academy of Management Journal***, 38(2): 453-482.

Christensen, C. M. 1997. ***The Innovator's Dilemma***. New York, NY: HarperCollins.

Christensen, C. R., Andrews, K. R., Bower, J. L., Hamermesh, R. G., & Porter, M. E. 1982. ***Business Policy, Text and Cases***. Homewood, IL: Richard D. Irwin, Inc.

Conover, W. J. 1999. ***Practical nonparametric statistics*** (3rd ed.). Hoboken, NJ: John Wiley & Sons.

Cyert, R. M., Dill, W. R., & March, J. G. 1958. The Role of Expectations in Business Decision Making. ***Administrative Science Quarterly***, 3(3): 307-340.

Daniel, W. W. 1990. ***Applied nonparametric statistics*** (2nd ed.). Boston, MA: Cengage Learning.

Eisenhardt, K. M., & Zbaracki, M. J. 1992. Strategic decision making. ***Strategic management journal***, 13(S2): 17-37.

Fiegenbaum, A., & Thomas, H. 1988. ATTITUDES TOWARD RISK AND THE RISK-RETURN PARADOX: PROSPECT THEORY EXPLANATIONS. ***Academy of Management Journal***, 31(1): 85-106.

Foster, R. 1986. ***Innovation, The Attacker's Advantage***. New York, NY: Summit Books.

Ghemawat, P. 1991. ***Commitment, The Dynamic of Strategy***. New York, NY: The Free Press.

Griliches, Z. 1990. Patent Statistics as Economic Indicators: A Survey. ***Journal of Economic Literature***, 28(4): 1661-1707.

Henderson, R. M., &, & Clark, K. B. 1990. Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms, ***Administrative Science Quarterly***, Vol. 35: 9-30: Cornell University Samuel Curtis Johnson Graduate School of Management.

Kahneman, D., & Tversky, A. 1979. Prospect Theory: An Analysis of Decision under Risk. ***Econometrica***, 47(2): 263-291.

Klepper, S. 1997. Industry Life Cycles. ***Industrial and Corporate Change***, 6(1): 145-181.

Mintzberg, H. 1990. THE DESIGN SCHOOL: RECONSIDERING THE BASIC PREMISES OF STRATEGIC MANAGEMENT. ***Strategic Management Journal***, 11(3): 171-195.

Nelson, R. R. 1991. Why Do Firms Differ, And How Does It Matter? ***Strategic Management Journal***, 12: 61-74.

Pavitt, K. 1988. Uses and Abuses of Patent Statistics. In A. F. J. v. Raan (Ed.), ***Handbook of Quantitative Studies of Science and Technology***: 509-536. North-Holland: Elsevier Science Publishers B.V.

Porter, M. E. 1980. ***Competitive Strategy***. New York, NY: The Free Press.

Scherer, F. M. 1965. Firm size, market structure, opportunity, and the output of patented inventions. ***American Economic Review***, 55(4): 1097-1125.

Schmookler, J. 1966. ***Invention and Economic Growth***. Cambridge, MA: Harvard University Press.

Schumpeter, J. A. 1975 [Originally published 1942]. ***Capitalism, Socialism and Democracy***. New York: Harper.

Schwenk, C. R. 1984. Cognitive simplification processes in strategic decision-making. ***Strategic management journal***, 5(2): 111-128.

Staw, B. M., Sandelands, L. E., & Dutton, J. E. 1981. Threat-Rigidity Effects in Organizational Behavior: A Multilevel Analysis. ***Administrative Science Quarterly***, 26(4): 501-524.

Tripsas, M. 1997. UNRAVELING THE PROCESS OF CREATIVE DESTRUCTION: COMPLEMENTARY ASSETS AND INCUMBENT SURVIVAL IN THE TYPESETTER INDUSTRY. ***Strategic Management Journal***, 18: 119-142.

Tushman, M. L., & Anderson, P. 1986. Technological discontinuities and organizational environments. ***Administrative Science Quarterly***, 31: 439-465.

Walker, G., Madsen, T. L., & Carini, G. 2002. HOW DOES INSTITUTIONAL CHANGE AFFECT HETEROGENEITY AMONG FIRMS? ***Strategic Management Journal***, 23(2): 89.

VITA

Denis G. Hamilton

1968	Graduated from Lexington Catholic High School, Lexington, KY
1968-72	Attended Thomas More College, Fort Mitchell, KY
1972	B.A. Thomas More College, major in Accountancy
1972 – 74	Employed as staff accountant by Deloitte Touche, CPAs, Cincinnati, OH
1974 – 79	Employed by W.R. Grace & Co., Chemed Subsidiary in various senior management roles including Director of Internal Audit Dubois Chemicals Division Cincinnati, OH; Controller and Chief Financial Officer Vestal Labs Division, St. Louis, MO
1979 – 87	Employed by American Sterilizer Company, Erie, PA, in various senior management roles including Director of Internal Audit – Corporate; Director of Operations, Director of Business Planning & Development, and Director of Marketing- Medical Products Division
1985 – 87	Attended University of Pennsylvania, Wharton School of Business, Philadelphia, PA, Executive MBA Program, concentrations in strategy and marketing
1987	M.B.A. University of Pennsylvania, Wharton School, with distinction
1987 – 2007	Employed by Johnsons & Johnson, New Brunswick, NJ in senior management roles including Director Business Development & Planning, Director Corporate Programs, and Business Director Hospital Marketing – Hospital Services; Director Quality Management, and Corporate Vice President Process Excellence – Corporate Headquarters
2007 – 2009	Employed by American International Group, New York, NY as Divisional Senior Vice President of Operations & Systems – Corporate Headquarters
2009 – Present	Attended Rutgers Business School, Rutgers University, Ph.D. program
2010 – Present	Employed by Rutgers Business School as Part Time Lecturer, Assistant Instructor, and Full Time Instructor
2014 (expected)	Ph.D. Rutgers University, Organization Management, Strategy Concentration