INTER-TEMPORAL EFFECT OF TECHNOLOGICAL CAPABILITIES ON FIRM PERFORMANCE
A LONGITUDINAL STUDY OF THE U.S. COMPUTED TOMOGRAPHY INDUSTRY (1972-2002)

by

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Dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
Department of Business Administration in the Graduate
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ABSTRACT

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Abstract

In this dissertation, I investigate how capabilities drive firm performance as an industry evolves. I show that in spite of significant research on firm capabilities, we do not understand whether technological capabilities continue to drive firm performance as an industry evolves or whether they become weaker drivers of performance over time. This question is also important to managers because its answer would inform whether in a given context, firms should invest in building technological capabilities or not.

I predict and find that in low complementarity contexts, as technology advances, customer demand for greater product performance becomes satiated. As a result, customers neither pay for greater product performance nor shorten the life cycle of previous purchases. As firms lose these two levers by which technological capabilities drive performance, they find that technological capabilities become weaker drivers of performance. I also propose that when technological capabilities become weaker drivers of performance, firm performance becomes more persistent, in the sense that past performance drives future performance.

Through a rigorous quantitative analysis, complemented by an in-depth qualitative analysis of the US CT scanner industry from its inception, I find support for the theory. Using robust regression and multinomial logistic regression models, I find that as technology in an industry advances, technological capabilities become weaker drivers of firm performance.

I discuss the shortcomings of this research and potential for future research. I also discuss the implications of this research on capability theory, resource based view, and on existing explanations of industry shakeout. From a firm strategy perspective, this research shed light on how firms can use complementarity as a strategy dimension.

This work is dedicated to my late mother
Chanchal Chopra

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Contents

List of Figures

1. The research problem

At a certain level we generally believe that higher capabilities are better than lower capabilities. This general notion usually translates into a more concrete notion that greater technological capabilities, especially in technology driven industries, would be better than lower technological capabilities. In light of this notion, an example from the US CT scanner industry is surprising.

In 1975, when Technicare, a small entrepreneurial company, launched a faster CT scanner in the US CT scanner market, its market share jumped from 11% to 46% in one year. Technicare took over the market leadership from EMI, the pioneer of CT scanner technology. This is consistent with the general belief I mentioned earlier. What is surprising is that just nine years later, in 1984, when Imatron, a small entrepreneurial company, launched a significantly faster scanner, it hardly moved the market shares in the industry. In fact, Imatron continued to struggle for many years after which GE acquired it.

More recently, in 2006, Microsoft launched Zune, an MP3 player touted as the iPod killer. At around the same time, Jaguar decided to pre-install high definition (HD) radios (terrestrial technology) in its cars. How should Apple and Satellite radio players respond to the respective threats in their industries? Should they invest in their technological capabilities, some other capabilities, or should they just ignore the threat?

The answer would clearly depend on which capabilities drive performance in these industries. If technological capabilities drive performance, then the appropriate response would be to invest in improving hard disk space (or some other feature) in the iPod and signal quality (or some other feature) in the satellite radios. The CT scanner industry example shows that the answer to this question may not be a straightforward one. But what determines whether the 1975 scenario or the 1984 scenario of CT scanner industry will play out? It would depend on whether technological capabilities of firms drive firm performance or not. This raises a bigger question about what determines the causal link between capabilities and performance. How does this causal link between capabilities and performance change with the evolution of an industry? In this dissertation, I examine this particular question in significant depth.

This question is important for two reasons that make it worthy of study. First, existing literature does not sufficiently explain how capabilities affect performance as industries evolve. Consequently, this research will fill an important gap in the literature. Second, as shown by the examples of iPod and Satellite radios, the answer to this question would inform resource allocation decisions of firms.

1.1 A critical gap in the literature

A vast, though nascent, literature on organizational capabilities stands on a powerful thesis that capabilities drive firm performance (for example, see Helfat, 2003a).

An organizational capability refers to the ability of a firm to perform a coordinated task, utilizing organizational resources, for the purpose of achieving a particular end result (Helfat, 2003a). As organizations are goal driven, boundary maintaining, activity systems (Aldrich, 1999), capability theory goes a long way in explaining the effectiveness of organizations in achieving their goals. Some scholars have criticized the capability view as tautological: if capability is the ability to achieve a goal then the argument that firms with capabilities performs better is tautological (Williamson, 1999). While this criticism is valid when capabilities are viewed as monolithic firm level phenomenon, it is not valid at a fine grained level of capability view (Eisenhardt & Martin, 2000). Furthermore, it is more accurate to view capabilities as the things that firms are able to do, which may or may not contribute to firm performance (Helfat, et al. 2007). Finally, firms choose which capabilities they develop and that highlights the key message of capabilities view – some capabilities enable firms to perform better than other capabilities do. Consequently, further research on capability-performance relationship across different types of organizational capabilities would make a meaningful contribution to the capabilities literature.

Although the capability literature has made significant strides in the last decade (Helfat, 2003b), we do not understand how capabilities affect firm performance as an industry evolves - we do not know whether the relationship between capabilities and firm performance remains the same or it changes with the evolution of an industry. This gap points to a less understood issue of limits of capabilities - when do capabilities become less effective in enabling firms achieve higher performance? This is an important question because it can explain the extent to which capabilities affect performance. As capabilities are important to scholars because they explain performance, questions about limits of capabilities in driving performance are important questions too. Without an answer to this important question, it is difficult to predict firm performance over the evolutionary trajectory of an industry.

1.2 An Important guide for resource allocation decisions

As the examples in the beginning of this chapter show, an understanding of conditions that limit the ability of firm capabilities to drive performance would go a long way to guide investment allocation decisions of firms. In early eighties, digital cameras had very low resolution that could not match the 35mm film resolution. Firms continued to pour investments dollars to improve the image resolution. Firms that could build their technical capabilities continued to survive in the industry where as firms that could not do it left the market. A less known fact of this industry is that Apple was one of the firms that designed an aesthetically pleasing camera (QuickTake) but exited the market in a short period of time. Eventually, the technology improved and the industry crossed the megapixel barrier – a major milestone that led to greater adoption of the digital technology among consumers. This led to significant growth in the industry and firms enhanced their performance by building their technological capabilities. Even today, firms continue to pour investments in their technological capabilities to get higher resolution. It is not clear whether these investments are still driving the performance of the firms.

Similarly, in the flat screen television industry, two competing technologies clashed head on with each other. While plasma technology was more expensive than liquid crystal display (LCD) technology, it provided a better picture quality than LCD in large screen sizes. As a result, initially, plasma technology took a major share of large screen segment while LCD technology took over a large share of small screen segment. Due to the availability of computer industry as a customer segment, LCD technology attracted greater investment dollars. This enabled LCD manufacturers to improve their technology and produce plasma quality images in large LCD screens too. As a result, LCD technology started gaining an advantage over plasma technology. Clearly, improvement in technological capabilities enabled LCD manufacturers to improve their performance. Currently, major LCD TV manufacturers are setting up large plants to manufacture even larger screen sizes. Such firms face a critical question: although improvement of technical capabilities led to greater performance of LCD manufacturers, will these investments and the resulting improvement in technological capabilities result in similar performance improvements in future too?

To give a definitive answer to this concrete question that several firms face today, we need a better understanding of how capabilities drive performance as an industry evolves. Such decisions are important for various stakeholders in the economy because investments in capabilities that bring no return are wasteful and decrease the productivity in the economy with significant impact on various stakeholders. Such waste can lead to slower career growth or retrenchments for employees. They can result in redistribution of profits from an industry to other industries or customers which can make such industries structurally unattractive. This can lead to loss of shareholder value for investors in the industry. Moreover, as unattractive industries do not attract investment dollars, they can eventually result in a decline of a nation’s dominance in an industry. In short, a lack of understanding of how capabilities drive firm performance as an industry evolves could lead to wasteful expenditures which could harm employees, firms, industries, investors, and the economy. This makes the question important from a pragmatic perspective too.

1.3 Context of Research

The effect of capabilities on performance over time would depend on the context of the firm because the evolutionary forces may differ across contexts. In order to keep the research focused and manageable, I examine this question within a commonly occurring context of low complementarity. By complementarity, I refer to the extent to which a complement changes the utility customers derive from a level of product performance. A complement is traditionally defined in economic terms as that product whose demand is positively correlated with the demand of a focal product. Car and gasoline, digital camera and computer, and operating system and computers are just a few examples of complements. However complementarity is a more subtle notion because complementarity does not exist for all complement product scenarios. An example of high complementarity is the case of computers and operating systems; subsequent generations of operating systems decrease the utility that customers derive from a given computer because newer operating systems demand higher hardware performance. However, higher resolution digital cameras do not decrease the utility from a given computer. In effect, computer hardware and operating system industries have strong complementarity whereas digital camera industry and computer industry have weak complementarity.

1.4 Dissertation layout

The dissertation is structured as follows: Chapter two examines the literatures dealing with capabilities, evolution, and firm performance to understand the current state of knowledge on this question. The chapter shows that the literature has underemphasized this research question. In chapter three, I develop a theory that states that in low complementarity contexts, technological capabilities of firms lose their ability to drive performance as the industry evolves. Chapter four explains why CT scanner industry is a suitable context for this research and details the data used in this research. The chapter explains in detail the dependent variables, independent variables and control variables used in the research. In chapter five, I conduct a qualitative analysis of the industry history to test the theory. In chapter six, I conduct statistical analysis of data to test the theory. Finally, in chapter seven, I discuss the implications of this research, and discuss the key contributions and shortcomings of this research.

2. Literature review

Before venturing into an analysis of the research question and developing a theory to answer the question in the next chapter, I will examine the prior literature to understand the extent of current knowledge regarding my research question; this will show that a gap in the literature exists. Although a vast literature has examined firm capabilities, firm performance, and industry evolution, I will structure the literature review to understand what these literatures have talked about the role of capabilities in driving performance over the evolutionary trajectory of an industry. This structure is better than examining the three literatures in depth because it will keep the review focused and manageable and will avoid unnecessary digressions from the research problem.

2.1 Firm Capabilities: What we know and what we don't know

A vast literature on firm capabilities enabled scholars to understand some antecedents of firm performance that were hitherto unexamined or less understood. With intellectual roots in the resource based view (Barney, 1991; Penrose, 1959; Wernerfelt, 1984), capability literature not only extended the original RBV but also created a deeper understanding of firms and how firms achieve their goals. Resources refer to an asset or input to production (tangible or intangible) that organizations own, control or have access to on a semi-permanent basis (Helfat, 2003a). A capability, a resource of an organization, refers to an organizational ability to perform a coordinated task, utilizing organizational resources, for the purpose of achieving a particular end result (Helfat, 2003a). Scholars have made significant strides in better understanding the nature of capabilities, types of capabilities, sources of capabilities, evolution of capabilities, and the relationship between capabilities and sustained competitive advantage.

Capabilities are important for organizational scholars because they are antecedent of firm performance (Douglas & Ryman, 2003; HALL, 1993; Henderson & Cockburn, 1994; HITT & R, 1985; Huselid, Jackson, & Schuler, 1997; Kusunoki, Nonaka, & Nagata, 1998; Makadok & Walker, 2000; Ray, Barney, & Muhanna, 2004; Song, Droge, Hanvanich, & Calantone, 2005). Scholars have found that different capabilities make different contributions to performance (Ethiraj, Kale, Krishnan, & Singh, 2005) and that capabilities interact with each other in affecting performance (Song et al., 2005).

Scholars have also studied the evolution of capabilities over time and explored how firms transform one set of capabilities into another set of capabilities as the environment changes (Helfat & Raubitschek, 2000; Holbrook, Cohen, Hounshell, & Klepper, 2000; Karim & Mitchell, 2000; Klepper & Simons, 2000; Rosenbloom, 2000; Tripsas & Gavetti, 2000). These capabilities are collectively termed as dynamic capabilities and offer significant understanding of how organizations change their routines over time. This literature provides significant insights on organizational transformation.

Although capability literature did not delve into the effect of capabilities as an industry evolves, resource based view posited that the gap in firm capabilities between different firms in an industry tends to persist over the evolutionary trajectory of an industry, thereby resulting in sustained competitive advantage for firms (Barney, 1991). The underlying explanation for persistence of capability gap is twofold – causal ambiguity and social complexity. This view of capabilities is agnostic about the inter-temporal effect of capabilities on firm performance. Other literatures and empirical evidence provide somewhat more information as I will shortly demonstrate.

Although it is meaningful to explore the literature to find answers to this question, the principle of Ockham's razor dictates that we must first consider well established neoclassical principle of diminishing marginal returns to answer this question. Based on this principle, one would conclude that increase in capabilities would result in less than commensurate returns and thus capabilities should drive performance to a lesser extent as an industry evolves. However, several counter arguments and empirical observations weaken this argument sufficiently to show that the answer to the question is neither trivial nor straightforward.

First, in a technology driven industry, it appears counter intuitive to think that technological capabilities would not drive performance at some time in industry evolution. Secondly, a counter argument based on customer heterogeneity, information impact, and diffusion would predict that over time, the effect of core technological capabilities on performance would increase. Given that customers enter an industry when technology advances beyond their minimum performance threshold (Adner & Levinthal, 2001), it is likely that as technology evolves, customers with lower threshold will have already purchased the product and new customers who enter the market would not purchase a lower performance product. Moreover, customers who enter the market at a later stage are more aware: they already know which product attributes to value, how much to value, and which suppliers exist in the market. Furthermore, diffusion of the product with technological advancement would lead to early majority and late adopters entering the market. Since later adopters are more deliberate than early adopters (Rogers, 1995), they will be harsh on lower performance products. In short, firms with lower capabilities will find their low capability to be a much bigger liability as technology advances in the market; the effect of technological capability on performance would increase as technology in the industry evolves. Similarly, where network externalities exist, complementary capabilities (Teece, 1986) would show an increase in the effect of capabilities on performance rather than otherwise.

Furthermore, empirical observations show that we need to further examine the inter-temporal effect of firm capabilities on performance. On the one hand, we observe that in the micro chip industry, even after decades of industry evolution, incremental innovations by AMD are enabling it to gain share from market leader Intel, on the other hand, we observed that when Imatron introduced the most advanced CT scanner in the industry, it couldn't build market share. Although, one can begin to explain these empirical puzzles by borrowing from other research, it is clear that the answer to the question of limits of capabilities is not a trivial one; it needs systematic research effort and deeper analytical thought.

2.2 Core capabilities, technological change, and performance

In this dissertation, I will focus on technological capabilities of firms to examine the effect of capabilities on performance. As I need a concrete capability to study the effect of capability on performance and there has been significant research on technological capabilities, I chose technological capabilities for this research.

A vast literature on strategy and innovation has focused on technological capabilities (Abernathy & Clark, 1985; Helfat, 1997; Teece, 1986) over the last few decades. Supply side based literature on technology and innovation examined factors affecting the ease or difficulty in innovation (Abernathy et al., 1985; Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Suarez & Utterback, 1995; Tushman &

Anderson, 1986; Utterback, 1996) and focused on the technological capabilities of firms. Similarly, competence destroying innovations (Tushman et al., 1986), architectural innovations (Henderson & Clark, 1990) and incremental innovations (Banbury & Mitchell, 1995) dealt with the technological capability aspect of firms.

Firms use technological capabilities to achieve several objectives, but I focus on only a small set of technological capabilities called core capabilities. A firm such as Kodak may use digital imaging technologies to produce a state of the art digital camera, an ERP (enterprise resource planning) technology to manage the production, distribution, and finances, and agent based system simulation technology to improve its logistics systems. However, not all technologies are equally important to Kodak. Some of these technological capabilities are core to the firm in the sense that it allows the firm to enhance the product of the firm directly.

I use the term core technological capability in the same sense as originally used by Teece (1986). According to him, core capabilities refer to the ability of a firm to innovate or improve the state of art. Such capabilities enable a firm to improve an existing product, create new features in an existing product, or create new to the world products. An example of product improvement is when an automobile manufacturer improves the fuel efficiency of a car; an example of new features is when a telecommunications manufacturer adds a camera to a cellular phone; an example of new to the world product is when a firm develops the first MP3 player.

Such capabilities require an absorptive capacity (Cohen & Levinthal, 1990) that enable firms to integrate new knowledge and embody it in a product. Such capabilities also encompass configuration knowledge that enables a firm to configure and reconfigure a set of component technologies (Henderson et al., 1990). While core capabilities often evolve in a path dependent manner (Helfat, 2000), firms sometimes use path-breaking external methods to acquire such capabilities (Karim et al., 2000). In this manuscript, I will use the terms core technological capabilities and technological capabilities to refer to those set of technological capabilities that are core to the firm in the way Teece used the term.

Although some scholars have defined the term core capabilities differently from how Teece defined the term, I am using Teece's definition because it reflects the technological capabilities I decided to study. My intention here is not to answer the question about what capabilities are core to the firm, but to identify a set of capabilities that I can study in order to answer my research question. Since the technological capabilities I selected for my research match Teece's definition of core capabilities it is appropriate to use his term rather than coin a new term.

By enabling firms to improve the state of the art, such technological capabilities enable firms to create value in two ways. First, by improving the state of the art, they increase the utility derived from a product. For example, a car with fuel efficiency of 30 miles per gallon provides higher utility than the same car with 20 miles per gallon. When customers pay for this added utility, it contributes to firm performance. Second, since the output of such technological capabilities is visible to customers through new features or better product performance, such capabilities also help attract customers. Because customers can observe the car mileage (it is a verifiable claim), they can use this information in their purchase decision.

2.3 Effect of technological capabilities on performance over time

While a majority of research on technological changes focused on the large scale technological changes requiring new technological capabilities (Christensen, 1997; Henderson et al., 1990; Tushman et al., 1986), some research has also focused on technological changes requiring refinement and development of existing technological capabilities (Banbury et al., 1995; Klepper & Graddy, 1990; Utterback & Abernathy, 1978). The latter stream of research is instructive for my research question because it informs on the effect of a set of capabilities on performance over evolutionary trajectory of an industry.

Banbury and Mitchell (1995) found that incremental innovations – innovations resulting from higher level of existing technological capabilities – affected market share and survival of firms much after the emergence of the pacemaker industry. This is a significant finding because it points to the ability of technological capabilities to drive performance over the evolutionary trajectory of an industry.

Research by other scholars has shown that the improvement in technological capabilities slows down and thus technological capabilities do not drive performance in industries after a point in time. Utterback (1996) observed that as industries evolve technological capabilities go through a period of product innovations followed by a period of process innovation. Similarly, Klepper and Graddy (1990) also model a move from product to process innovation which shows that improvement in technological capabilities slow down and thus stop driving performance. However, Adner and Levinthal (2001) show that this sequence of product innovation followed by process innovation is not necessary and both types of innovation can take place simultaneously.

Although the above-mentioned research touches upon the effect of capabilities on performance over evolutionary trajectory of industries, it does not question how the relationship between capabilities and performance changes. While Banbury and Mitchell's (1995) research shows that technological capabilities continue to effect firm performance, Utterback's (1996), Klepper and Graddy's (1990) research shows that improvement in technological capabilities come to an end. Although this research raises an interesting question on why some industries witness an end to improvement in technological capabilities while other industries do not, it does not tell us whether capabilities continue to drive performance or not. One can draw the inference from research that shows an end of product innovation that capabilities must become ineffective in driving performance due to which firms stop improving technological capabilities. Alternately, due to a limited technological space firms may find that after a point it becomes very difficult to improve product but the same effort results in much higher improvement in process innovation. However, this inference is hard to support in light of empirical observations in the real world. We continue to witness better fuel efficiency cars, higher resolution digital cameras, and faster computers. This shows that neither do firms stop product innovation nor do firms face a limited technological space.

The above discussion shows that in spite of a vast literature on capabilities, industry evolution, and firm performance, we do not understand the relationship between capabilities and firm performance as an industry evolves. This is an important gap in the literature and needs attention. In the next chapter, I will develop a theory that will answer this question.

3. Theory

The literature review in the previous chapter showed that there is no clear and definitive answer to the research question I raise in this dissertation: we do not know whether the power of capabilities to drive firm performance changes or remains the same as an industry evolves. We found that research showed that in some contexts, the capability development stopped and firms began to pour investment dollars in other capabilities while in some instance firms continued to invest in the same capabilities. Furthermore, we see continual improvement in firms' technological capabilities in a whole host of industries such a consumer electronics, cars, computers and so on. In this chapter I will develop arguments to support the proposition that in low complementarity contexts, the ability of technological capabilities to drive firm performance decline as the technology in the industry evolves.

While developing the theory, I will focus on technological capabilities of firms that play the role of core capabilities and will analyze the problem in the context of low complementarity industries as mentioned in the previous chapters. I emphasize on core technological capabilities to keep the discussion focused and concrete and I choose low complementarity contexts in order to avoid the complexity of external factors that can change the capability – performance relationships. As low complementarity is a commonly occurring context, the research results will be widely applicable.

3.1 The relationship between capabilities and performance

We saw in the previous chapter that improved technological capabilities enable firms to produce better products which provide higher utility to the customers. Willingness of customers to pay for the higher utility leads to higher firm performance. Moreover, we know that improvement in technology reduces the product life cycle because customers replace a lower technology product with an improved product without waiting for the end of product life of a previous purchase. For example, customers of digital camera industry were willing to pay for higher resolution and regularly replaced their lower resolution cameras with higher resolution cameras as the resolutions improved from under 1 mega pixel to over 8 megapixels. In short, core technological capabilities affect firm performance through utility creation and shortening product life cycle. To answer the research question, we need to understand how the effect of core technological capabilities on these two levers change as an industry evolves.

To analyze inter-temporal effect of capabilities on performance, it is important to understand what changes when an industry evolves that may affect the relationship between capability and performance. Technological advancement in an industry is one such evolutionary change because in a low complementarity context, advancing technology can change demand conditions in the industry.

Technological advancement in an industry can potentially satiate customer demand for higher performance resulting in decline in the effect of core technological capabilities on market share and performance. As customers derive diminishing marginal utility from increase in product performance (Adner et al., 2001), they not only become less willing to pay for product improvement, they also become less inclined to replace their previous purchases. For a vivid example of this phenomenon, consider the digital camera industry. As the picture resolution improved with the evolution of the technology, many customers replaced their 1 to 3 mega pixel cameras with the more expensive 5 or 6 mega pixel cameras, but as the resolution improved beyond 5 and 6 mega pixel, fewer and fewer customers were inclined to either replace their 5 – 6 mega pixel cameras or to pay more for the higher resolution cameras. In short, demand for higher resolution satiated as the picture quality surpassed that of 35mm film cameras and improvement in picture quality was less noticeable with further improvement in camera resolution.

This demand side argument, in essence, says that as technology improves, the effect of core technological capabilities on performance will decline because the output of these capabilities – improved products – would neither shorten product life cycle nor induce customers to pay more. As these two levers lose their power, core technological capabilities also lose their power to drive performance.

3.2 Examination of theory

Demand satiation makes the context of low complementarity salient. Without the presence of complementary products that can reduce the utility from existing focal products (and thus create demand for higher product performance), firms will find that technological capabilities become less able to drive performance. If, however, the context included a high complementarity such as video games and consoles or operating systems and hardware, the technological capabilities may continue to drive driving performance as AMD and Intel experience in their industry. Although it is possible that in high complementarity context, the results may differ, in this dissertation I make no definitive claims regarding high complementarity industries because I have not studied such contexts with a rigorous methodology.

My demand side argument is consistent with the supply side argument in previous studies that state that due to limited technological space (Dosi, 1988; Foster, 1986), firms may find it difficult to improve the product performance at a reasonable cost. This could make further investment in core technological capabilities risky due to uncertain returns from the investments. However, it is noteworthy to mention that demand side argument of satiation only complements the supply side argument and the boundary of low complementarity adds a significant contingency to even the supply side argument of diminishing returns. As a result, the supply side argument can now be examined in a different light – it may not apply if the context does not show satiation phenomenon. For example, as technology in microchip industry reaches a barrier beyond which it is not possible to improve processor speed the firms will have to invest in nanotechnology and biological sciences to get greater processor speeds. These firms will invest in these new technologies only if the customers demand greater speeds. If the complementarity in the industry remains high, it is likely that such firms will find enough demand for greater processor speeds and thus would be able to bust the barriers of existing technology.

The above discussion does not imply that firms would be unable to improve products or that by improving their products they would not be able to gain more market share in a weak complementarity contexts. Instead, it implies that firms will find that core technological capabilities and product improvement do not allow them to gain as much share at a later stage as during the early stage of industry evolution. As several industries experience an improvement of technology over time (Jovanovic, 1982; Jovanovic & MacDonald, 1994), in weak complementarity contexts, we should observe a decline in the effect of technological capabilities on performance.

The above discussion will hold even when customers are heterogeneous and demand different levels of attributes. The inability of capabilities to drive performance will occur in individual segments. Consider digital photography industry where there is a clear demarcation between consumer and professional digital cameras. Professionals demanded resolutions of over 30 mega pixel even at a time when consumer segment (mass market cameras are defined by price point of 500 dollars) did not cross 1 mega pixel milestone. Satiation of professionals and consumers would happen at different resolutions but satiation will occur when further improvement in resolution gives professional photographers no added benefit in picture manipulation.

Although firms may find that their existing technological capabilities have become ineffective in driving performance, they can still change the demand conditions and make some other technological capabilities drive performance. This is what firms often do when they succeed in making new features important to customers. For example, slick interface in iPhones became important to customers after advertising and word of mouth changed customer demands from a cellular phone. This change in demand is not a result of core technological capabilities but a result of complementary capabilities as defined by Teece (1986). Teece used the term complementary capabilities to refer to those set of capabilities that enable firms to commercialize an invention and include marketing, manufacturing, and after sales service. Using such capabilities, firms make new features an important part of the purchase criterion of customers. For example, Canon responded to digital photography innovation by making SLR (single reflex lens) capabilities more prominent through its Rebel XT series of prosumer digital cameras. The use of complementary capabilities to make core technological capabilities drive future performance does not contradict the original thesis of this dissertation but enhances understanding of how capabilities drive performance. This goes to show that while core technological capabilities will eventually stop driving performance in low complementarity industries, firms have several ways to respond to this situation. One of the responses includes using complementary capabilities to make novel technological capabilities drive performance. In the final chapter, I will show how this strategy may not always work.

One aspect of firm reaction to competitive threat that the above discussion does not take into account is price. Since price remains an important aspect of customer choice, can some firms not offer lower price and thus gain market share? According to Cohen and Klepper (1996), firms who would have an advantage in price are the firms who have scale; such firms can spread their product improvement costs on a larger scale and thus gain a cost advantage. As firms with the strongest capabilities would be able to attract high market share, they would have a cost advantage too. In absence of the avenue to spread costs over a large volume, firms with lower capabilities will have to reduce prices below cost in an attempt to attract customers. As customer demand is satiated to an extent, price drop in absence of commensurate capabilities could increase hazard rate of the firm. This is so because in presence of satiated demand, price reduction is a speculative move which may not lead to sustained increase in sales or market share. Although some firms may use it as a strategy to temporarily gain market share, the efficacy of this strategy in long run is suspect.

Consider Kodak in the digital camera context. It was a leader in 35mm market primarily due to its film business, but it struggled in the digital context from the very beginning. By offering lower priced cameras at high resolution, it was able to gain significant market share. However, in absence of adequate technological capabilities, it continued to make losses that resulted in significant drop in its stock price. Eventually, it decided to pull out of the low price (sub USD 100) segment of the digital camera market in mid 2006. In short, lower price in absence of high capabilities may not enable firms to gain significant share over a long period. In fact it may threaten the survival of the firm itself.

3.3 Performance persistence

If technological capabilities drive performance to a lesser extent with time, then what drives performance? Given that we are considering technical capabilities that are core to a firm, using Teece's (1986) distinction between core and complementary capabilities, could it be that complementary capabilities begin to drive performance. In contexts where complementary capabilities have increasing returns, complementary capabilities could drive performance and thus such industries would tend towards "winner take all" kind of stability (Arthur, 1996); operating system industry witnessed this quite early in the evolution of the industry. As several industries do not demonstrate increasing returns on complementary capabilities, would complementary capabilities still drive performance? The following analysis suggests that it would not.

Complementary capabilities affect performance in two ways. First, they inform customers about the core technological capabilities of the firm and thus induce customers to switch from existing suppliers. For example, when the cereal box on the supermarket shelf shouts out that it lowers cholesterol, it is complementary capabilities (shelf space and packaging) at work to inform customers of a technological capability of the firm – the ability to make cereal that lowers cholesterol.

Second, complementary capabilities ensure that the promise of core technological capabilities is delivered to the customers. When a customer brings home a high definition LCD TV with unsurpassed picture quality and theater quality sound, the complementary capability such as manufacturing quality enables the customer to continue to derive the expected benefits from the TV. High complementary capabilities ensure that the customers remain loyal to the supplier. For example, if the customer who bought the TV ended up facing defects and service quality issues, the customer would hardly be expected to buy the product from the same supplier again. Knowledge of current supplier's complementary capabilities and lack of knowledge of a competitor's complementary capabilities accentuates the customer retention effect. Since a customer who bought the TV cannot experience the complementary capabilities of another supplier, she is unlikely to move to another supplier because of better complementary capabilities. In short, complementary capabilities contribute to firm performance through their informational and customer retention impact. As technology in an industry improves, both these effects of complementary capabilities will decline.

As demand for higher product performance satiates, customers are less willing to switch to competitor products with higher technical capabilities. As customers are less willing to switch, increase in complementary capabilities would not demonstrate commensurate increase in customer retention. As a result, on the one hand, the informational impact of complementary capabilities (i.e. informing about technical capabilities) would demonstrate a decline, on the other hand the customer retention aspect of complementary capabilities would also demonstrate a decline. Consequently, on the whole, with an improvement in technology, complementary capabilities should also have lower impact on performance.

In short, the ability of core technological capabilities to attract new customers declines with technological advancement, and the ability of complementary capabilities to retain existing customers (and existing market share) decline with technological advancement. As technological capabilities affect performance by creating new value for customers and satiated customers do not find value in higher product performance, with advancement in technology, technological capabilities would also have lower effect on firm performance. Similarly, as complementary capabilities affect firm performance through customer retention, the lower effect of complementary capabilities on customer retention would also translate into lower effect of complementary capabilities on firm performance.

The above discussion suggests that in low complementarity contexts, the effect of capabilities on performance and market share declines as technology in an industry advances. The inability of firms to further improve performance by improving capabilities is also consistent with the vast literature on organizational ecology that shows that hazard rates of firms become more stable over time (Aldrich, 1999; Carroll, 1984). Thus, from the capability theory perspective, although firms improve their performance by building capabilities, beyond a point, higher capabilities would not yield higher performance.

However, this raises an important question: if capabilities do not drive performance then what does drive performance as an industry matures? From an econometric perspective, if variance in capability level does not explain variance in performance level, then something must explain the variance in performance level because we do not witness regression to mean performance in any industry. The above discussion points to another answer – performance persistence. As technological capabilities lose their switching effect on customers and complementary capabilities lose their customer retention effect, the industry would tend towards homeostasis. In such a scenario, the future performance would appear to be driven by past performance – firms with high market shares would continue with high market shares whereas firms with low market shares will continue with low market shares. From an econometric perspective, variance in past performance will determine the variance in future performance.

Does this homeostasis imply that leaders will always remain leaders? Although organizational ecology literature maintains that unless the environment changes, homeostasis would continue in an industry, from capability perspective it does not necessarily have to be. If a firm loses capabilities, it is bound to experience share loss and performance deterioration. If a firm loses technological capabilities for some reason (say loss of personnel or know how) to the extent that the output of capabilities is visibly affected, it is very likely that customers will simply prefer other suppliers. Similarly, if a firm loses complementary capabilities for some reason (say a reorganization or plant relocation resulting in higher defects in manufacturing), customers would not stay with such a firm. Although such a scenario is unlikely, it is still theoretically possible and thus must be considered. Ecology literature has a different view because it assumes that as organizations age, they become more inert; successful routines in inert organizations would ensure that such organizations do not lose capabilities.

Thus, in statis, although higher levels of capabilities would not lead to higher performance, a decline in capabilities would still result in lower performance because a drop in product performance would induce customers to switch suppliers while a drop in complementary capabilities would reduce the customer retention effect. As a result, firms would have to sustain their capabilities in order to maintain performance.

3.4 Formalization of theory

The ideal firm performance measure is return on gross assets (ROGA) because this single measure shows the investment needed to generate a unit return. For example, if two firms - firm A and firm B - generate same profits, the firm that uses lower gross assets to generate the same returns will have higher performance and this higher performance will be reflected in its stock price. However, gross assets and net profits are often difficult to determine in a population of firms because privately held firms do not disclose this data while multi business firms often club these data in their financial statements. As a result, researchers often have to rely on proxy data measures.

Usually, capital requirements within an industry are more similar than capital requirement across industries. This is the key reason why Price-Earnings ratios of utility firms are low while price - earnings ratios of pharmaceutical firms are high. As a result, it is reasonable to find a proxy for profits when conducting a single industry study. Market share is one such proxy. Since firms with higher market share will likely have lower costs (based on cost spreading argument discussed earlier), it is a good measure of performance. However, in some instances higher market shares may not lead to higher profits. For example, when there are distinct price based market segments in an industry a mass market producer may in fact have lower profits than a premium product producer have. Similarly, when the cost of complexity of a business increases exponentially, higher market shares may lead to lower profits. In short, although market share has been used in several studies as a proxy for performance, it is not always an appropriate measure.

Because market share is not always a good proxy for firm performance, we need to formalize the above discussion for effect of capabilities on at least one other proxy of performance. Since firm survival is a commonly used performance measure in ecological literature and in strategy literature (Amburgey & Rao, 1996; Baum & Amburgey, 2002; Hannan & Freeman, 1989; Suarez et al., 1995), I use both market share and survival to formalize the above discussion.

The reasoning behind capabilities affecting firm survival follows directly from the discussion on the effect of capabilities on firm performance. As demand satiates, customers neither pay for greater product performance nor reduce the cycle time of product purchase. As a result, firms find that increase in technological capability does not improve the buffer that the firm builds through super normal profits. As a result while improving technological capabilities would initially enable firms to accumulate slack (or buffers), as the technology improves further increase in technological capabilities would not enable firms to increase buffer. As a result, increase in technological capabilities would become weaker drivers of firm survival as technology in the industry evolves.

Formal statements of the thesis go as follows:

> **Hypothesis 1**: In industries with weak complementarity, higher the technological advancement in the industry, lower will be the effect of technological capabilities on market share.

> **Hypothesis 2:** In industries with weak complementarity, higher the technological advancement in the industry, lower will be the effect of technological capabilities on hazard rates of firms.

3.5 Firms at limits of capabilities

However, this raises another question: how can firms at the limits of their capabilities improve performance? Other literatures have answered this question to some extent. Penrose (1959) explained that firms continue to find new avenues to appropriate rents from their capabilities. Consistent with this view, firms will explore other markets and applications of their capabilities to improve performance. Similarly, literature on innovation shows that industries go through waves of discontinuous changes (Gersick, 1991; Romanelli & Tushman, 1994; Tushman et al., 1986) and dynamic capabilities literature (Helfat, 2003a; Helfat & Peteraf, 2003) shows that when such changes take place, firms need to build new capabilities to sustain or improve performance. Similarly, acquisitions literature shows that acquisition is another mode by which firms can improve performance. In line with this literature, firms faced with limits of their capabilities have several avenues to improve performance – they can find new application of existing capabilities, can change the rule of competition by changing customer needs, and can use acquisitions to enhance performance. Finally, I mentioned earlier that firms sometimes succeed in the use of complementary capabilities to make new technological capabilities drive performance as shown in the case of Canon's response to digital photography innovation. Although firms can improve performance at limits of capabilities in many ways, this is not inconsistent with the discussion above that shows that the effect of capabilities on performance declines as an industry evolves.

3.6 Boundaries of the theory

It is important to note the context and boundaries of the theory above. Several studies have shown that industries go through cycles of change wherein stability is punctuated with waves of change (Tushman et al., 1986). Literature has also examined the capabilities that enable firms to face such discontinuities (Christensen, 1997; Eisenhardt et al., 2000; Henderson et al., 1990). My research relates to time between major technological changes; the theory holds for times when a new technology emerges and the industry tends towards greater stabilization. For example, it would hold for television industry from the time color televisions emerged up to the time plasma televisions emerged but would not hold for the time period when plasma and LCD technologies replace CRT technology. Since such innovations would need new technological capabilities, they would start a new temporal episode when technical capabilities would drive performance initially and would lose the ability to drive performance eventually.

3.7 Synthesis

How do capabilities affect performance over time and with technological advancement in an industry? I identified this gap in the capability literature and demonstrated how the answer to this gap can also assist managers in making resource allocation decisions. I find that when complementarity in an industry is low, the effect of technological capabilities on market share and survival decline with technological advancement in an industry. This takes place because improvement in technology satiates customer demand for higher technology. As a result, customers become less willing to pay for better technology. The end result is an inability of technological capabilities to drive firm performance.

4. Data and Methods

I use both quantitative as well as qualitative analysis to test the theory developed in the previous chapter. In this chapter, I will focus on the data and methods used for quantitative analysis. In the next chapter, I will discuss the empirical context in a qualitative analysis and finally use the data for quantitative analysis in chapter six.

4.1 Desirable empirical context

For this research, an ideal empirical context should offer some important characteristics to get robust and meaningful results. As the theory is relevant only in the context of weak complementarity, the empirical context should not have strong complementarity. Second, as the theory predicts the impact of capabilities on performance as an industry evolves, the context should have witnessed significant evolution to be a good fit for this research. Finally, as segmentation in an industry may confound the impact of capabilities on market share and survival, such an industry should not have developed distinct segments early on. Segmentation is an important consideration because in presence of different segments, higher capability may not lead to higher market share if firms decide to play in different segments; a lower core technological capability firms may garner higher market share by supplying to low end segments alone. Consequently, it may be difficult to ascertain whether the effect of capabilities on performance varies over time when looked at from the lens of aggregate data.

US computed tomography equipment industry offers an empirical context that fulfils the above requirements. It is a USD 1.5 billion industry (2002 industry sales) with a 30-year history of innovations. In the first 30 years, 24 business units of 27 firms competed in the industry with a maximum of fourteen and current strength of eight competitors. It is a part of the broader medical diagnostics imaging industry and emerged from the X-ray technology but created a separate niche without substituting the base industry. Early in the industry history, customers came to value the speed of the scanner and the quality of the images generated. Consequently, scan speed, reconstruction speed, and image resolution became the key metrics of scanner performance. Firms continued to improve product performance by improving these measures.

CT scanners are stand alone products without complements that can reduce the utility derived from a scanner. As a result, CT scanner industry remained a low complementarity context and is suitable for this research.

A useful aspect of the CT scanner industry for this research is the fact that in initial years of the industry, segmentation of the market did not take place. In fact, customers were willing to pay for better product performance; firms gained little or no advantage by offering ‘low price – low performance’ products in the market. This not only enables me to use market share as a proxy of firm performance but also allows me to observe firm capabilities by observing product performance. I will discuss this aspect of the industry in greater detail in the qualitative study of the industry.

4.2 Sources of data

I used hundreds of sources of data including thousands of news reports, industry reports and company reports to study the CT scanner industry in the US between 1972 and 2003. From these diverse set of data sources, I created a rich panel that includes the needed variables to test the above hypotheses. For empirical testing in this research, I used data for a 15 year period from 1973 to 1987 during which the industry witnessed incremental product improvement on three metrics of product performance. Due to different sources used over the years, some data after 1987 were unreliable and unavailable and this led to the exclusion of some years. However, the decision does not materially affect the research because the available data period is sufficient for a longitudinal study. Demand satiation effects were visible within this time period and thus the time period is suitable. With 24 business units over a 15 year time horizon, I have 157 usable observations in my dataset and include all firm years between 1973 and 1987.

In an attempt to investigate the empirical context extensively, I used all possible data sources. The complete list of data sources is attached at the end of this manuscript. In order to keep the list manageable and relevant, I have listed across year sources of one kind within a single reference. For example, I used multiple annual reports of several firms but I list all annual reports in a single reference. Similarly, Lexis Nexis alone accounted for several thousand news reports which I have not tabulated individually.

4.3 Dependent variables

To test the theory that predicts the effect of capabilities on firm performance, I measure dependent variable – firm performance – in two different ways. Market share and survival are two commonly used performance measures that adequately reflect firm performance in the given context of US CT scanner industry. Although, profitability is a key measure of firm performance (for a counter argument, see Freeman & Boeker, 1984), it is often difficult to ascertain. For example, in my empirical context, several firms were privately held while other firms were multi business firms who reported aggregate profitability from different businesses. In such cases, market share and survival are reasonable proxies for performance.

I use inflation adjusted (PPI) revenue share of industry to measure the market share of a firm in a given year. While market share may sometime be a misleading indicator of performance, especially when the profitable segment is a small one while the mass market segment is large, I do not face this problem in my empirical context. In CT scanner industry, market demanded higher price higher performance products thereby leading to a high correlation between market share and profitability. This ensures that higher market share was an indicator of higher profitability.

A significant literature on business survival uses exit as a measure of performance and scholars in that literature maintain that profitability is a poor reflector of relative performance because firm performance tends to revert to mean over time (Freeman et al., 1984). In line with this literature and extensive usage of survival as a performance measure, I use survival as an alternate measure of performance. Exit refers to discontinuation of a business unit through dissolution or through sale to a competitor, which I coded as different types of exit. Dissolution refers to shut down of business as a going concern whereas sell off refers to sell off of a business unit to another firm.

4.4 Independent Variables

The key independent variables for this research are core technological capabilities and technological advancement which I operationalize as follows.

4.4.1Core Technological Capabilities

I measure core technological capabilities of the firms by precisely measuring their ability to improve product performance on attributes valued by customers. In CT scanner industry, customers valued scanner speed, reconstruction speed and scanner resolution for the first 20 years of the industry. As customers demanded the highest quality product from suppliers, firms had incentives to produce products reflecting their capabilities rather than to produce below capability level. Consequently, the best product performance of a firm in a given year would adequately reflect a firm's technological capability. I used the best product performance of a firm on each product attribute each year to measure technological capability. In some cases, the exact product specifications were not available and I had to estimate the product performance based on other industry data. For example, the Neuroscan scanner details were not available but according to some sources, its specifications were the same as EMI scanner and thus I used the EMI scanner specifications in this case. I calculated technological capability as the Euclidean distance of a firm from industry origin and from best in class products in a given year, as detailed below.

Since the three attributes of the product did not follow the same scale, I first scaled the attributes to make them comparable on a percentile measure of each attribute over the data period. This provided firm positions in any given year in a Euclidian space. An implicit assumption that this calculation incorporates is that the three attributes were equally important to the customers; in absence of knowledge of the relative importance of these three features, equal importance is a reasonable assumption. I calculate the technological capability by measuring the distance of a firm in the Euclidean space from two points of reference: industry base and industry best in class.

Industry base is the product performance at industry beginning and does not change over time. By computing the distance of a firm from this point, I measured the technological capability of the firm in a given year. The rationale behind this measure is that firms had incentive to produce to the maximum capability and thus the actual product specification was an excellent measure of technological capability of firms. As scanner speed and resolution were the features that customers valued most, firm capabilities can be measured on these attributes. It is possible that another firm had superior capabilities to produce more aesthetic product or more feature rich product, but if it could not produce a fast scanner with high resolution, it is reasonable to interpret this fact as if that firm's technological capabilities were low. This would be akin to how Apple entered the digital camera market with an aesthetically pleasing camera but couldn't continue to produce better resolution cameras and exited the industry quickly. In effect, firms' capabilities to produce products with high levels of attributes valued by customers had high technological capabilities while other firms had low technological capabilities. I call this measure absolute technological capability or absolute core technological capability.

I also use an alternate measure of technological capability wherein I measure technological capability of firms relative to other firms in the industry. It is likely that customers do not care about how much product improvement a firm has achieved since industry beginning. Instead, they may only care about how the product performs relative to other products available in the market at a given point. As a result, I measured distance of a firm from the best in class in a given year. The best in class refers to the highest value of all product attributes in the industry in a given year irrespective of which firm's product it refers to; in many cases, the best in class is a hypothetical best product in the market as different firms excelled on different attributes. In short, if EMI had the shortest scan speed, GE had the highest resolution, and Technicare had the shortest reconstruction time then the best in class product is a hypothetical product with EMI's scan speed, GE's resolution, and Technicare's reconstruction time. In measuring the relative capability of firms, I measure their capability to produce the three attributes compared to the best capability in the industry. As the distance measure reflects the degree of lack of technological capability of firms, I reversed the sign so that higher number reflects higher capability. I call this measure relative technological capability or relative core technological capability.

Figure 4.1 graphically demonstrates the two measures of core technological capabilities.

Ideally, one should use alternate measures of different types to increase the validity of research I have used similar alternate measures of core technological capabilities both arising from the product performance levels. I find it adequate to use these two measures because of three key reasons. First, the lack of price segments in the data period points to the fact that customers were not making price performance trade-offs. As a result, firms could improve their performance by improving their technological capabilities and then producing scanners as per their maximum capabilities. I further detail this in the qualitative analysis chapter and also discuss the potential limitations in the discussion chapter. Second, the total industry R&D spending correlated heavily with industry technology frontier. The total correlation between the two was 0.68. Third, even after the price segments began to emerge later in the industry, firms with higher capabilities continued to launch the fastest and highest resolution scanners in their product portfolio. This allowed the firms to play in a high price niche and allowed it to strengthen its reputation for high quality. As a result, while it is appropriate to be cautious about using two alternate measures of capabilities which arise from single source, the additional information on the industry provides me sufficient confidence that the measure would be appropriate for this research.

4.4.2 Evolutionary measure

Although I developed the theory with technological advancement as a measure of industry evolution, I also test the theory with time as a measure of industry evolution. I measure technological advancement through the evolution of the industry technology frontier each year. The industry technology frontier is represented by the best attribute levels across all products in the industry in a given year. The frontier is the frontier in the Euclidean space dimensioned by the same three attributes as for technological capability measure (scanner speed, reconstruction speed, and resolution). The Euclidean distance of technological frontier from industry origin measures the level of technological advancement each year. This represents the technological advancement in the industry in a given year compared with the industry base technology at the time of industry beginning.

As mentioned earlier, I also use a time measure of industry evolution to test for inter temporal effects. I expect that time measure will be a weaker proxy of evolution because it would weakly approximate the evolution of the technology.

4.5 Control Variables

4.5.1 Complementary Capabilities

In the previous chapters I had discussed the research that posited that as an industry evolves the nature of innovation changes from product innovation to process innovation. Since process innovation tend to enhance complementary capabilities (e.g. manufacturing reliability, service, defect rate), that research suggests that complementary capabilities have a positive impact on performance. Consequently, I must use complementary capabilities as a control variable. Without controlling for complementary capabilities, it is not possible to unequivocally demonstrate the effect of technological capabilities on performance decline with the advancement of technology.

I use commercialization capability to measure complementary capabilities of firms in my dataset. As complementary capabilities are often an amalgam of several component capabilities including brand equity, reputation, sales force size, sales force effectiveness, number of sales offices and so on, it is difficult to get a good measure that is equivalent of core technological capability measure whose output is clearly visible. My attempts to get a direct measure of complementary capabilities such as defect rates of scanners, service quality of firms, number of sales people, number of sales offices, and advertising spending by firms did not achieve success because these data were not available across firms. Unfortunately, the attempted direct measure was a noisy measure of complementary capabilities, and therefore I refined it further. In this research, I measure a specific complementary capability - product commercialization capability. From one perspective, such a measure is superior to any one specific complementary capability because a given complementary capability (say manufacturing or sales force size) may not have sufficient variation or may not be important in a given industry. However, just as core technological capabilities can be observed directly through their output, complementary capabilities can be viewed as their collective output – commercialization quantum.

CT firms have to take an FDA approval for each commercialization attempt they make. These approvals are required for each product enhancement and thus provide information on every commercialization attempt made to date. As the FDA requirement came into effect in 1975, I could get data for prior years from FDA archives. For the data for years 1972 – 1975, I used the product introduction and product improvement data from other sources to estimate the commercialization attempts.

The number of commercialization attempts by a firm is a result of both technological and complementary capabilities. I do not expect a firm with low technological capabilities to commercialize several improved products. At the same time, a firm with low complementary capabilities would not make numerous commercialization attempts. As a result, I needed to tease out the commercialization capability from this measure before I could use it. I derive the complementary capabilities from this number as follows:

After regressing the cumulative commercialization attempts on absolute technological capabilities (as measured above), the error term would correlate heavily with the complementary capabilities of the firm. This residual is a measure of complementary capabilities. Cumulative number of attempts is useful because each commercialization attempt adds to the capability of the firm through learning. I expect this residual to correlate with several complementary capabilities such as service quality, manufacturing capabilities, sales and distribution capabilities. The reasoning behind my expectation is that if a firm had weak service or manufacturing capabilities, it would find itself losing customers due to it. As a result, it would find superior returns from improving the specific complementary capability instead of attempting to commercialize more products. Thus, although this is not a perfect measure, it should be highly correlated with the complementary capabilities of firms.

I also tested the correlation between total complementary capabilities of all firms and the diffusion in the industry and found a high correlation of 0.8 between the two. This shows that my measure of complementary capabilities has some external validity because if complementary capabilities for all firms are a good proxy for commercialization strength in the industry, such commercialization efforts should have led to overall diffusion of the product. A high correlation shows that there is extra evidence on the appropriateness of the measure for complementary capabilities.

I scaled the complementary capabilities to vary in the same range as technological capabilities vary. This allows me to examine the relative effect size of core technological and complementary capabilities.

4.5.2 Pre entry capabilities

A firm entering an industry with high pre entry capabilities would likely perform better than a start up firm with no pre entry capabilities. This follows from the fact that a firm with previous routines will be able to use its prior knowledge and capabilities while a new firm or a firm with weak pre entry capabilities may in fact spend effort and resources on not just the most important capabilities but also the capabilities that play the role of hygiene factors. By hygiene factor I imply that such capabilities would not allow firms to win over other firms but a lack of such capabilities would cripple a firm versus the competition in some meaningful way.

Furthermore, pre entry capabilities may determine the extent to which firms could develop post entry capabilities. This follows from the absorptive capacity argument (Cohen et al., 1990) which states that prior knowledge determines the extent to which new knowledge can be assimilated by a firm. As a result, it is likely that pre entry capabilities would not only affect post entry performance but also affect post entry capabilities. Therefore, I control for pre entry capabilities in the tests.

Market share in the base medical diagnostics industry is a fair measure of pre entry capabilities because firms with higher capabilities must have higher market share in the base industry from which several firms came. While it may at first seem unreasonable to combine new firms with the non medical diagnostic firms, which this approach implies, there are strong reasons for doing so. First, diversifying firms from other industries and the start up firms lack technological and complementary capabilities relevant in the CT scanner industry. Second, while diversifiers bring pre existing routines (Nelson & Winter, 1982), they face the challenge of adapting to a new dominant logic (Bettis & Prahalad, 1995; Prahalad & Bettis, 1986), while new entrants do not bring along pre existing routines they face less of a challenge in adopting a new mindset required to win in the CT scanner industry. As a result, I find it reasonable to use medical industry market share as a proxy for pre entry capabilities of firms in the CT scanner industry. I use square root of base share to reflect the pre entry capabilities because of a large difference in market shares of entrants.

4.5.3 Entry Rank

A significant literature shows that entry rank of firms affect their subsequent performance (Christensen, Suarez, & Utterback, 1998; Mitchell, 1991). Clearly, early movers have advantages in some instances while late movers have some advantages in other instances. These findings from entry timing literature make it necessary to control for entry timing of firms. I control for entry timing by controlling the rank of entry of each firm into the industry. Where two firms enter the same year, I use the same rank for both the firms.

4.5.4 Competition

The number of competitors in an industry at a given time would determine to what extent the capabilities of a firm drive the performance. While there are several reasons to suspect that competitive intensity would affect the relationship between capability and performance, limited cognitive processing capability and limited environmental resources are two strong reasons for this argument. A customer choosing from 5 suppliers would probably examine all 5 suppliers whereas a customer choosing from 100 suppliers will eliminate several suppliers from consideration; this is consistent with the decision making literature (Goldstein & Hogarth, 1997; Tversky & Kahneman, 1982) that proposes that decision makers use heuristics to screen out several choices. As a result, higher number of competitors would increase the likelihood that a focal firm will be crowded out from the mind of a potential customer. Similarly, limited shelf space in a supermarket prevents a manufacturer firm from gaining unlimited shelf space by significantly improving its customer relationship management. This is the also consistent with the carrying capacity argument in population ecology literature

(Aldrich, 1999; Carroll, 1984; Hannan & Freeman, 1977) that states that each environment has a limit to which it can support a population size.

The number of competitors in an industry would affect the ability of capabilities of a focal firm to drive performance because in presence of several competitors a firm would find it hard to gain customers while in presence of fewer competitors a firm would find it easier to gain share. For example, a new entrant with significant complementary capabilities will find it easier to achieve superior performance if there are a handful of prior entrants; however, the same firm will find it hard to achieve the same superior performance if the market is served by hundreds of firms. Mitchell (1991) found this in the context of diagnostic imaging industry and thus it necessitates that I control for a proxy of competitor capabilities.

I use number of competitors as a proxy for the intensity of competition in the industry. This variable changes each year for every firm.

4.5.5 Industry cumulative effort in technological improvement

As capabilities of all firms in the industry lead to advancement of industry frontier, I need another causal variable that can cause advancement of frontier in the industry. It is reasonable to assume that the total number of commercialization attempts in an industry is a proxy for the effort in product improvement in the industry. As a result, I control for total industry effort in technology improvement by controlling for log of cumulative number of product commercialization attempts made by all firms in the industry. I use log because as the industry evolved the number of commercialization attempts increased exponentially. Since FDA required firms to take approval for even a small improvement (including small changes in gantry or other parts of scanners that do not affect speed and resolution) and after a point smaller improvements need lower effort, it is reasonable to assume that the log of commercialization attempts reflected the effort put in by the industry in advancing the technology frontier.

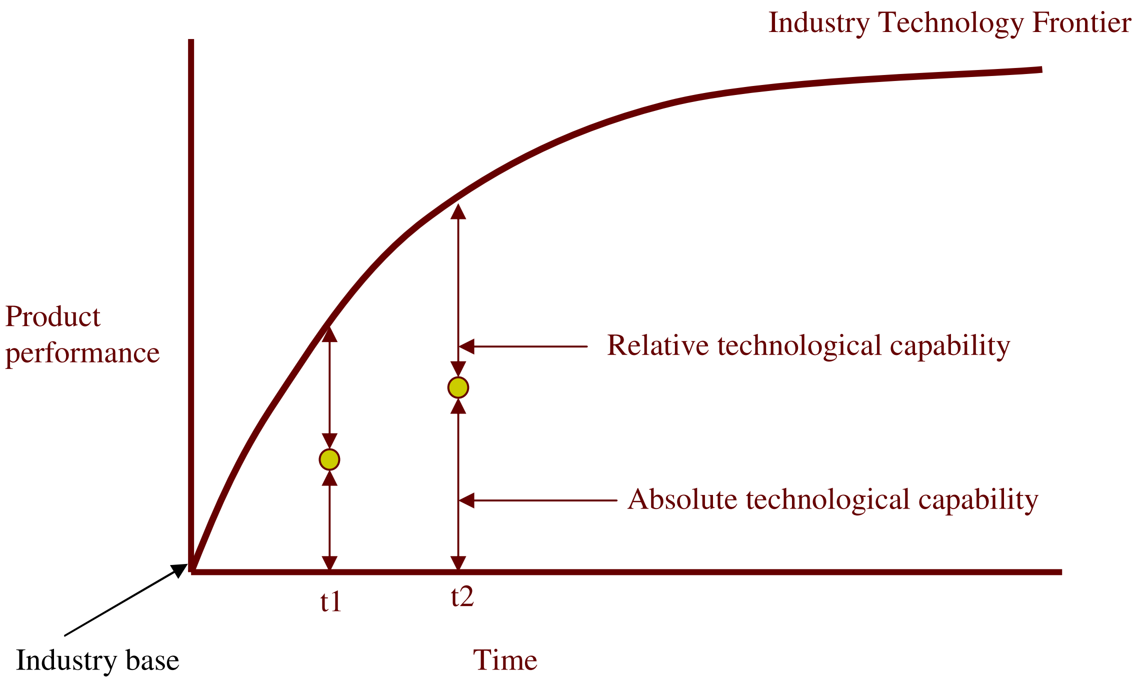
In the next chapter, I will study the history of the CT scanner industry from its inception in 1972 to test the theory and then use these variables in the subsequent chapter to statistically test the theory.

4.5.5 Weighted sales

To test for performance persistence hypothesis, I needed a measure of past performance. Since autocorrelation in market share time series is high, including this variable made every other variable insignificant. Consequently, I needed an alternative measure that would be sufficient but would have somewhat weaker correlation with market share or survival. Cumulative sales level is a good measure of past performance and when such as measure is weighted by absolute capabilities, it’s correlation with market share declined. The reasoning behind weighting with absolute capabilities was that the sales reflected the performance at the given technological capability level.

Moreover, weighted cumulative sales is an increasing measure of past performance and a significant coefficient would imply that past performance becomes increasingly more significant driver of firm performance. As a result, I used this variable to control for the effect of past performance driving the current performance. This also provided a test for performance persistence prediction.

Figure 4.1: Calculation of core technological capabilities



5. Qualitative analysis and results

I conducted a qualitative longitudinal study of the U.S. Computed Tomography (CT) industry over the life of the industry and found strong support for the theory developed earlier. A qualitative analysis of the industry complements the quantitative analysis done in the later chapter because it tells the entire story of the industry history along with the actions of the firms. I described why this context is a suitable for this research in the previous chapter; this chapter will further demonstrate why the context was an ideal test bed for this research.

The Computed tomography (CT) equipment industry in the United States is a 1.5 billion-dollar industry (2002) with a 35-year history of several waves of major and minor innovations. In the first 30 years, 27 firms competed in the industry with a maximum of 14 firms and just 8 firms in 2002. Like many other industries, it witnessed several types of firms entering and exiting the industry, using different modes of entry and exit and a steady consolidation over time. Science and innovation, government action, public opinion, customer preferences and firm strategies contributed to the evolution of this industry.

The following analysis of the industry over a 30 year period will demonstrate that the technological capabilities drove performance of the firms as long as the technology didn't satiate customer demand but once the demand for technological improvement satiated, technological capabilities did not drive firm performance. It will also show that the firm performance became persistent in the latter stages and in fact several technological innovations also failed to change the relative firm performance.

5.1 The pre CT era of medical diagnostic industry

X-ray remained the most popular non invasive technique to look within the human body for over 70 years and was a mature industry at the time when CT technology appeared. Radiology departments of hospitals were the main users of X-ray machines while neurology and cardiology departments also used the technology to some extent. Beyond X-rays, other techniques for digital imaging included ultrasound and nuclear medicine; however, even up to 1972, when the CT technology emerged, x-ray was the dominant method for diagnostic imaging[1].

Over 50 firms from around the world catered to the US X-ray market and several of these firms later entered and succeeded in the CT scanner market. With the advent of nuclear medicine and ultrasound technologies in 1960s several new firms entered the diagnostic imaging industry. Nevertheless, the industry was dominated by a handful of

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[1] X-ray accounted for net sales of USD 206 million, nuclear medicine accounted for USD 37 million, and ultrasound accounted for USD 7 million in the US market.

firm only: General Electric, Picker, Westinghouse, Philips, and Siemens accounted for 70% of market share in the US. Globally, five companies dominated the X-ray market: Siemens had 22% share of world market, Philips had 18%, CGR had 16%, GE had 15% and Picker had 12%. However at home in the US, GE and Picker dominated the market: GE had 30% market share while Picker had 20% market share.

As the dominant firms from diagnostic imaging industry play a significant role in the CT industry later on, a closer look at these notable firms would help us understand the history of CT industry better.

5.1.1 General Electric

General Electric (GE) was an early entrant in the X-ray market being among the first to introduce X-ray equipment in 1895. It was the leader in the conventional x-ray market in 1970 with the largest direct distribution system in the U.S. with over 1200 sales representatives. It also had a small presence in electro diagnostic industry.

GE had a long and interesting history going back to 1876 when Thomas Edison opened his first laboratory in 1876. By 1890, Edison had consolidated his various businesses into Edison General Electric Company which was also among the original 12 companies in the Dow Jones index; it is the only company among those 12 to be still listed on the Dow Jones index.

By 1970s, GE had become a large conglomerate with interests across several industries. CT scanner business was a part of its diagnostic imaging business which was a part of its healthcare business.

5.1.2 Picker

Picker X-ray was incorporated in New York City in 1915 to offer sales and service of X-ray equipment, film and accessories; over the years, it became a key player in the diagnostic imaging industry with a strong position in X-rays. In 1958, it was acquired out of private ownership by CIT financial corporation but the family members continue to play leadership role in the business. In 1967, Picker changed its name from Picker X-ray to Picker international and also acquired Dunlee Corporation, a Chicago based x-ray maker, to meet the demand for quality X-ray tubes and special purpose tubes. During the 60s, Piker played the role of an innovator in nuclear and ultrasound imaging industry.

5.1.3 Siemens

Siemens was a large and diversified conglomerate founded in 1847 in Berlin, Germany. The medical business can be traced back to its beginning in 1877 from a small business family in Erlangan, Germany. Siemens introduced its first X-ray in 1896 and eventually became a major player in the X-ray market worldwide. Starting with a strong base in Europe and small positions in Japan and America, it drastically expanded its US operations in the 1960s. It also had minor positions in nuclear and ultrasound markets.

5.1.4 CGR

Compagnie Generale Radiologie (CGR) had long been successful in X-ray market in France, where it had operated since before World War II. It positions outside France was negligible and as a result it acquired Westinghouse X-ray operations in 1971 to gain strength in the U.S. Westinghouse had significant position in the US market which made CGR a key player in the US too.

5.1.5 Philips

Philips' origins can be traced back to Eindhoven, Netherlands in 1891 when it started as a carbon filament lamp producer. The Dutch firm entered the X-ray market in 1916 with the introduction of X-ray tube. Over the years, the parent company expanded into several businesses including consumer electronics, music labels, and semi conductors. During the World War II, the company was run out of the United States as North American Philips Company. It built a strong position in the global medical diagnostics industry and had strong technical and financial resources by the time CT technology emerged.

5.1.6 Technicare

Technicare was a small non X-ray imaging specialist whose medical diagnostics history can be traced back to Ohio Nuclear, a nuclear medicine scanner company that was owned by scientific advances incorporated. Technicare's FDA applications continued in the name of Ohio nuclear. Technicare's non medical history can be traced back to Boston Capital Corporation, incorporated in 1960, which changed its name to Technicare in 1971. Even in 1974, the total sales of Technicare were only USD 50 million with medical diagnostics accounting for a mere 20 % of the total business.

In 1960s, the most exciting areas in the medical diagnostics industry were the new technologies including ultrasound and nuclear medicines; these segments witnessed significant growth and thus attracted attention of many firms. Table 5.1 shows the relative size and growth rate of these three segments.

5.2 The innovation and evolution of CT scanner technology

Prior to the first commercial production of X-ray equipment in 1896, the only way to look inside human body for purpose of diagnosis was to perform a surgery. X-rays changed that forever. It became possible to see inside a human body without an invasive technique. However, X-ray technique had its limitations too. An X-ray image is a superimposed image of three-dimensional human body on a two dimensional plane.

Furthermore, its ability to differentiate between internal organs was limited. It allowed practitioners to differentiate among 20 densities of bone, muscle and fat. In spite of these difficulties, it was a major advance in medical diagnosis. Computed tomography was a significant improvement over x-ray imaging. It overcame both the limitations mentioned above. It allowed physicians to differentiate over 200 densities in human body. Moreover, it provided a tomographic slice of body rather than a superimposed image.

In 1967, an English electrical engineer, by the name of Godfrey Newbold Hounsfield came up with the idea that one can find out what is inside a box by taking x-ray readings from all different angles. He had been working with EMI since 1951 and had helped design the first all transistor computer made in Great Britain. He started work on building a computer that would take input from X-rays at different angles to compute a tomographic slice. This invention led to Godrey winning a Nobel Prize in Medicine in 1979.

Computed tomography uses collimated[2] x-ray beams, x-ray detectors, a translation algorithm, computing technology and display to provide images of thin slices of human body. When a highly collimated x-ray beam is passed through body

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[2] Collimated light is light whose rays are parallel. Light can be collimated by a number of processes, the easiest being to shine it on a parabolic concave mirror with the source at the focus. Collimated light is sometimes said to be focused at infinity

from all points on a circumference of a small area, it generates sufficient data that, after transformation through an algorithm, provides an accurate image of the cross section of the body. Several such adjacent scans provide enough data to create three-dimensional images of internal organs.

Neurology departments of hospitals were the first customers for the head CT scanners but soon radiology departments and later on even cardiology departments became customers. Though CT scanners find use in industrial settings such as aircraft manufacturing and airports, I focus on the medical diagnostic sector of CT scanners. Speed and image resolution became the most important attributes of CT scanners that customers considered for purchase decision. Service and support were also important in purchase decision for hospitals.

Movement of target during scanning operation not only deteriorates the image quality but also shows motion artifacts that reduce the accuracy of results. Since breathing causes such artifacts, faster scanners produce fewer motion artifacts. Faster reconstruction time allows the operator to adjust the patient during the scan if the results are not satisfactory. Hospitals value scanner speed for another reason too. Scanner speed determines the patient throughput and therefore the returns from scanner investment. Service and support determine the downtime of a unit, and therefore its profitability. This makes service and support important to customers.

Finally, image quality defines the quality of output and is the core benefit of diagnostic imaging.

CT industry witnessed several generations of technological changes over the first 30 years. First generation scanner used a single collimated x-ray beam and a paired detector. The X-ray source moved in a linear fashion over the patient to make a single scan. At the end of a scan the ray and detector moved by 1 degree. This continued until 180-degree rotation was completed. Speed was a main disadvantage of this scanner. Second-generation scanners significantly improved on speed. They used multiple detectors and a single fan shaped beam, which allowed significantly higher data gathering and larger rotations of 30-degrees. Such a movement reduced the scan speed to less than 2 minutes. Third generation scanner used many more detectors (288 – 700 detectors) and both beam and detectors rotated around the patient rather than move through linear motions followed by rotation. It decreased scan time to 1 second. However, these scanners suffered from motion artifacts. These artifacts reduced accuracy of image. Subsequent improvements in third generation scanner technology overcame the problems of motion artifact. Fourth generation scanner did not suffer from artifacts as they used contiguous row of detectors that remained fixed. There was little difference between the third and fourth generation scanners as far as overall product attribute level performance was concerned. All four generations appeared in the market by 1976.

Firms continued to improve third and fourth generation technology to improve various product attributes. Electronic beam tomography (EBT) scanner, appearing in 1984, was the next major technological advancement that took place in the industry. It made X-ray source an integral part of the design and it electronically swept the x-ray beam around the patient in a semi-circular manner. There were no moving parts and the entire scan took 50 milliseconds – fast enough to scan the beating heart. This extended the reach of CT scanners into cardiology departments of hospitals.

A new technology – power slip rings enabled the next significant technological advance in the industry. Third and fourth generation scanners used power cables that had to be unwound between scans. This led to lower patient throughput. Slip rings eliminated the need for power and signal cables that allowed continuous scanning of the patient. The scanners incorporating this technology were called spiral or helical scanner due to the helical path of the source and detectors around the patient body.

The most recent technological change that took place in the industry was the multi slice scanner. It allowed simultaneous production of several tomographic slices. Main advantage from multi slice scanner is faster scanning speed. Though these were the major innovations in the industry, these were not the only ones. Several minor innovations were interspersed between these major innovations. 3-D imaging, zoom, variable speed scanning and mobile scanners were some of the minor innovations the industry witnessed over its history. Figure 5.2 shows the major innovations in the industry.

Each new scanner improved upon the earlier scanner on important attributes that customers desired. Within a decade, technological advances allowed firms to meet most customer needs. Figure 5.3 shows attribute level improvement during the first 10 years. Spatial resolution is a proxy used for image quality and measures the smallest size of image data captured by the scanner.

5.3 The launch and early adoption of CT scanners

When Hounsfield started building the first CT scanner, EMI had no position in medical diagnostics industry. Electrical and Musical Industries (EMI) Limited had started in 1931 as a result of merger of UK Columbia Graphophone Company and the Gramophone Company. From its inception, EMI focused on recording and playback equipment and music recordings – it was and still is a major record label. During the World War II, the company developed and manufactured guided weapons and radar equipment which helped it build several non music related capabilities too. As it had no position in the medical diagnostics industry, there was significant debate within the company on whether to enter into medical diagnostics business or simply license the technology. Just as Google in late 1990s could not interest any company to buy its search technology and thus entered the internet search business, EMI could not interest any X-ray manufacturer in 1970 to license the technology of CT scanners and entered the industry directly.

In 1971, the British department of health became interested in Hounsfield's work and supported the construction of prototype head scanner. The first ever CT scanner was installed in Atkinson Morley's hospital in Wimbledon, England and the first brain scan was taken in 1972. The prototype scanner took scans in 2.5 hours and the first commercial CT scanner, Mark I, took 10 minutes for a scan. In 1972, EMI started taking orders for the scanners and sold 2 more scanners to Department of health. In the US, first three customers for the scanners were Lahey Clinic (Tufts University), Massachusetts general hospital, and George Washington University in 1973. At that time EMI's core business had been doing extremely well with rising sales and profits for several years; EMI's sales and profits for 1972 were 250 million pounds and 23 million pounds. The management had estimated that the market for CT scanners will come from the nuclear medicine market and it will merely serve the neurological applications. Furthermore, they had anticipated that they had 3 to 4 years of lead over the competition – they were wrong on both counts.

By 1974 EMI had installed 10 scanners in UK and 40 scanners in the US. Furthermore, after the tests on CT technology far exceeded expectations, National

Cancer Institute (NCI) in the US became interested and funded research on CT; it asked for bids from GE and American Science and Engineering (AS&E). NCI decided in favor of AS&E and didn't believe that GE's technology would succeed. The buyers in the US quickly adopted the CT technology; in fact, the buyer interest exceeded expectations of EMI and other players in the medical diagnostics industry.

In 1974, a startup company based in California, Neuroscan, introduced a scanner identical to EMI scanner in its specifications but a few thousand dollars cheaper than EMI scanner. EMI's first scanner was marked to be sold at USD four hundred thousand. In the next three years a wave of new entrants hit the CT scanner industry.

5.4 Rapid technological evolution and a wave of new entry

In 1975 a wave of firms entered the industry, built and improved their technological capabilities significantly, and as a result pushed the technological frontier of the industry significantly higher.

Digital Information Sciences corporation (DISCO), a small, Maryland based company introduced the first full body scanner with similar specifications as EMI scanner but with an ability to scan the entire body. This single introduction expanded the reach of CT scanners to radiology departments and expanded the potential application domain. DISCO was founded by a dentist, Robert Ledley, the builder of the first full body CT scanner in the world. He developed the scanner while working at George Washington University and founded the company to commercialize the product. Although DISCO sold scanners for $100,000 less than EMI scanner, the product had little market success. The scanner was called ACTA (automated computerized transverse axial) scanner and is now placed at the National Museum of American History.

Pfizer, the USD 1.5 billion pharmaceutical giant, became interested in diagnostic imaging business and acquired manufacturing and distribution of DISCO’s scanner to enter the market. At that time, Pfizer was doing exceptionally well and its sales from its core business had increased 50% in just two years. With the enormous resources at hand, and a working model of faster and better resolution ACTA scanner (compared to EMIs scanner), Pfizer was able to garner 13% of the market at entry.

The pharmaceuticals producer Syntex also entered the market in the same year and it used licensing route for its entry into the fast growing and lucrative business of CT scanners. It licensed the second generation technology from Stanford and was the first to introduce the second generation scanner. Syntex never made an impact on the market although it introduced the first second generation scanner.

Other industry observers have noticed the fact that complementary capabilities played a significant role in this industry. I also observed that larger companies with significant complementary capabilities and large resource base could garner market share provided they had the needed technological capabilities to produce a comparable product. Artronix was a case at hand where an innovator didn't make much of a mark in the industry. Artronix was a nuclear imaging incumbent that manufactured nuclear computers. It started an in-house research program and developed the third generation technology and became the first to commercialize it.

In 1975, the best product was introduced by Technicare. Its Delta 50 scanner was a 2nd generation scanner but was the fastest and had the highest resolution. While EMI scanner took 4.5 minutes to scan, Delta 50 took only 2.5 minutes to scan. As a result of its superior technological capabilities, manifested by its superior scanner, Technicare could garner 11% of the market in the year of its entry. It also announced doubling of its capacity due to early success.

While Pfizer's entry raised eyebrows in the market, it was GE's entry in 1975 that added legitimacy to the industry; it was the first long standing X-ray producer to enter the market. When GE's internal efforts to produce a scanner met with significant delays, it licensed Neuroscan's scanner and entered the market. GE's scanner was a first generation scanner that didn't help GE get much market share. However, with GE in the fray, customers started expecting improved scanners in near future. When GE entered the market it brought significant resources and strong complementary capabilities – its sales force had 300 people and its service and support team had 1200 people. Although it was selling the first generation scanner, it announced that in near future it will launch a 5 second scanner; EMI's scanner at that time took 20 seconds to scan.

EMI responded to the unexpected rapid entry of firms in the industry by introducing its second generation scanner and upgraded all its previously sold machines free of charge. It also increased it service organization to 150 engineers across 20 sites amounting to 2-3 machines per service rep. It was facing growth related problems such as capacity constraints in spite of increasing it capacity; its delivery times were slipping from 6 to 12 months and in some cases even 15 months. All the competitors put together had 29% share in 1975. EMI's scanner was no longer the best scanner in the market; increasing delivery times also didn't help the business.

In 1975, the state of the art in scanner technology left much to be desired by the customers. At the same time, a CT scanner added significant advantage to a hospital. As a result, hospitals were buying scanners and making them a center of attraction in their facilities. This enabled faster adoption of the technology. As scanners made a big difference to customers, they were willing to pay for speed and resolution.

The performance and price dynamics in the industry were interesting, to say the least. EMI's second generation scanner, CT 5000, scanned in 20 seconds and reconstructed the image in 100 seconds and was priced at 495 thousand dollars. EMI's first scanner was priced at 400 thousand and was discounted significantly to that price. When Technicare launched its Delta scan FS 50 that could scan an image in 15 seconds, its price was 515 thousand dollars.

Figure 5.4 shows how the average price of the scanner continued to increase over time. Figure 5.5 and 5.6 shows how the price segments did not emerge in the market. Figure 5.5 shows the share of segments in the market based on price points of USD 200 thousand and USD 400 thousand while figure 5.6 shows the share of the segments in the market based on price points of USD 400 and USD 700 thousand. Both figures show that a low price segment didn't exist in the market; customer were willing to pay more for better scanner which made it imperative that the scanner producers improve their technological capabilities as quickly as possible.

5.5 Rapid technological evolution and change of guard

The fourth generation scanner appeared in the market in 1976 and it was launched by AS&E. It had developed the system for health department and licensed it from Health, Education, and Welfare (HEW) department for three years. AS&E was founded in 1958 in Cambridge, Massachusetts and catered to NASA and the defense industry.

At this stage, the CT market appeared to be witnessing an exploding growth and its adoption was significantly faster than expected. The technology had started improving, start-ups, incumbents, and diversifying entrants had entered the market and the competition was becoming fierce. Customers were looking for better scanners and were willing to pay significantly higher prices for a better scanner. In 1976 annual report, Technicare reported that hospitals were increasingly reallocating angiography budgets to CT scanner purchases. In 1976, at Radiological Society of North America (RSNA) conference, a disproportionately large number of papers (120 out of total 280) focused on CT technology.

GE announced that it will be launching significantly superior scanners in the near future and Technicare actually launched a 15 second scanner in 1976. As a result, EMI's second generation scanner couldn't help it maintain its market share – it was fast losing share to GE and Technicare. Other than product inferiority, long wait times didn't help EMI either. It doubled capacity in Europe and started a manufacturing plant in Chicago to alleviate customer concerns and wait times. In spite of losing share, EMI was doing exceptionally well and its profits had exponentially increased in the past three years from 5 million in 1972 to 26 million in 1976. Diagnostic imaging business contributed 40% of EMI's profits.

Technicare's scanner succeeded in the market because it was the fastest scanner. As a result, it experienced rapid growth and began expanding capacity and invested in capability development. It increased the size of its facilities by 50%, doubled employment to 930, and extensively trained over 100 people in its sale and service organization. It had a 15.5 million bank line of credit that it hoped to use in future expansions which seemed inevitable after the recent success of its scanner. It projected that the market would more than double in 4 years to USD 800 million. Traditionally, Technicare was a niche player who played in segments where large competitors were not present and thus it was inexperienced in competing with firms with significantly larger resources. However, it appeared that it was able to compete in presence of big players.

In 1976, although EMI was succeeding financially, it lost its leadership position to Technicare who became the market leader primarily due to its superior technological capabilities which enabled it to improve its scanner speed and resolution faster than competition. In response, EMI filed a lawsuit against Technicare for patent infringement.

GE launched its third generation scanner in early 1976. The scanner created a buzz in the market and GE accumulated several orders even before the scanner went through clinical trials. GE's inroads into radiology departments enabled it to generate significant interest and demand for its own scanner. This system was built in house through its own technological capabilities, unlike the first scanner introduced.

In the next year, 1977, the market more than doubled with 12 firms competing for the rapidly expanding industry. The sales increased from 159 million in 1976 to 350 million in 1977; figure 5.7 details industry sales over the most of the industry history. The effect of competition and industry investment in technological capability pushed the technology frontier far ahead in this year. Scanner speed improved to mere 2 second in the Technicare scanner and GE's scanner was not far behind. The market demonstrated a clear preference for full body scanner and as a result head only scanner accounted for less than 20% of all scanner sales (see figures 5.8 and 5.9). It was clear that the technology was changing fast and the way to win was to improve the technological capabilities – faster and better resolution scanners were taking a giant share of the market.

Two big events for the industry in 1977 involved the entry of X-ray giants Picker and Siemens, and increasing focus on costs of CT scanners by government agencies. Picker had planned an entry through license route just the way GE did, however the project did not pan out as expected and this led to delay in its entry. It entered into an agreement with University of Washington for joint effort in development of a CT scanner and subsequent rights to sell the scanner. As Picker had no knowledge of algorithms and the microelectronics involved in CT scanners, this joint effort enabled Picker to learn about the technology to a great extent. Furthermore, it also hired several university researchers after the project was cancelled. However, it lost precious time in entering the market due to these delays. As a result, when Picker entered the market, it entered with its own technology. Its scanner came out in the middle of the pack in the market as the technology was fast evolving and firms were improving their technological prowess rapidly. The technology Picker chose to enter was the AS&E's 4th generation format. Middle of the pack scanner didn't help Picker capture much of the market. Figure 5.10 shows the market shares of various key players in the US market.

Siemens had been active in the international CT scanner industry since 1975 but had delayed its entry to the US. It began its first generation project in 1974 and sold its scanner in Europe in 1975. It introduced its second generation scanner in the US and at the same time was working on its third generation scanner. Siemen's scanner Siratome 2000 was a 60 second scanner but its mid 1977 scanner Somatom was a 5 second scanner. In presence of superior scanners in the market Siemens' scanner did not enable it to get share; its lack of sales and service capabilities didn't help either. However, Siemens later improved its technology significantly to be among the best scanners in the market by 1980 and garnered a sizable portion of the market. As a result Siemens entry in the market was insignificant in terms of its immediate impact but significant in terms of the impact a few years later.

The second major change that occurred was capital spending limits by state governments, who were worried about the rising costs of capital equipment. In response to these new spending limits, several hospitals opened outpatient CT scan centers that were not covered by the regulation. Some CT scanner companies started mobile CT scanners that were outside the purview of the regulations.

EMI had managed to retain its market share in 1977 because of delivery delays from orders taken in the previous year; at the end of 1976 EMI had a backlog of 250 machines. As a result, GE’s superior scanner affected Technicare’s market share which declined in response to GE’s announcement of future improvements in the scanner. However, Technicare still remained a strong number 2 player in the market. Its new delta scan series brought down the scan time to mere 2 seconds and was in high demand. Due to time lag in launching a better scanner, it lost some share. Other issues were also mounting up on Technicare. AS&E sued Technicare for antitrust and anti competitive practices. In response, Technicare countersued AS&E for defamation and unfair trade practices. The success of Technicare led to an unintended business transformation of the firm. By 1977, Technicare had become a primarily diagnostics imaging company, especially after the sale of its ball bearing operations. (See figure 5.11). It appeared that in spite of losing its first position, Technicare had learnt to compete in presence of large competitors. It had seen its scanner sales rise to near 90 million dollars in 1977.

More entry and exits for the industry took place in 1977. Phillips had begun its 2nd generation project in 1975 and introduced its scanner in 1977 in both the US and Europe; the scanner made no major impact in the US market. Varian Associates, a California based electronics manufacturer, long time producer of X-ray tubes, also entered the market. It had acquired the rights to Stanford's scanner but introduced its in-house 3rd generation format scanner. Furthermore, Searle, a strong incumbent of the pharmaceuticals industry also entered the same year. Searle had entered diagnostic imaging in 1966 through acquisition of Nuclear Chicago and had subsequently entered Ultrasound segment too; however it had no position in X-ray segment. It introduced an in-house 3rd generation format scanner that did not enable it to garner much share.

If 1977 was a landmark year for the industry in terms of a rapid expansion in the industry and concomitant confidence of continued growth, 1978 was a landmark year because it reversed the trend of market growth to such an extent that market consolidation began to take place rapidly. From 1973 to 1975, the industry grew at least 100% per annum to reach an industry size of USD 360 Million, but in 1978 the sales declined 33% over 1977. The primary reason for this decline was a new regulation called Certificate of Need (CON) that most states began. Under this legislation, capital purchases over 100,000 needed an approval of state department and this curtailed capital spending on CT scanner. Moreover, Medicaid and Medicare started flat rate disbursements eliminating any cross subsidy from operational budgets to capital budgets in the hospitals. Private insurers also started taking the lead of public agencies. The result was a drastic reduction in the market demand: "Most of the hospitals don't even apply for certificate of need any more", a Technicare executive mentioned to Business Week in 1977.

This market reduction led to the most notable exit in the industry – Technicare. After becoming the leader in CT scanner market in a short period of time, Technicare felt the effect of GE's entry in 1977 when it lost its first position. As product performance (speed and resolution) was clearly driving the firm performance, Technicare rushed it third generation scanner to the market in 1977 to counter GE. The rush in product launch created engineering and production issues for Technicare and resulted in lower demand for its product. Technicare could not take control of the issue and lost money. 1979 annual report highlighted the production and delivery issues as key challenges for Technicare. This resulted in significant decline in profitability and decline in stock price; in 1977-78, Technicare's CT division went into red. To counter the cash flow issues, it sold its wheelchair and reactive metals division and agreed to restrictive financing from its bankers. It also actively campaigned against government regulation and even brought out a 95000 dollar brain scanner which was just below the mandated CON limit.

On the one hand its responses did not enable it to get market share and increase profitability, on the other hand it's declining stock price and erosion of takeover buffer made it an easy takeover target. J&J (Johnson and Johnson) acquired Technicare in 1978 for USD 87 Million in stock. J&J was doing exceptionally well and had doubled its sales in the previous five years; it entered medical diagnostics industry to expand its base and achieve continued growth. Recent success ensured that J&J had the financial muscle to support Technicare's growth. It expected continued losses but wanted to gain more market share; it succeeded in gaining market share.

Technicare's exit demonstrated that a firm who could improve its technological capabilities commensurately with competition but couldn't improve its other capabilities (in this case production), faced a capability constraint which prevented any further improvement even in technological capabilities. Moreover, it demonstrated that in spite of a cheap scanner, it couldn't get share or profitability because the market didn't really want a cheap scanner, it wanted a better scanner.

EMI faced several difficulties and began to lose money; its share declined precipitously. It was losing share because it could not improve its scanner performance in line with the market. As a result, it made a twenty-eight million dollar loss in the year. It was surprised at the speed at which third generation scanners improved given their poor resolution in the early stages. As EMI was under pressure to respond to the fast evolving technology, it acquired Searle's CT scanner operations after Searle decided to exit the market. However, EMI also decided to leapfrog into 4th generation scanner. Since EMI was losing share in the US, where price was less of an issue, it began focusing on improving Searle's 3rd generation scanner. This was until the 4th generation scanner was ready to be launched. Here was a stark example of technological capabilities driving firm performance; with EMI's relative capabilities in the market declining, its performance also declined.

GE was one firm that was consistently improving its performance in the industry; it indicated an improvement in performance over 1977 and began to succeed internationally too. Clearly, GE's ability to improve its technological capability along with its significant marketing and service muscle enabled it to gain share.

Picker had a similar distribution and service muscle as GE had but its scanner had much higher reconstruction time due to which it was unable to gain much market share at this time. It share was still below 5% showing how technological capabilities drove the industry to a great extent.

Firms that couldn't improve the product and were incurring losses for some time began exiting at this stage. Other than Searle, AS&E, the pioneer of 4th generation scanner, Varian associates, the X-ray incumbent, and Searle, the pharmaceuticals giant, also exited the industry. AS&E had been incurring losses and was unable to gain share due to its long reconstruction speed; it decided to exit the industry. Varian took a bleak view about the future of the market and decided to pull out, selling all of its patents to GE. Some market watchers actually believed that the CT industry went through a bubble that had finally burst; a Union Carbide's medical division chairperson Robert King said "The CT bubble was unfortunate". Union Carbide, a nuclear scanner incumbent, never entered the market.

Two players entered the market in 1978 as they had planned entry prior to the market decline. Omnimedical entered to take advantage of the regulatory hurdle by entering the mobile CT scanner segment that had emerged to circumvent the regulation. Elscint, an Israeli nuclear imaging manufacturer, entered the market with Technicare's second generation scanner.

The market size further declined in 1979, reaching a mere 200 million dollars that created another shocking exit - the exit of the CT pioneer EMI who merely 7 years back had created a revolutionary technology and a new industry. Delays in improving the scanner and technical issues with the 4th generation scanner and production problem led to further erosion of profitability. It made an even bigger loss in 1979 than it made in 1978. The shrinking CT market further exacerbated the problem for EMI. As the parent company's core music business was in trouble, it decided to sell off the CT scanner business to Thorn International. EMI closed the year ending Jun 30, 1979 with a USD 23.5 million loss, primarily from the CT scanner business. Just as Technicare had faced resource issues in a tough market, EMI met with a similar fate in presence of a declining market. Sir John Read, Chairman of EMI said “We didn't have the muscle or cash to see this thing through ourselves."

Picker also saw a change in ownership, but at a parent level. RCA acquired its parent CIT financial to enter the financial services business. Picker continued to run its operations as earlier, but it was finding it hard to get market share in a tough market. It had improved its scanner speed to 1 second by now but its market share improved less than commensurately; its market share edged up to 5% in 1979.

Pfizer also had a 5% market share and had even started selling to China. It launched its 4th generation scanner with significantly better speed and resolution which enabled it to maintain its position in the market. It showcased its entire line of new scanner including the PZ-2400 with 2400 detectors and a superior resolution. Although it reported in its annual report that the response to the scanner was gratifying, the next year revealed that it was losing money on the scanners when it exited the market. It took a total loss of 52.5 million dollars after taxes from discontinued operations when it exited the market. It sold its operations to Elscint.

GE also used the continued downturn in the market as an opportunity to enter the mobile CT segment. Due to CON regulation, community hospitals were unable to purchase CT scanners which gave some entrepreneurs an opportunity to install CT scanners in trucks and serve several hospitals at the same time. Some consortium of hospitals and several independent agencies began serving the mobile CT market.

Although the market expanded in 1980 by 30%, Thorn international was unable to revive EMI's operations and continued to make losses. Eventually, it sold the EMI's global business to GE for 37.5 million dollars. The US business was out of the purview of this deal to smoothly take the deal through US Justice department. This also ended the lawsuit that EMI had filed against GE for infringement of its patent. With this purchase, GE got the largest installed base of scanners which helped its bottom line due to lucrative annual service contracts.

Thomson CGR, after distributing Pfizer's system in Europe, entered the US market in 1979 and in 1980, Toshiba and Hitachi entered the industry. Both Toshiba and Hitachi had licensed GE's 3rd generation scanner; Toshiba was earlier a distributor of EMI in Japan. In 1981, Shimadzu, another Japanese company entered the US market after licensing GE's 3rd generation scanner. Among the Japanese players who entered the CT scanner industry in 1980s, only Toshiba survived in 2002, the others exited the market. Thomson exited in 1987 through a famous swap of electronics business and medical diagnostics business with GE; Thompson could never establish a strong position in the market.

Toshiba's entry strategy was aimed at the low cost no frills equipment segment which was almost nonexistent at the time. Walter Robb, vice-president and division general manager of GE medical systems, argued that the Japanese low-cost strategy will not work, he said "users of medical electronic equipment are more concerned with quality than with price, and if you cut price, you lose vital accuracy and resolution." Clearly, low cost low performance segment was not present in the market until 1980 when the technology was rapidly evolving. By 1982, almost all hospitals with 300 or more beds had purchased a CT scanner.

During 1979-1980, J&J-Technicare continued to make losses. The losses stemmed, in part, due to inventory write off and license fees to EMI.

1982-83 saw the expansion to CT industry beyond its previous peaks; the market expanded to USD 750 million dollars in 1983. However, after making significant losses, Pfizer had already exited the industry in 1981, GE had established itself as the leader with a dominant market share, and Picker had improved its position in the market due to improved scanner and market growth. However, its market share never came close to that of GE; a 2 year delay led to a significant loss from this perspective. In 1982, by when it appeared that the demand for speed and picture resolution for most customers had been almost satiated, and technology evolution started to show signs of slow down, GE had three times the market share than picker had, although both had equivalent sales and service capabilities.

The story of the industry until now shows that while complementary capabilities allowed firms significant ability to gain market share, it was the ability to improve the technological performance of scanners that drove the performance to a somewhat greater extent. Firms who couldn't improve their technological capabilities suffered whether they had complementary capabilities or not, however firms with greater technological capabilities won or were bought over by other firms. In short, technological capabilities continued to drive performance in the industry.

5.6 Slowing technological evolution brings industry stability

After 1983, the market shares in the industry remained relatively stable and the technological improvement did not continue at the same pace as in the first 10 years in the industry. GE remained the market leader from then onwards. Picker, who had built a 15% market share by then, continued to hold the share. Elscint and Toshiba continued to maintain their share at 5% and 10% for the next several years. Siemens was the only player who was able to improve its market share after that, its share improved to around

20% in 1980s. Figure 5.12 shows market shares of key players in 2001; Marconi was the new name of Picker as I will detail shortly.

The stability of relative performance of key players was not because the technology had stopped evolving; it was because the customer demand had satiated. Industry watchers had commented that the technology had evolved significantly on the major performance dimensions by 5 to 50 fold. Furthermore, it was only towards the early 80s, the segmentation in the industry began to emerge showing satiation of customer demand for better technology.

5.7 Evidence of demand satiation and its impact on the industry

By 1983, it was clear that the demand for better scanners was becoming satiated. Some industry observers notice this phenomenon and three indicators reinforced the fact that demand was becoming satiated. First, segmentation began to appear when customers preferred low cost low performance product over the best product in the market. Second, the product life cycle did not shrink due to better scanners in the market. Third, firms began to look at service as a source of profitability as the margins declined in the scanner business.

The clearest indicator of demand satiation for superior scanners came when a major innovation resulting in 17 fold speed improvement in technology did not make any impact in the market. Imatron launched its new technology called electronic beam tomography (EBT) scanner but failed to make an impact on the industry for 14 years until GE acquired it in 1998.

Imatron, a technology start up set up in 1980, started working on a high speed scanner technology and went public in 1983. It placed its first scanner, C-100, at university of California, San Francisco. As the scanner was so fast that it could take a picture of a beating heart, it opened up the cardiac segment for CT scanners. However, its image quality was less than desirable but improved over the years. Priced at 1.4 million, the scanner was 25% more expensive than the most expensive scanner in the market – Picker's Sinerview 600S. In 1984, all major players had priced their top of the line scanner at around USD 1 million and had lower end scanner at less than half that price.

The fact that this significant improvement in speed at a 25% greater cost was not an acceptable trade-off for the market ensured that Imatron remained a niche player. Due to small volumes, its profitability also remained an issue over the years. This was one indication of demand satiation for scanner speed.

Furthermore, the emergence of price segments in the market in eighties shows that customers began to prefer lower performance at lower price to high priced scanners. This is a clear indication that some sort of demand satiation began to take place in the industry.

As the market evolved in the 1980s, firms began to become broader based multi segment players cross selling diagnostic products to the customers. GE, Picker, Toshiba, Siemens, Philips, and Elscint all became broad based players. Imatron was an exception to the rule. This led to margin reduction in the industry and firms began to target service contracts to shore up their bottom lines. J&J's Technicare division continued to make losses over the years and decided to exit the industry in 1986 by selling the Technicare division to GE. The 1986 annual report mentioned "The decision was reached to enhance the company's long term growth by eliminating a line of products in which a leadership position could not be established within a reasonable period of time". J&J took a USD 275 million loss from discontinued operations for this exit.

The margin reduction, in presence of inability to increase prices (a signal of demand satiation for higher performance), affected Elscint too. In 1985, it faced its first severe loss; it lost USD 33.7 million on sales of USD 147 million. In 1986, when the cumulative losses increased to USD 115 million on a USD 124 mm sales, Israeli government had to step in and bail out Elscint. The government helped it restructure debt by negotiating with the lenders and by placing government backed bonds with the customers in lieu of performance guarantee. By 1986, Elscint's scanner was among the best but its inability to charge a premium for higher scanner performance prevented it from improving its profitability. After a few years, Elscint returned to profitability in 1989.

In 1989, when Siemens came out with its helical scanner, it was a major breakthrough because the scanner could continuously scan patients and thus speed up the process. By 2001, Spiral scanner had given hardly any performance advantage to Siemens whose share had remained around the same level as it was in 1987.

In early 1991, Siemens started distributing Imatron's EBT technology based Evolution range; cardiac CT as niche had come into existence, although it remained a small market.

Elscint came out with a multi slice scanner in 1992; it could take adjacent scans of a target area and thus speed up the process of scanning. This was another major innovation that speeded up the scanners but the technology made no impact on the market. Its sales growth had come from the low end CT scanners and Elscint had hoped that multi slice scanners would pave way for the future.

In 1990s GE started multi vendor service program wherein its service technicians provided service to non GE equipment too. This program was a major success as customers preferred large multi product companies to smaller and narrow product range companies. Elscint felt the brunt of continued tough times and went through a re-organization from functional to a product based organization in 1995. GE faced an anti-trust suit over its service contracts in 1996.

During the 1990s, the average age of CT scanners in the US increased from 4.5 years to 5.5 years, another indication that the technological improvements were no longer shortening the life cycle of the scanners.

By 1996, Siemens entered into a joint development agreement with Elscint for the multi slice scanners; until then, multi slice scanners had made no impact on the market. At this time, the average age of scanners and life of scanners had increased manifesting maturity in the industry; by 1998 replacement age of scanners had increased to 7 years. Siemens' move towards multi slice scanners was aimed at renewing momentum in the industry. Moreover, multi slice scanners also promised the entry into cardiac CT that until then was completely dominated by Imatron's EBT technology.

In 1998, GE and Siemens came out with multi slice scanners. Elscint already had a multi slice scanner but as the increased speed did not enable it to improve its profitability, it decided to exit the industry in 1998 by sell-off to Picker. Its CFO mentioned the intense competition as the reason why Elscint couldn't go it alone anymore and had to sell off to a major player. By 1999, all players had their offering of multi slice scanners and supplier pushed the market to multi slice scanner market.

In 1999, Siemens came up with a four slice scanner that could scan a beating heart, thereby entering the Cardiac CT domain via traditional CT scanner technology. In the same year, GEC, the parent of Picker, went through a demerger and became Marconi to emphasize the focus on telecommunications industry. Furthermore, Marconi exited the X-ray business as it was a low margin business.

By 2001, the market showed a clear movement towards multi slice scanners, however the cost conscious buyers continue to stick with single slice scanner (see figure 5.13). Furthermore, this move towards multi slice scanner was primarily in replacement sales; hospitals did not rush to buy new technology to replace their existing scanners prior to the end of life of their existing scanners. By this time, price segment had become clearly demarcated in the market place.

By 2001, the market witnesses a price reduction in single slice scanners and a premium for multi slice scanners. Single slice scanner prices fell from an average price of 587 thousand dollars in 1998 to 398 thousand dollars in 2001. At the same time, the prices of scanners on average went up from 660 thousand dollars per scanner in 1997 to 863 thousand dollars in 2001.

In 2001, Marconi systems decided that diagnostic imaging was no longer a core business and in order to focus on telecommunications, it sold off medical diagnostics business to Philips. In the same year, Analogic, a long time component supplier to the CT industry announced that it would enter the CT system industry with an OEM model wherein it will sell the entire CT scanner to the existing firm for sale under their own brand name. By 2002, there were 4 players in the market: GE, Siemens, Toshiba, and Philips and by 2005 their market shares were 37%, 26%, 19%, and 18% respectively. Consolidation and purchase of market share through acquisition appeared to be the main reason for change in market share since late 80s.

After 2002, the technological breakthrough of multislice scanner enabled significant scope for future innovation by expanding the number of slices in the scanners. The players continued to increase the number of slices in CT scanners. However, the radiology application domain could not make a business case for premium on more slices in scanners. Multi slice scanners and their high speed allowed cardiac applications but the limited reimbursements constrained the demand from this application domain too. Increasing number of slices resulted in even more niche application such as oncology and bariatrics. Consequently, hospitals are forced to make a combined business case to purchase new technology scanners. It is becoming increasingly difficult for customers to make a case to pay premium for better speed while the technology shows no limits.

Once the demand in the industry began to satiate, firms found that customers were less willing to pay for greater scanner performance. As a result, further investment in technological capabilities did not result in greater performance. At this stage firms began to look at other avenues for greater profits. While firms continued to improve technology, the improvements were much smaller and the effect of technology improvements on firm performance was not clearly visible.

5.8 Analysis

The history of CT scanner industry in the U.S. is a fascinating case to investigate how capabilities, especially technological capabilities, drive firm performance and whether there is a limit beyond which capabilities do not drive performance. This was the key question that I focused my research on and this is important from a strategic perspective for managers and for the literature on capabilities.

From the beginning of the industry, technology drove the industry. The promise of clear internal images, whether tomographic or three dimensional, was a revolutionary step from super imposed images from X-ray machines. It was also clear to the firms that early technology was far from the minimum desired scanner quality. As a result, firms invested heavily in developing their technological capabilities. EMI was surprised to notice how quickly the competition came out with their scanners. Patent regime in 1970s was not the same as it is today and thus even when EMI exited the industry, the patent suit it had filed (for Technicare and GE) was not fully resolved.

The industry history showed that when firms improved their technological capabilities their performance improved and when they lagged behind the competition their performance declined. In the CT industry, both the technological and complementary capabilities played a major role. Until GE entered the industry, Technicare could build its technological capability and take over the market leadership from EMI, but with the entry of GE, it was the customer expectations from GE that made them wait for a superior product. In effect, GE started taking orders for a superior scanner that had not even been through clinical trials; this was the best example of the role of complementary capabilities. However, technological capabilities continued to drive the firm performance until the early eighties. Although Picker had superior complementary capabilities compared to EMI or Technicare, it could not simply get share in the market without commensurate technological capabilities. Finally, by the time Picker improved it technological capabilities, the market shrunk significantly due to legal reasons and thus Picker could not establish a strong position until the market upturn. Fortunately for Picker, it was able to get a reasonable market share of 15% by the time customer demand for speed and better resolution began to satiate.

Demand satiation was clearly shown by the fact that Imatron's super speed scanner did not make a mark in the industry. This vivid trade-off was also visible in the emergence of price segments in the industry. If the customer need for higher speed was not satisfied in 1984, even if Imatron did not have complementary capabilities, one of the major players such as Picker or GE would have either formed a joint venture with Imatron or would have acquired it to get greater market share.

Once the demand for greater speed and resolution tended towards satiation, technological capabilities no longer drove firm performance. The innovation of multi slice scanner showed that technological space in the industry was not really limited; the limitation came from the customers who could not justify paying a premium for a faster scanner once their need for speed was satiated.

The persistence of market shares until year 1998 showed that in spite of all types of responses, the firm performance in the industry became persistent. Clearly, a sell-out of Picker to Philips was a strategic decision rather than a performance based exit decision that Elscint made.

The industry history supported the theory I developed earlier that in a low complementary context, as a technology evolves, the ability of technical capabilities to drive firm performance diminishes.

Figure 5.1: Growth of segments in medical diagnostics industry during the 1960s

Year	X-ray		Nuclear Medicine		Diagnostic Ultrasound	
	Sales	**Growth Rate**	**Sales**	**Growth Rate**	**Sales**	**Growth Rate**
1963	69		4		0.2	
1964	77	12%	6	50%	0.4	100%
1965	84	9%	9	50%	1	150%
1966	85	1%	10	11%	1	0%
1967	171	101%	14	40%	1	0%
1968	180	5%	17	21%	1	0%
1969	172	-4%	19	12%	2	100%
1970	173	1%	24	26%	3	50%
1971	190	10%	31	29%	4	33%
1972	206	8%	39	26%	7	75%
1973	273	33%	40	3%	10	43%

Figure 5.2 Major innovations in the industry

Major Innovations in the CT scanner industry (1972 - 2002)				
	Innovation	**Details**	**Year**	**Innovator**
1	1st generation head	Cross section slices / Degree of differentiation in shades (5 to 300)	1972	EMI
2	Body scanner	Whole body instead of just head	1975	DISCO
3	2nd generation	Multi beam - multi detector	1975	Syntex
4	3rd generation	Rotating beam - rotating detector	1975	Artronix
5	4th Generation	Rotating beam -Fixed Detector	1976	AS&E
6	EBT	No rotating parts - Electron beam	1984	Imatron
7	Spiral	Continuous motion - Slip rings	1989	Toshiba
8	Multi slice	Multiple slices at one rotation	1992	Elscint

Figure 5.3: Technological advancement in CT technology during first 10 years

Year	Scan time (Sec)	Reconstruction time (sec)	Spatial resolution (mm)
1973	300	300	3.13
1974	300	30	1.67
1975	120	10	1.43
1976	5	10	0.91
1977	2	1	0.77
1978	1	1	0.77
1979	1	1	0.6
1980	1	1	0.5
1981	1	1	0.5
1982	1	1	0.42

Figure 5.4: CT scanner prices in the first decade

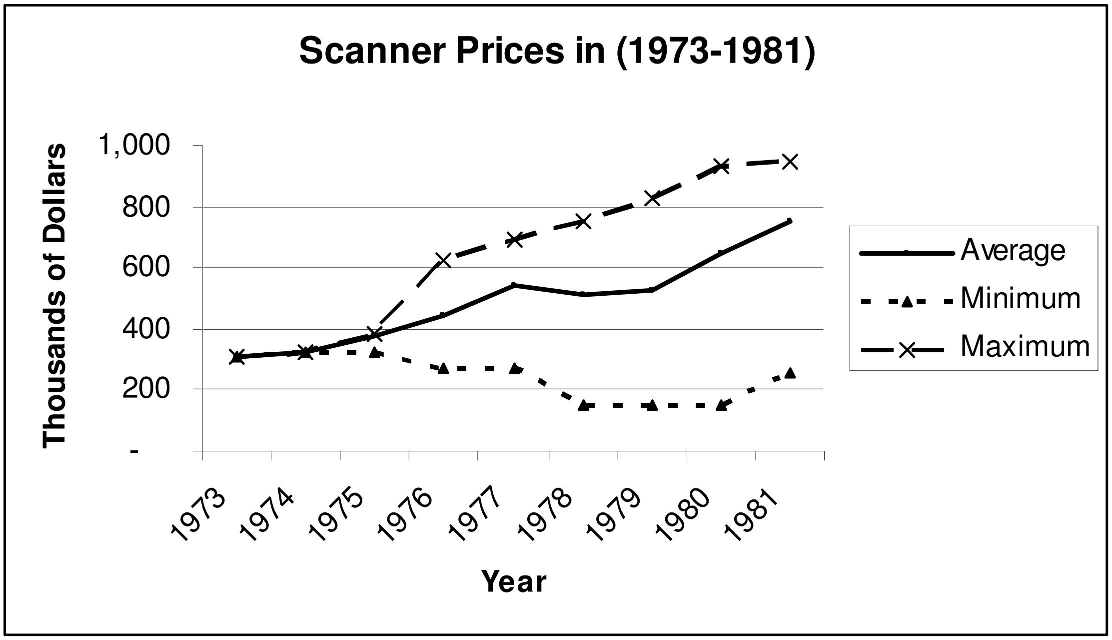


Figure 5.5: Price based segment share in the CT scanner industry

Volume share by segment									
Price Range (USD)	1973	1974	1975	1976	1977	1978	1979	1980	1981
<200K	0%	0%	0%	0%	0%	25%	29%	21%	15%
200-400K	100%	84%	0%	5%	6%	2%	0%	2%	1%
400K+	0%	16%	100%	95%	94%	74%	71%	76%	84%

Figure 5.6: Price segments in the CT industry

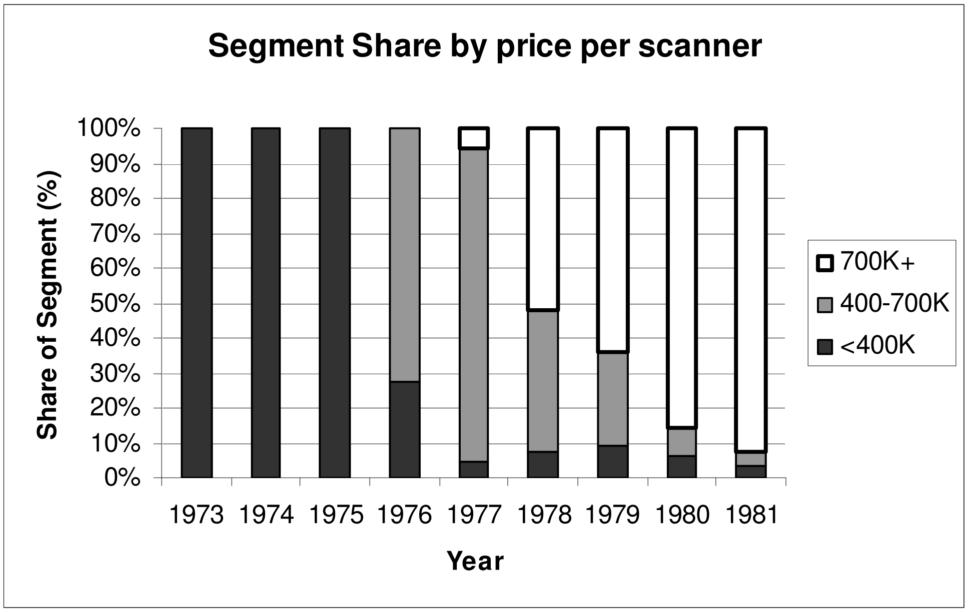


Figure 5.7: Growth in the CT scanner industry

US CT Scanner Sales		
	$ million	Growth Rate
1973	7	
1974	20	186%
1975	80	300%
1976	160	100%
1977	360	125%
1978	240	-33%
1979	200	-17%
1980	260	30%
1981	390	50%
1982	525	35%
1983	750	43%
1984	575	-23%
1985	500	-13%
1986	465	-7%
1987	520	12%
1988	475	-9%
1994	557	
1995	577	4%
1996	576	0%
1997	624	8%
1998	668	7%
1999	803	20%

Figure 5.8: Distribution of installed base of CT scanners (1977)

Type and mfg of CT scanners in use by May 1977						
Firm	**Total**		**Head**		**Body**	
	#	%	#	%	#	%
EMI	232	58	211	92	21	12
Technicare	109	27	0	0	109	64
Pfizer	40	10	0	0	40	23
Syntex	9	2	9	4	0	0
Artronix	3	1	3	1	0	0
Total	393	100	223	57%	170	43%

Figure 5.9: Distribution of installed base of CT scanners (1980)

Type and mfg of CT scanners in use by may 1980						
Firm	**Total**		**Head**		**Body**	
	#	%	#	%	#	%
EMI	284	61.6	267	26.4	551	37.5
Ohio Nuc	109	23.6	309	30.6	418	28.4
GE	16	3.5	221	21.8	237	16.1
Pfizer	0	0	107	10.6	107	7.3
Artronix	28	6.1	4	0.4	107	28
Syntex	11	2%	17	2%	28	1.9
Picker	0	0	22	2.2	22	1.5
Elscint	0	0	13	1.3	13	0.9
Varian	0	0	16	1.6	16	1.1
AS&E	0	0	11	1.1	11	0.7
Philips	0	0	10	1	10	0.7
Omni	9	1.9	0	0	9	0.7
Others	3	0.6	14	1.4	17	1.2

Others include Neuroscan, CGR and Siemens

Figure 5.10 Market shares of key players in the early years

Market Share (%) of Major player over (1973 - 1987)

Year	EMI / Thorn	Pfizer	Technicare/J &J	General Electric	Picker / RCA/GEC	Philips	Siemens	Elscint	Toshiba	Imatron
1973	100									
1974	98									
1975	71	13	11	1						
1976	37	8	46	3						
1977	41	8	20	17	1	1	1			
1978	23	5	34	23	2	2	1	1		
1979	17	5	38	25	5	1	1	3		
1980	1	3	23	55	5	2	3	3	1	
1981	1	3	6	60	4	3	4	8	1	
1982			13	50	16	3	3	5	2	
1983			13	43	15	6	5	5	7	
1984			11	35	15	8	6	5	10	1
1985			10	34	15	11	7	5	10	1
1986			4	38	16	3	20	6	6	1
1987			2	43	6	4	23	6	10	1

Figure 5.11: Technicare – The case of business transformation

Technicare: Transforming Business

($mm)	**1974**	**1975**	**1976**	**1977**
Diagnostic Imaging Sales	6	19	52	125
Total	43	61	93	164
% Sales from imaging	14%	31%	56%	76%
Diagnostic Imaging	1.1	2.5	11.5	30
Total profits	4.7	7.5	16	32.8
% Profits from imaging	23%	33%	72%	91%

Figure 5.12 Market shares in 2001

Market Shares in 2001

	Single Slice	Multi Slice	Total Market
GE	28%	48%	43%
Siemens	32%	23%	23%
Shimadzu	15%		2%
Marconi	12%	19%	17%
Toshiba	8%	10%	9%
Philips	5%		1%

Figure 5.13: Share of segments in the industry at the turn of the century

Share of market			
Year	**Single Slice**	**Multi Slice**	**Cardiac**
1998	91%	7%	2%
1999	47%	49%	4%
2000	16%	77%	7%
2001	11%	83%	6%

6. Statistical Analysis

While the previous chapter supported the theory from a detailed qualitative perspective, this chapter will show how rigorous analysis and careful testing also supports the theory. The previous chapter not only supported the theory, but also demonstrated how the context of first 15 years of the US CT scanner industry is an ideal context to test this theory.

6.1 Methods

I used robust regression and multinomial logit regression for the various tests used to test the theory. In preliminary testing using ordinary least square method, I received supporting results. However due to heteroskedasticity and potential outliers in the data, I used robust regression. The default robust regression method in SAS uses M estimation which is a commonly used in robust regression. In this method, the algorithm tries to minimize a Huber type M estimator which minimizes a less rapidly increasing function of residuals. The procedure solves the system of equations by using iteratively reweighted least squares (IRLS).

Hazard rate models are used across several disciplines, especially where dependent variable is duration or time to an event. I use multinomial logistic regression because it supports time varying measures that I use in my models and allow me to use more than one exit type. As I test for the impact of capability on performance over several years, I needed a model that allows for this.

6.2 Descriptives

Figure 6.1 shows the descriptive statistics and figure 6.2 shows the correlations between independent variables for models where I used level of capabilities as independent variables and level of market share as dependent variable. The total number of data points for all firms in the industry totaled to 157 but when some of the variables were lagged, the total dropped to 133. Some of the correlations appear high but by using adequate controls and alternate operationalization of variables, I took precautions about these. For example, the key correlations are those between key independent variables– technological advancement, technological capabilities, and complementary capabilities. While the correlation between absolute technological capabilities and technological advancement is 0.8, the correlation between relative technological capabilities and technological advancement is 0 (due to the construction of the relative technological capability variable). Similarly, the correlation between absolute technological and complementary capabilities is 0; while between relative technological capabilities and complementary capabilities is 0.27. In the models, I use adequate controls to ensure that correlations among independent variables do not affect the results. Finally, I also use alternate model structure where I test for the impact of change in capabilities on change in market share; the correlations for these models were modest.

Figure 6.3 and 6.4 shows descriptive and correlations for variables used in change models where I used change in market share as the dependent variable and change in capabilities as independent variables. Capabilities in these tables refer to change in capabilities from period 0 to period 1 while share in these tables refer to change in share from period 1 to period 2. Other variables are for period t where variable change each year. As can be noticed from the correlations table, the correlations in change variables are not as high as in the level variables.

6.3 Results regarding market share

I used Breusch-Pagan and White tests to test for heteroskedasticity in the data and found that both the tests showed that data was heteroskedastic. I used the PROC MODEL in SAS to run the tests for heteroskedasticity. Due to heteroskedasticity in the data I used robust regression in SAS using PROC robustreg. Although the OLS models gave me similar results as the robust regression models did, OLS models cannot be used because the standard errors would be incorrect and thus the inference would be inaccurate.

I tested the first hypothesis by operationalizing the variables in different ways. I used absolute and relative technological capabilities, absolute complementary capabilities, technological advancement and time as proxies of industry evolution. Furthermore, I used lagged capabilities in all models to eliminate the reverse causality explanation. The exact model used is as follows

$$\text{Performance}_t=\beta_{0+}\ \beta_1.\text{Capabilities}_{t-1}+\ \beta_2.\text{Technical\_advancement}_{t-1}\ \text{controls}_t$$

Figures 6.5 and 6.6 shows the models used to test hypothesis 1 that posited that the effect of technological capabilities on market share will decrease with technological advancement in an industry. These models test how the level of capabilities in a year affects the level of market share in the next year. Figure 6.5 uses relative technological capabilities and technological advancement whereas figure 6.6 uses absolute technological capability and technological advancement. Using different operationalizations would help in better understanding the role of capabilities and may either reinforce the overall theory or provide subtle distinctions.

For both sets of model, I use the same model building strategy – first model shows the effect of control variables (technological advancement, competitor experience, entry rank, pre-entry capabilities, and industry effort in technical advancement), the second model adds complementary capability measure, model 3 adds technological capability measure, Model 4 adds the interaction term for technological capabilities and industry evolution, model 5 adds the interaction term for complementary capabilities and industry evolution measure, and model 6 adds the weighted lagged sales variable. This sequence shows the effect of technological capabilities and industry evolution after considering all other controls, thus showing the added explanatory power these variables bring to the models.

Model 1 in table 6.5 shows no surprising results except that competitor experience is insignificant. This could be due to the fact that technical advancement is highly correlated with competitor experience and thus both the terms do not become significant. When complementary capability is added, in model 2, it shows a strong significance on market share. Relative technological capability in model 3 shows no significance in spite of the fact that its addition increases the R-square of the model.

In Model 4, when interaction term is added, relative technological capabilities become significant and explains why in model 3 this variable was not significant. In absence of the interaction term, the main and interaction effects of capability were confounded and thus it showed no significance. Model 4 supports the theory that technological capabilities increase market share and that this effect declines as the technology in the industry evolves.

As expected, the complementary capabilities also show a similar effect in model 5. Greater complementary capabilities lead to greater market share and this effect of complementary capabilities decline with the evolution in an industry. The coefficient of complementary capabilities increases significantly in model 5 because the main effect and interaction effect are now considered together whereas in model 4 only the main effect of complementary capabilities was considered. Since the main and interaction effect of complementary capabilities are in opposite directions, it is normal for the main effect to suddenly increase. This significant increase allows the opposite signs in the model which show that while complementary capabilities drive share, as technology evolves the complementary capabilities become weaker drivers of performance. If the coefficient had not jumped to this extent, evolving technology would have made complementary capabilities as liability very early as the net effect of complementary capabilities would have become negative. In short, although the jump in coefficient of complementary capability is large, this is reasonable and should be expected given that complementary capabilities continue to remain an asset and its effect on market share declines as technology evolves.

Finally, model 6 adds weighted sales to test the performance persistence theory and finds support for the theory. It shows that while capabilities lose their power to drive market share, past performance increases the power to drive performance. By adding weighted sales (lag cumulative sales weighted with lagged absolute technological capabilities) I avoid the extremely high correlation between sales and share. Moreover, cumulative sales at higher capability will show higher persistence effect as it is the sales at a certain level of capability that drive future performance.

The fact that capabilities provide explanation of market share after controlling for known drivers of market share shows that capability explanation works over and above the other variables such as pre entry capabilities, entry rank, and competitive intensity. The fact that entry rank remained significant even after controlling for capabilities shows that the effect of entry rank on market share is not mediated by capabilities alone.

I expected that competition of all firms in an industry would hurt the ability of a focal firm to gain market share. However, this variable was not significant. I suspect that this is due to the high correlation between industry effort and competitor experience. Alternately, it is possible that cumulative industry effort in technological advancement is a good proxy of competitor capabilities and after controlling for this variable number of competitors does not affect focal firm performance.

The fact that pre entry capabilities remained significant even after controlling for the current capabilities shows that pre entry capabilities continue to affect the post entry performance for a long period of time. This implies that although pre entry capabilities affect firm performance in longer term, firms are not bound by their pre entry capabilities. When viewed from the perspective of previous studies that posit that pre entry capabilities are key determinant of post entry performance (Aldrich, 1999; Carroll, 1984; Hannan et al., 1977; Hannan & Freeman, 1984; Klepper et al., 2000), this is a significant result. The population ecology literature would expect pre entry capabilities to determine longer term firm performance and to completely mediate the relationship between current capabilities and current performance. This result however shows a constrained evolution of firm capabilities; pre entry capabilities continue to have longer term effect but current capabilities appear to have a stronger effect. This finding is in line with the business dynamics literature (Banbury et al., 1995; Karim et al., 2000; Mitchell, 1994; Mitchell & Singh, 1993; Nagarajan & Mitchell, 1998) that studies the conditions under which firms overcome constraints to change.

Finally, the performance persistence argument is supported by the fact that weighted sales variable was significant. It shows that while capabilities become weaker driver of market share, past performance becomes a stronger driver of performance (cumulative sales increase each year).

An interesting finding in these models is that relative technological capabilities have a higher impact on market share than complementary capabilities have. In a technology driven industry, this would be expected as customers deeply care for product performance.

Figure 6.6 shows the models that use absolute technological capability as the measure of technological capability. Using the alternate measure of technological capability allows me to test the robustness of the results and discover any subtle distinctions that may arise due to the use of absolute capabilities. Similar to the previous models, technological capabilities drive market share but as the technology in the industry advanced, technological capabilities became a weaker driver of firm performance (model 4); this is consistent with hypothesis 1.

A major difference between the models using relative and absolute technological capability is the relative effect size of technological and complementary capabilities. Relative technological capabilities were stronger driver of share when compared with complementary capabilities; however absolute technological capabilities were a somewhat weaker driver of share when compared with complementary capabilities. This pattern suggests that customers care less about absolute technological capabilities than about relative technological capabilities.

An interesting outcome in these models was the lack of significance of entry rank in spite of the fact that entry rank was significance in models using relative technological capabilities. This implies that entry rank gives a better indication of the absolute capabilities a firm builds but not the relative capabilities a firm builds. As a result, when the model accounted for the absolute capabilities, entry rank lost significance but when the model accounted for relative capabilities, entry rank continued to remain an important determinant of market share.

Figure 6.7 shows the graphical representation of the results in figure 6.6. The graph shows the relationship between market share level and absolute capability levels. The graphs were drawn based on the coefficients in figure 6.6. I used actual mean values of significant independent variables and used actual capability level from dataset to get the resulting market share values for these graphs. In order to get two technical advancement scenarios, I used high technical advancement as 90% of final technology advancement and low technical advancement as 10% of final technical advancement. The graphs shows that the relationship between absolute capability level and market share level (in the subsequent period) is strong when the technical advancement is low but becomes weak when technological advancement is high. This is consistent with the theory which predicted that due to demand satiation due to technological advancement, the technological capabilities will become weak drivers of performance.

When I used time as the proxy of industry evolution, I did not find results and this implies that it is not temporal advancement of an industry but technological advancement that weakens technological capability as the driver of market share. Figure 6.8 and 6.9 show the models where I used time as a proxy of evolution. This is consistent with the theory which states that advancement of technology (rather than temporal progression of an industry) results in demand satiation which weakens the power of technological capabilities to drive share.

Figure 6.10 and 6.12 shows the tests of the hypothesis 1 using change models. In these models, I use change in market share as the dependent variable and change in capabilities as the independent variables. Figure 6.10 uses change in relative technological capabilities whereas figure 6.12 uses change in absolute technological capabilities. The results in these models are consistent with the results in models that used level instead of change in variables. Change in technological capabilities has a strong positive effect on change in market share in both the models. However, change in complementary capabilities is significant only when used with absolute technological capabilities but loses significance when used with relative technological capabilities.

Similar to level models, absolute technological capabilities have a smaller effect on share than complementary capabilities do but relative technological capabilities are stronger than complementary capabilities. Entry rank shows an interesting result in these models. Although entry rank had a negative impact in level models, it has a positive impact in change models suing relative technological capabilities. This suggests that after controlling for relative technological capabilities, early entry is detrimental for share gain.

Finally, the weighted lagged sales show a negative effect which is opposite sign of the effect in market share level models. Since these models use change rather than absolute levels, the results, although opposite, still reaffirms the performance persistence hypothesis. The small negative effect can be interpreted as follows: as weighted sales increase, the change in market share declines. If performance persistence hypothesis has to hold then change in market share change should decline over time. The results are consistent with my expectations.

Figure 6.11 is a graphical representation of the results in figure 6.10 which vividly shows that as technology advances, the relationship between change in relative capabilities and change in market share became weaker. Overall, the results support the hypothesis 1 and suggest that as technology improves, the ability of capabilities to drive performance goes down.

6.4 Survival models

In the theory section, I had built two hypotheses that primarily tested the same argument – capabilities lose their ability to drive firm performance as an industry evolves. Tests for the first formalization used robust regression method and used market share as the dependent variable. I argued that in the US CT scanner industry, market share was an excellent proxy for firm performance and thus the results supported the central thesis here. By operationalizing the capabilities in two different ways, I got more robust results as the results held across different operationalizations.

By using a second dependent variable, I formalized the central thesis in an alternate way with the objective of attaining more support for the thesis. In line with extant literature in population ecology, I used firm survival as a proxy of firm performance. As survival is a significantly more stringent measure of firm performance, supportive results would add to the robust results in the previous models. I consider survival to be a more stringent measure of performance because traditional usage has considered survival to be a categorical performance measure; all survivors are higher performers than non survivors are. In my previous work on survival (Chopra, 2005), I examined this categorical nature of performance measure in significant detail. There, I categorized various gradations in survival that would make survival a less stringent measure. In absence of a larger population and greater details of different levels of exits, I decided to use the traditional definition of exit – dissolution and sell off. In line with the traditional definition of exit, a firm will be considered a high or low performer when viewed from the survival lens; consequently, a firm with minuscule market share would be considered as high a performer as a firm with market leadership share. This would make getting significant results even more difficult. Thus I tested the survival models with great apprehension.

Figure 6.13 shows the pattern of entry and exit over time. The chart shows population pattern at a business unit level which assumes only dissolution as exit. The pattern shows that the time period of the data set was long enough to include shakeout type of population decline.

Figure 6.14 to figure 6.17 show the population's survivor functions and hazard functions along with the effect of incumbency on survival. The graphs show that hazard of survival for an average firm increase and then decreases but the hazard for non-incumbents continue to increase with time. The statistical results confirm the visual output that the hazard functions of incumbents and non incumbents are indeed different. This shows that the incumbents from the medical diagnostics industry had a strong survival advantage. After these results, I tested the robust regression models with incumbent as a control variable but didn't get significance for the variable.

When testing the survival models, I made a few changes to the control variables in line with the context. As the hazard functions and survivor curves shows that incumbents had a different hazard rate than non incumbents did, I added incumbent as a control variable. Furthermore, since survival rates are enhanced in munificent environments, I added industry growth rate as another control variable. All the other variables remained the same as in robust regression models using market share as the dependent variable. The charts do not show industry effort because I removed the variable; the variable was not significant and it did not affect the other results. I also removed the weighted sales variable as it was also not significant. Finally, I transformed the capability variables into a percentile measure to get a better interpretation of the results; this has no impact on the results at all.

I used multinomial logit regression to test the survival models. I coded sell-off and dissolution as two distinct exit modes in the models. Figure 6.18 shows the results from the survival models using relative technological capability and technological advancement as the key variables affecting firm survival and figure 6.19 shows the results from the survival models using absolute technological capability and technological advancement as the key variables. A positive coefficient implies that the variable increases the odds of one event versus the other. For example, in figure 6.18, a 5.3 coefficient in the model titled survive versus shut down implies that 1 percent point increase in relative technological capabilities increase the odds of surviving (versus those of shutting down) by $e^{5.3}$ times. In this case it implies that firms increased their chances of survival by building technological capabilities relative to their competitors.

In both tables (6.18 and 6.19), models 1 and 2 use shut down as the omitted case while model 3 uses survive as the omitted case. Although model 3 case could be calculated from models 1 and 2, I decided to use SAS so as to get standard errors in model 3 too.

The results are in line with the robust regression results where market share was the dependent variable. However, the results have lower significance than the results in robust regression models. By splitting the exit mode into shut down and sell off, these models provide some interesting insights.

Both the models show that increase in relative technological capabilities increases the odds of survival. In turn, consistent with hypothesis 2, this increase in odds of survival becomes lower with technological advancement.

Similarly, relative technological capabilities also result in greater odds of sell off versus shut down and these odds become lower with technological advancement. This also shows that added capabilities result in greater odds of being acquired rather than being shut down – which is intuitively accurate. Also, by building absolute capabilities a firm's odds of sell off are greater than by building relative capabilities.

Complementary capabilities also have similar main effect – increase in complementary capabilities increases the odds of surviving (rather than shutting down) and sell-off (rather than shut down). Moreover, this increased odds of survival (versus shut down) and of sell-off (versus shut down) decrease with technical advancement.

However, increase in relative capabilities does not increase the odds of sell off (versus shut down) to the same extent as increase in absolute capabilities do. It appears that relative capabilities are less valued in the market for capabilities when compared with absolute capabilities. As a result, increase in relative capabilities leads to increase in odds of sell-off versus shut down but to a lesser extent than increase in absolute capabilities.

As expected, higher industry growth rate results in greater odds of survival (versus shut down) when considering relative capabilities. However, when considering absolute capabilities, higher industry growth rate increases the odds of survival as well as of sell off (versus shut down). A munificent environment created by high industry growth rates would enable firms to attract resources which allow even weaker firms to survive.

Incumbents show greater odds of surviving (versus shut down) whereas incumbents show no greater odds of sell off (versus shut down). I interpret this as a choice that incumbents make – perhaps incumbents wanted to avoid handing over valuable capabilities to competitors who could then use the same capabilities in other markets against the incumbent.

The result of technological advancement is interesting when compared across two types of technological capabilities. When the model used relative capabilities, technological advancement had no impact on survival however when the model used absolute capabilities, technological advancement increases the odds of survival (versus shut down) and the odds of sell off (versus shut down). I interpret it as the value of absolute capabilities versus relative capabilities; in the case of relative capabilities this implies that given that a firm has survived until the beginning of a period, after controlling for relative technological capabilities, higher technological advancement has no impact on its relative odds of surviving versus shutting down. Clearly, relative capability is more volatile than absolute capability since a competitor can make major advances and reduce a firm's relative capabilities. However, when controlling for absolute capabilities, given that a firm has survived till the end of last year, higher technological advancement would increase its odds of surviving (versus shut down) and of sell off (versus shut down). This is because even if a competitor enhances its absolute capabilities, high absolute capabilities will result in greater absorptive capacity (and thus the ability to improve relative capability) and will also have value in the market for capabilities which would increase the odds of sell-off versus shut down. A firm with higher absolute capabilities would be able to use its absorptive capacity to enhance its relative capabilities or sell out to another firm.

The other control variables did not have any significance in either model.

Supportive results in survival models add significant degree of support to the overall thesis of this dissertation. In line with my expectation, the significance level of the results dropped a little but continued to support the thesis. Considering how high the bar is when using a survival model, the weaker significance in results must be viewed with great confidence.

The models support the thesis that improving technology in low complementarity contexts satiates customer demand for better technology. As a result, higher technological capabilities do not induce customers to pay more or to switch suppliers. As a result, when technological advancement in an industry is low, higher technological capabilities would enable firms to demand premium on their products and would even induce customers to replace prior purchases and switch suppliers; these actions of customers would improve performance of firms and lower hazard rate of firms. However, once the technology has advanced to the extent that customers no longer demand better technology, no longer pay a premium on better technology, no longer switch suppliers to buy better product, and no longer replace their prior purchases to get the latest technology. This results in a situation when higher technological capability does not lower the hazard rate of a firm as it does not enable a firm to improve performance.

The result for complimentary capabilities also show similar results; complementary capabilities lower hazard rate of firms but as technology advances, even complementary capabilities lose their ability to lower hazard rate. I had explained this in the previous section as showing that complementary capabilities work to retain customers and since the customers no longer switch due to technological capabilities, complementary capabilities also become less relevant to retain customers. The result is that any improvement in complementary capabilities will show minimal effect on performance.

Consistent results across different models, using alternate performance measures and alternate operationalizations add to the robustness of the results.

6.5 Summary

In summary, the results support the central thesis of this dissertation and show that capabilities lose their ability to drive performance once advancing technology satiates customer demand for greater product performance. This is consistent across the different models and complements the supporting evidence found in the qualitative analysis of the context.

Figure 6.1: Descriptive Statistics for level models

Variable	N	Mean	Std Dev	Minimum	Maximum
Log share	157	0.57	0.57	0.00	2.00
Relative technological capability	133	-0.35	0.29	-1.60	0.00
Absolute technological capability	133	1.53	0.22	0.00	1.71
Complementary capability	133	0.36	0.33	0.00	1.48
Competition	157	11.29	1.92	0.00	14.00
Entry Rank	157	10.57	6.87	1.00	22.00
Pre entry Capability	157	1.46	1.69	0.00	4.90
Industry effort	157	3.89	0.69	0.00	4.44
Technological Advancement	157	96.36	10.21	0.00	100.00
Weighted sales	133	10.25	8.92	0.00	42.74
Time	157	8.19	3.71	0.00	14.00

Figure 6.2: Correlation matrix for level models

	Log share	Rel Tech capability	Abs tech capability	Comp capability	Comp etition	Entry Rank	Pre entry Cap.	Ind. effort	Tech Advce	Wght sales	Time
Log share	1.00										
Relative tech capability	0.32	1.00									
Absolute tech capability	-0.02	0.55	1.00								
Complementary capability	0.59	0.27	0.00	1.00							
Competition	-0.15	0.00	0.66	-0.16	1.00						
Entry Rank	-0.54	0.00	0.23	-0.72	0.45	1.00					
Pre entry Capability	0.45	0.43	0.37	0.32	0.00	-0.34	1.00				
Industry effort	-0.13	0.27	0.84	-0.14	0.80	0.52	0.13	1.00			
Technological Advancement	-0.19	0.00	0.80	-0.18	0.77	0.36	0.13	0.87	1.00		
Weighted sales	0.55	0.49	0.47	0.74	0.27	-0.39	0.47	0.38	0.27	1.00	
Time	0.00	0.32	0.60	0.00	0.66	0.55	0.00	0.82	0.55	0.44	1.00

Figure 6.3: Descriptives for change models

Variable	N	Mean	Std Dev	Minimum	Maximum
Share change	133	-0.23	7.49	-34.00	35.00
Technical Advancement	157	96.36	10.21	0.00	100.00
Competition	157	11.29	1.92	1.00	14.00
Entry Rank	157	10.57	6.87	1.00	22.00
Pre Entry Capabilities	157	1.46	1.69	0.00	4.90
Industry Effort	157	3.89	0.69	0.00	4.44
Absolute Complementary capability change	157	0.06	0.15	-0.63	1.17
Relative Core capability Change	132	0.00	0.22	-1.04	1.24
Absolute core capability change	157	0.23	0.50	0.00	1.69
Weighted sales	157	260.59	511.80	0.00	3236.00

Figure 6.4: Correlations for change models

	Share change	Tech. Advance	Compt.	Entry Rank	Pre Entry Capabilities	Industry Effort	Absolute Comp. capability change	Relative tech. capability Change	Absolute tech. capability change	Weighted sales
Share change	1									
Technical Advancement	0	1								
Competition	0.15	0.77	1							
Entry Rank	0	0.36	0.45	1						
Pre Entry Capabilities	0.2	0.13	0	-0.34	1					
Industry Effort	0	0.87	0.83	0.52	0.13	1				
Absolute Complementary capability change	0	-0.57	-0.32	-0.21	0	-0.41	1			
Relative technological capability Change	0.23	0.31	0.16	0	0	0.21	-0.12	1		
Absolute technological capability change	0	-0.22	-0.21	0	0	-0.35	0.2	0.38	1	
Weighted sales	0	0.15	0.18	-0.36	0.48	0.24	0	0	-0.21	1

Figure 6.5: Effects of relative technological capability and technical advancement

Robust regression results for the effect of relative technological capability and technical advancement on market share

(A positive coefficient means increase in market share)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	1.84 ***	5.18 ***	5.15 ***	2.90 *	-6.51 **	-8.75 ***
	(0.35)	(1.16)	(1.29)	(1.26)	(1.96)	(1.90)
Rel. tech. capability (t-1)			0.01	26.83 ***	20.08 **	27.33***
			(0.16)	(6.15)	(5.54)	(5.37)
Complementary Capability (t-1)		0.54 ***	0.54 **	0.44 **	8.67 ***	8.42 ***
		(0.18)	(0.18)	(0.16)	(1.83)	(1.77)
Technical Advancement (t-1)	-0.04***	-0.07 ***	-0.07 **	-0.02	0.07 **	0.14 ***
	(0.01)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)
Rel. tech. capability (t-1) *				-0.28 ***	-0.21 **	-0.28 ***
Technical advancement (t-1)				(0.06)	(0.06)	(0.06)
Complementary Capability (t-1)					-0.08***	-0.09 ***
* technical Advancement (t-1)					(0.02)	(0.02)
Competition (t)	0.01	0.06 ~	0.06 ~	0.06 ~	0.03	0.02
	(0.03)	(0.03)	(0.03)	(0.04)	(0.03)	(0.02)
Entry Rank	-0.05***	-0.02	-0.02	-0.04 ***	-0.05 ***	-0.04 ***
	(0.01)	(0.12)	(0.01)	(0.01)	(0.01)	(0.01)
Pre Entry Capability	0.09 ***	0.12	0.12 ***	0.13	0.13 ***	0.10 ***
	(0.02)	(0.02)***	(0.02)	(0.02)***	(0.02)	(0.02)
Industry Effort (t)	0.74 ***	0.32	0.31	-0.35	-0.13	-1.22 ***
	(0.12)	(0.20)	(0.23)	(0.27)	(0.24)	(0.25)
Weighted Sales (t-1)						0.04 ***
						(0.01)
N	157	133	133	133	133	133
AICR	168	157	159	183	225	203
R-Sqr	44%	48%	49%	52%	53%	59%

*** 0.1% significance **1% significance *5% significance ~10% significance

Figure 6.6: Effects of absolute technological capability and technical advancement

Robust regression results for the effect of Absolute technological capability and technical advancement on market share

(A positive coefficient means increase in market share)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	1.85 ***	5.18 ***	5.10 ***	3.00 *	-46.66 ***	-53.31 ***
	(0.35)	(1.16)	(1.17)	(1.34)	(9.10)	(8.35)
Abs. tech capability (t-1)			-0.13	-4.91 **	26.62 ***	29.83 ***
			(0.73)	(1.47)	(5.22)	(4.79)
Complementary Capability (t-1)		0.54 ***	0.53 **	0.47 *	44.08 ***	48.92 ***
		(0.18)	(0.18)	(0.19)	(7.71)	(7.05)
Technical Advancement (t-1)	-0.04	-0.07 ***	-0.07 ***	-0.03	0.45 ***	0.54 ***
	(0.01)***	(0.02)	(0.02)	(0.02)	(0.09)	(0.08)
Abs. tech. capability (t-1)*				-0.05 **	-0.27 ***	-0.30 ***
Technical advancement (t-1)				(0.02)	(0.05)	(0.05)
Complementary Capability(t-1)					-0.44 ***	-0.49 ***
* technical Advancement(t-1)					(0.08)	(0.07)
Competition(t)	0.01	0.06 ~	0.06 ~	0.03	0.07 *	0.06 **
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Entry Rank	-0.05 ***	-0.02	-0.02	-0.02 ~	-0.11	-0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.11)	(0.01)
Pre Entry Capability	0.09 ***	0.12	0.13 ***	0.14 ***	0.15 ***	0.12 ***
	(0.02)	(0.02)***	(0.02)	(0.02)	(0.02)	(0.02)
Industry Effort(t)	0.74 ***	0.33	0.37	-0.16	0.33	0.30
	(0.12)	(0.20)	(0.24)	(0.24)	(0.23)	(0.22)
Weighted Sales(t-1)						0.04 ***
						(0.01)
N	157	133	133	133	133	133
AICR	168	157	171	180	158	151
R-Sqr	45%	49%	49%	50%	57%	63%

*** 0.1% significance **1% significance *5% significance ~10% significance

Figure 6.7: Graph of test results: Effects of absolute technological capability level on market share level at different levels of technology evolution.

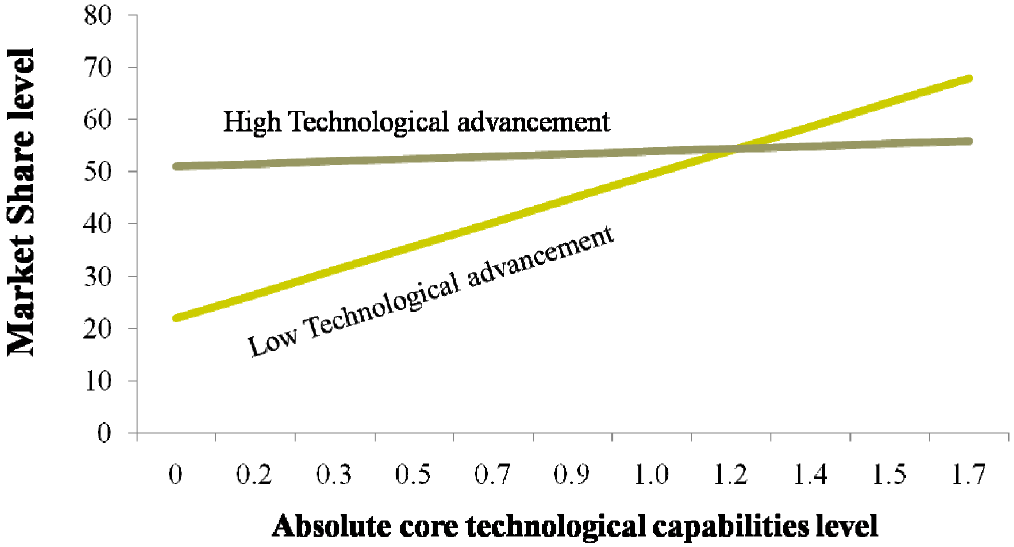
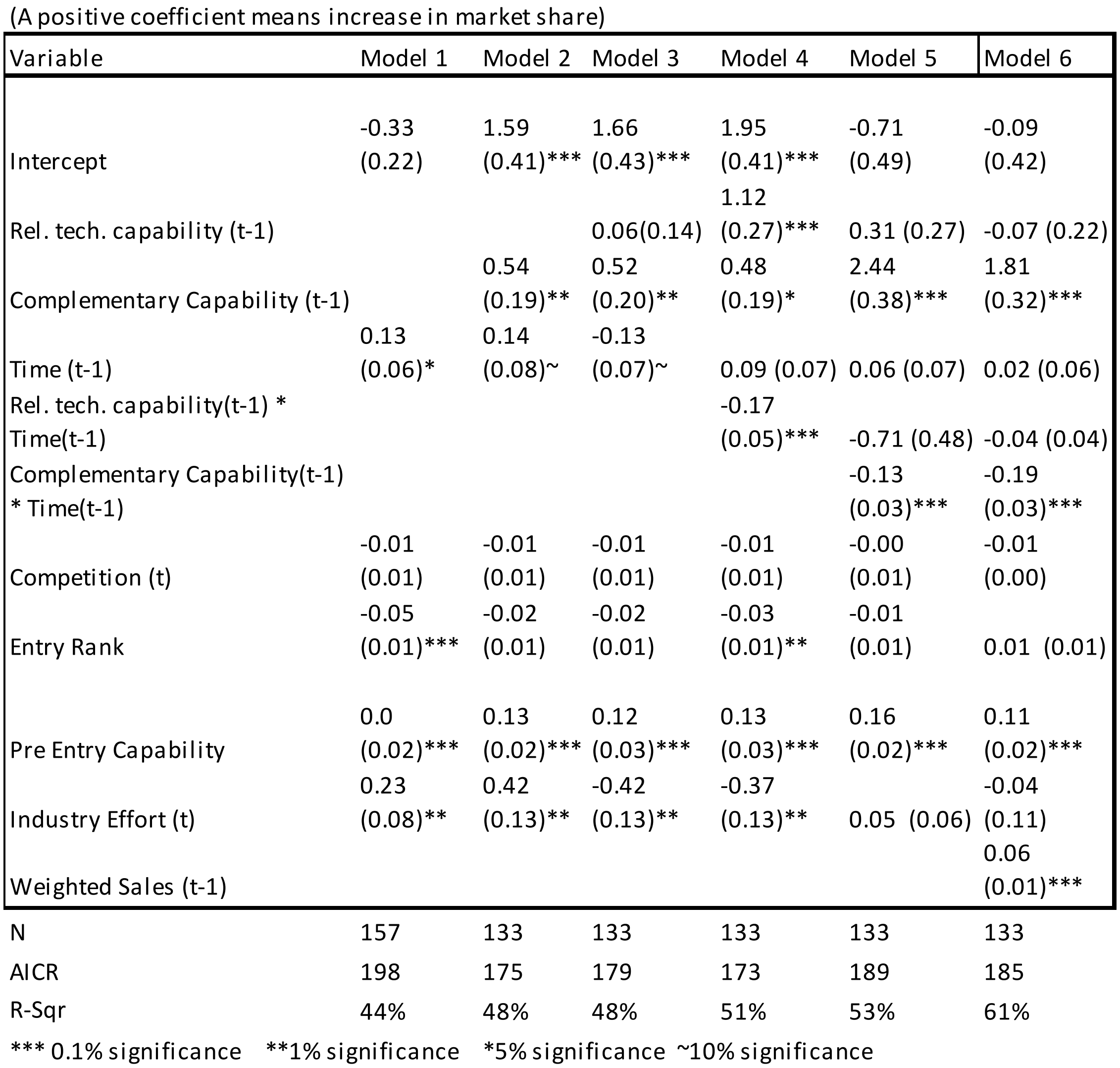


Figure 6.8: Effects of relative technological capability and time



(A positive coefficient means increase in market share)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	-0.33 (0.22)	1.59 (0.41)***	1.66 (0.43)***	1.95 (0.41)***	-0.71 (0.49)	-0.09 (0.42)
Rel. tech. capability (t-1)			0.06(0.14)	1.12 (0.27)***	0.31 (0.27)	-0.07 (0.22)
Complementary Capability (t-1)		0.54 (0.19)**	0.52 (0.20)**	0.48 (0.19)*	2.44 (0.38)***	1.81 (0.32)***
Time (t-1)	0.13 (0.06)*	0.14 (0.08)~	-0.13 (0.07)~	0.09 (0.07)	0.06 (0.07)	0.02 (0.06)
Rel. tech. capability(t-1) * Time(t-1)				-0.17 (0.05)***	-0.71 (0.48)	-0.04 (0.04)
Complementary Capability(t-1) * Time(t-1)					-0.13 (0.03)***	-0.19 (0.03)***
Competition (t)	-0.01 (0.01)	-0.01 (0.01)	-0.01 (0.01)	-0.01 (0.01)	-0.00 (0.01)	-0.01 (0.00)
Entry Rank	-0.05 (0.01)***	-0.02 (0.01)	-0.02 (0.01)	-0.03 (0.01)**	-0.01 (0.01)	0.01 (0.01)
Pre Entry Capability	0.0 (0.02)***	0.13 (0.02)***	0.12 (0.03)***	0.13 (0.03)***	0.16 (0.02)***	0.11 (0.02)***
Industry Effort (t)	0.23 (0.08)**	0.42 (0.13)**	-0.42 (0.13)**	-0.37 (0.13)**	0.05 (0.06)	-0.04 (0.11)
Weighted Sales (t-1)						0.06 (0.01)***
N	157	133	133	133	133	133
AICR	198	175	179	173	189	185
R-Sqr	44%	48%	48%	51%	53%	61%

*** 0.1% significance **1% significance *5% significance ~10% significance

Figure 6.9: Effects of absolute technological capability and time

(A positive coefficient means increase in market share)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	-0.33 (0.22)	1.59 (0.41)***	0.74 (0.40)~	1.87 (0.45)***	-0.82 (0.52)	-0.21 (0.44)
Abs. tech. capability (t-1)			-0.86(0.36)*	0.99 (0.65)	-0.06 (0.62)	-0.71 (0.51)
Complementary Capability(t-1)		0.54 (0.19)**	0.58 (0.19)**	0.54 (0.21)**	2.15 (0.41)***	1.68 (0.34)***
Time (t-1)	0.13 (0.06)*	0.14 (0.08)~	-0.11 (0.07)	0.51 (0.20)**	0.15 (0.19)	-0.01 (0.15)
Abs. tech. capability(t-1) * Time(t-1)				-0.19 (0.10)~	-0.05 (0.09)	0.01 (0.08)
Complementary Capability(t-1) * Time(t-1)					-0.14 (0.03)***	-0.19 (0.03)***
Competition (t)	-0.01 (0.01)	-0.01 (0.01)	-0.01 (0.01)	-0.01 (0.01)~	-0.00 (0.01)	-0.01 (0.00)
Entry Rank	-0.05 (0.01)***	-0.02 (0.01)	-0.01 (0.01)	-0.02 (0.01)~	-0.01 (0.01)	0.01 (0.01)
Pre Entry Capability	0.0 (0.02)***	0.13 (0.02)***	0.16 (0.02)***	0.15 (0.03)***	0.16 (0.02)***	0.12 (0.02)***
Industry Effort (t)	0.23 (0.08)**	0.42 (0.13)**	0.14 (0.21)	-0.97 (0.30)**	0.12 (0.18)	0.32 (0.23)
Weighted Sales (t-1)						0.07 (0.01)***
N	157	133	133	133	133	133
AICR	198	175	191	168	167	187
R-Sqr	44%	48%	48%	49%	53%	61%

*** 0.1% significance **1% significance *5% significance ~10% significance

Figure 6.10: Effects of change in relative technological capability and technological advancement on change in market share in the subsequent period

Robust regression results for the effect of change in relative technological capability and technical advancement on change in market share in the subsequent year
(A positive coefficient means increase in market share)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	-2.09	-3.63 ~	-89.49 ***	-84.11 ***	-61.04 *	-51.13 ~
	(1.56)	(2.05)	(7.84)	(8.66)	(28.46)	(28.75)
Rel. tech. capability (t1-t0)			-0.22	195.73***	195.71 ***	193.03***
			(1.07)	(10.87)	(26.12)	(26.33)
Complementary Capability (t1-t0)		1.32	2.75	5.89 *	37.51	54.28
		(1.25)	(2.62)	(2.48)	(37.8)	(38.98)
Technical Advancement (t)	-0.06~	-0.07 ~	-6.88 ***	1.13 ***	0.84 *	0.74 *
	(0.03)	(0.04)	(1.21)	(0.12)	(0.35)	(0.35)
Rel. tech. capability (t1-t0) * Technical advancement (t1)				-2.04 ***	-2.04 ***	-2.01 ***
				(0.12)	(0.27)	(0.28)
Complementary Capability (t1-t0) * technical Advancement (t1)					-0.33	-0.51
					(0.39)	(0.41)
Competition (t)	-0.08	-0.09 ~	-0.19	-0.13	-0.12	-0.20
	(0.15)	(0.16)	(0.23)	(0.22)	(0.22)	(0.22)
Entry Rank	-0.06~	0.06~	0.12 *	0.13 *	0.13 **	0.17**
	(0.03)	(0.03)	(0.05)	(0.04)	(0.04)	(0.05)
Pre Entry Capability	0.44 ***	0.44	0.68 ***	0.68 ***	0.66 ***	0.63 ***
	(0.10)	***(0.11)	(0.14)	(0.13)	(0.13)	(0.13)
Industry Effort (t)	-0.83 ***	-0.83	-6.88 ***	-7.04 ***	-5.64***	-5.60 **
	(0.63)	(0.66)	(1.21)	(1.11)	(1.91)	(1.87)
Weighted Sales (t-1)						-0.00 ~
						(0.00)
N	157	133	133	133	133	109
AICR	299	287	232	225	243	236
R-Sqr	5.3%	5.7%	6.9%	11.1%	11.4%	12.2%

*** 0.1% significance **1% significance *5% significance ~10% significance

Figure 6.11: Graph of test results: Effects of change in relative technological capability on change in market share at different levels of technology evolution.

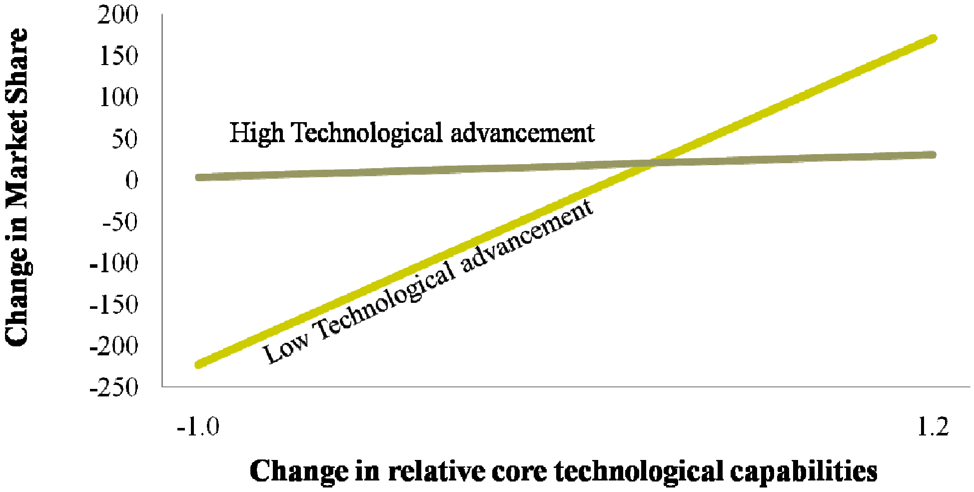


Figure 6.12: Effects of change in absolute technological capability and technological advancement on change in market share in the subsequent period

Robust regression results for the effect of change in Absolute technological capability and technical advancement on market share in the subsequent period

(A positive coefficient means increase in market share)

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Intercept	-2.09 (1.56)	-3.63 ~ (2.05)	-4.99 * (2.08)	-4.97 * (2.26)	-67.43 *** (5.42)	-66.70 *** (4.74)
Abs. tech. capability (t-1)			-0.35 (0.36)	-1.90 (3.16)	24.83 *** (4.71)	26.87*** (4.07)
Complementary Capability (t-1)		1.32 (1.25)	2.48 ~ (1.30)	2.62 * (1.32)	56.27*** (4.71)	55.62*** (4.11)
Technical Advancement (t-1)	-0.06~ (0.03)	-0.07 ~ (0.04)	0.10 * (0.04)	0.10 * (0.04)	0.85 *** (0.08)	0.80 *** (0.14)
Abs. tech. capability (t-1)* Technical advancement (t-1)				0.02 (0.03)	-0.25 *** (0.05)	-0.27 *** (0.04)
Complementary Capability(t-1) * technical Advancement(t-1)					-0.51*** (0.06)	-0.51*** (0.05)
Competition(t)	-0.08 (0.15)	-0.09 ~ (0.16)	-0.08 (0.16)	-0.07 (0.16)	-0.16 (0.16)	-0.14 (0.14)
Entry Rank	-0.06~ (0.03)	0.06~ (0.03)	0.08 * (0.04)	0.08 * (0.04)	0.09 * (0.04)	0.04 (0.04)
Pre Entry Capability	0.44 *** (0.10)	0.44 *** (0.11)	0.46 *** (0.11)	0.46 *** (0.11)	0.48 *** (0.12)	0.41 *** (0.10)
Industry Effort(t)	-0.83 *** (0.63)	-0.83 (0.66)	-1.30~ (0.77)	-1.43 * (0.79)	-4.03*** (0.89)	-2.89 ** (0.89)
Weighted Sales(t-1)						-0.00 ** (0.00)
N	157	133	133	133	133	109
AICR	299	287	286	293	295	320
R-Sqr	5.3%	5.7%	6.0%	6.0%	4.3%	4.5%

*** 0.1% significance **1% significance *5% significance ~10% significance

Figure 6.13: Entry and exit of firms over time

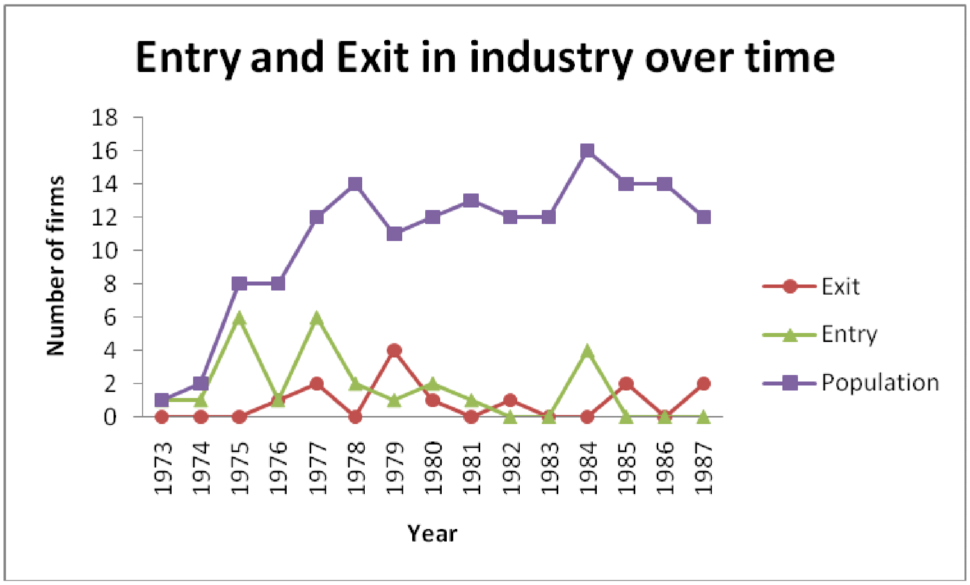


Figure 6.14: Survivor function of business units in CT Scanner industry

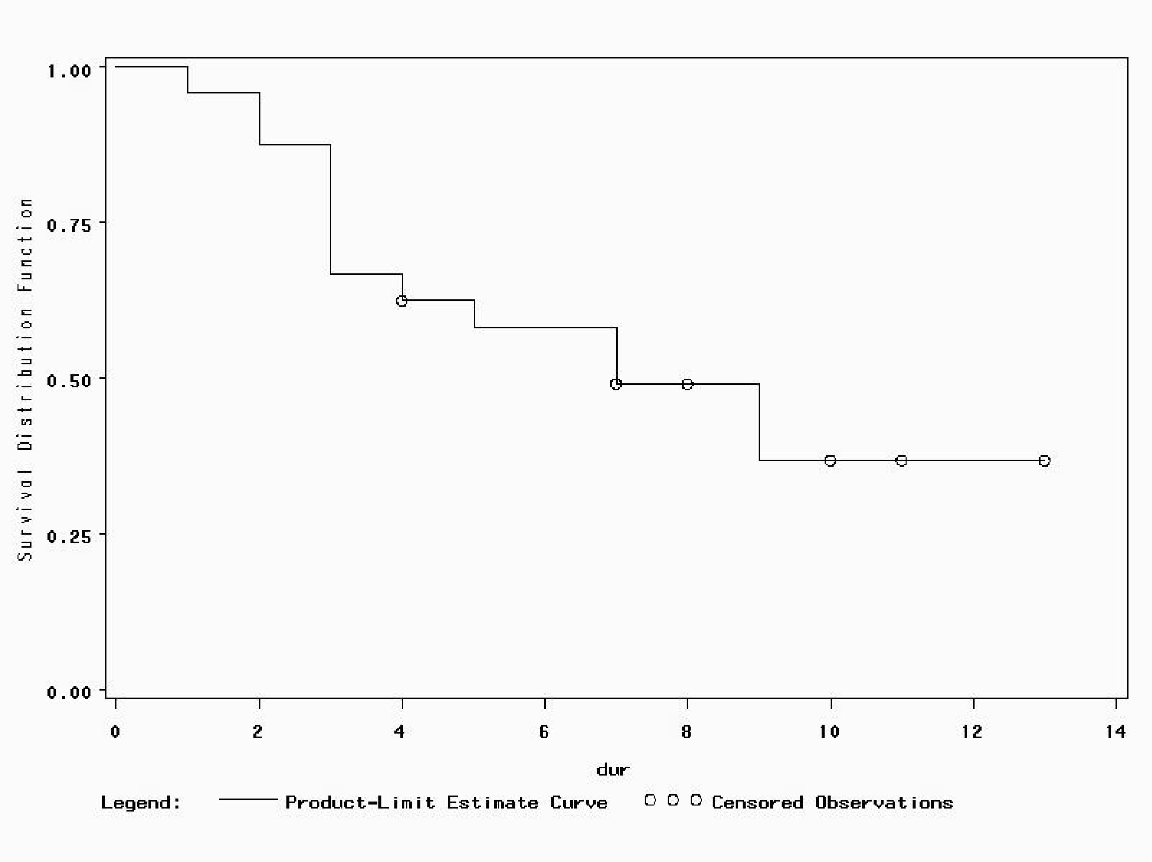


Figure 6.15: Survivor functions of incumbents versus non-incumbents

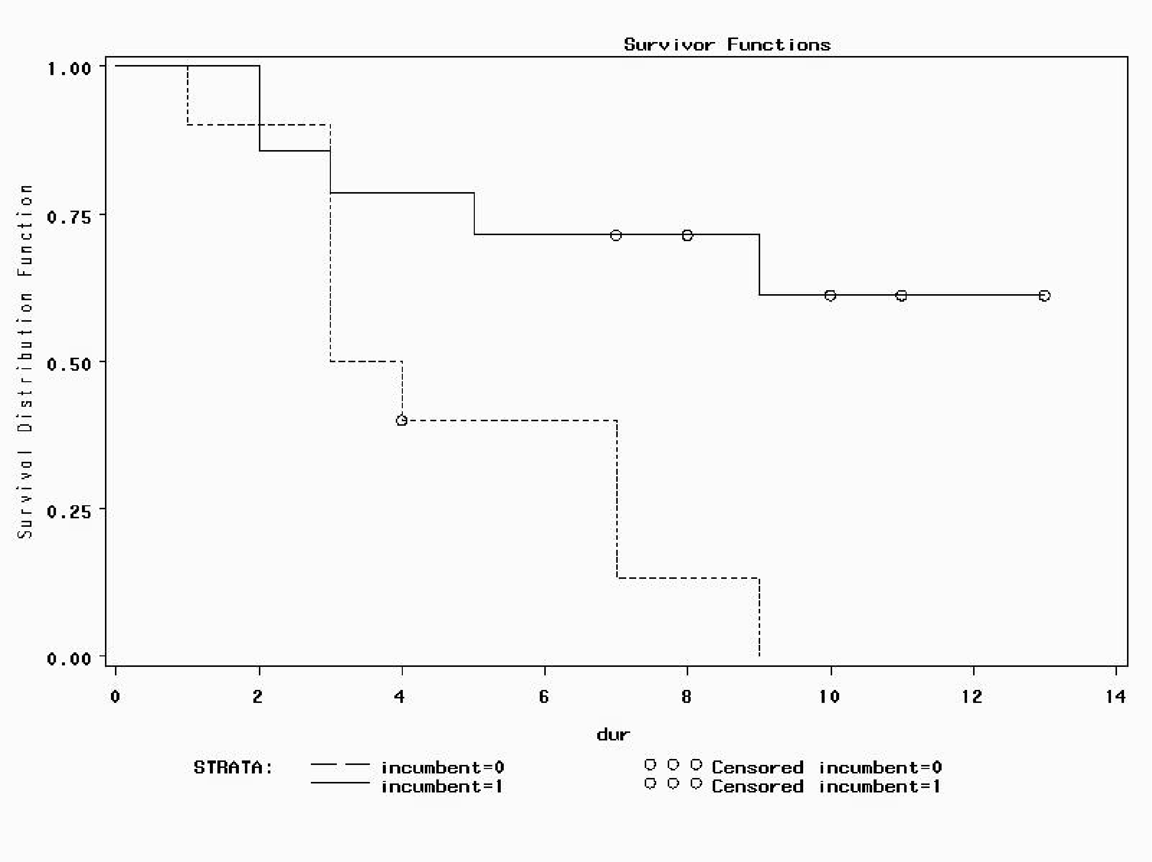


Figure 6.16: Hazard function for the population

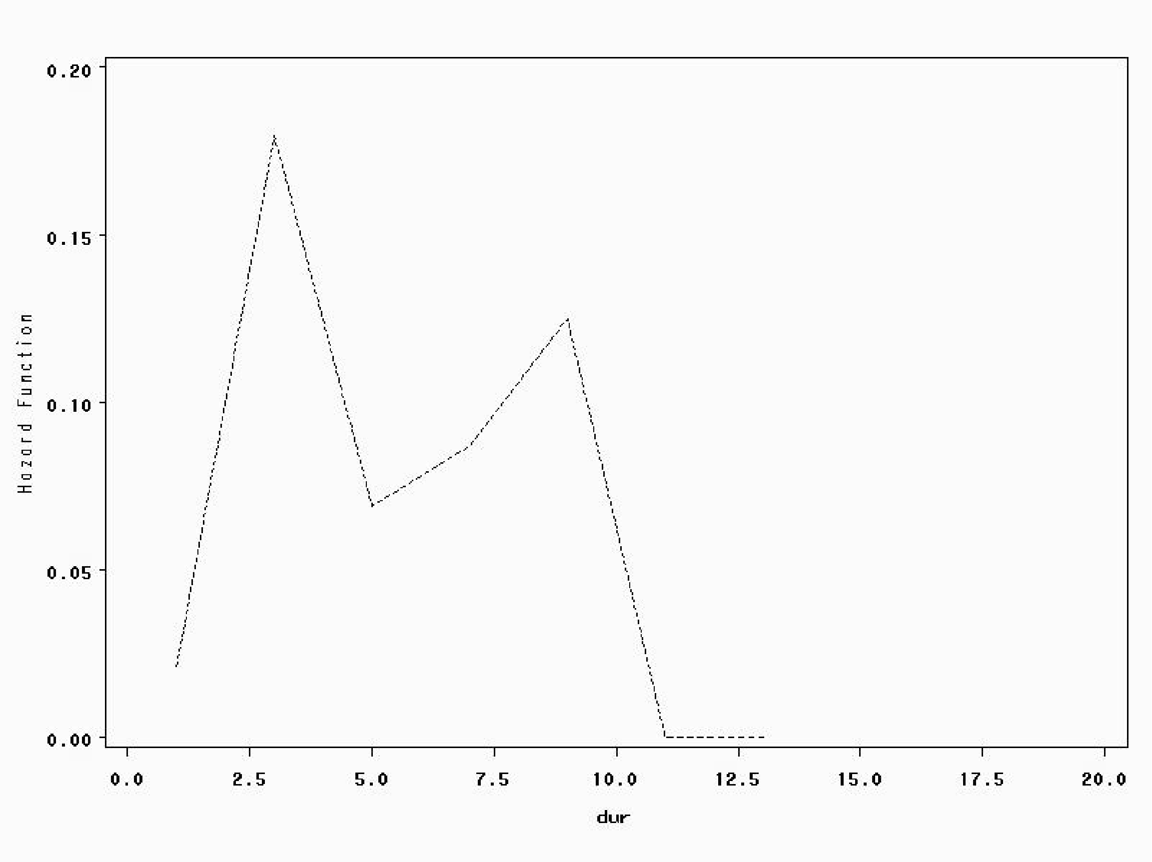


Figure 6.17: Hazard function for incumbents and non-incumbents

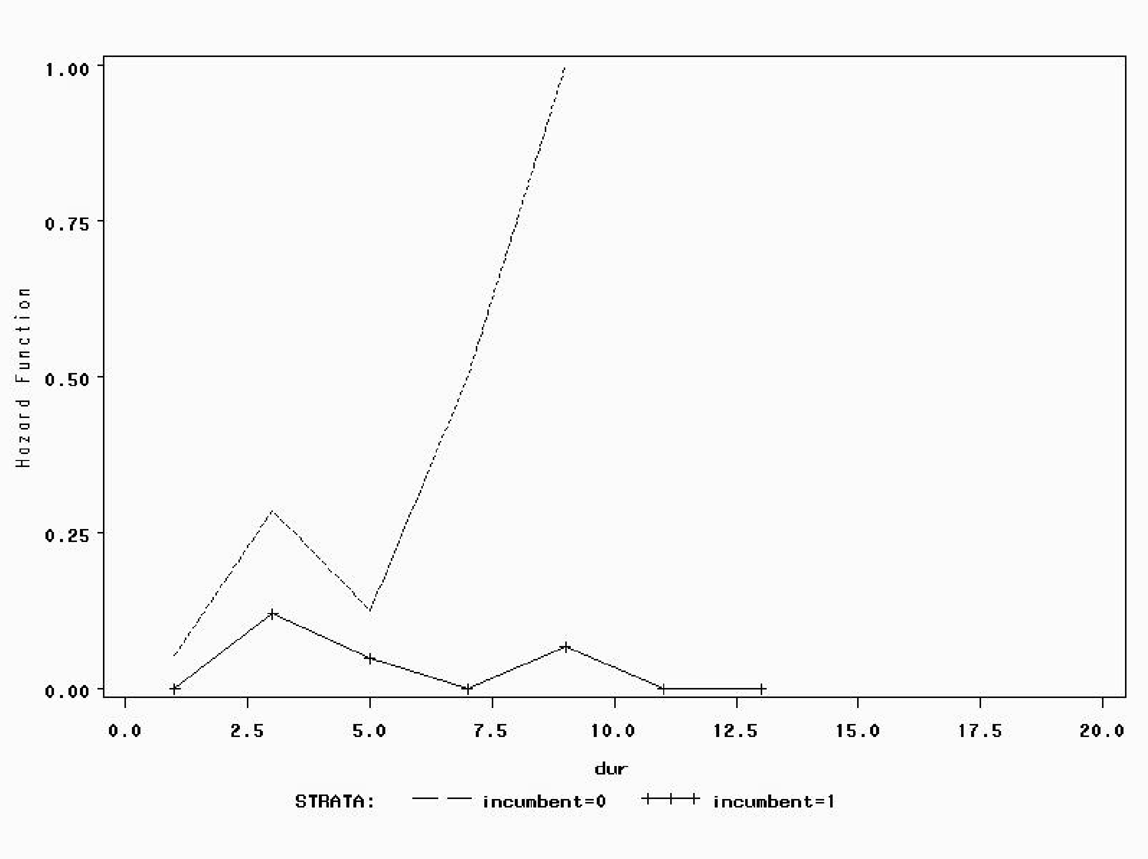


Figure 6.18: Effect of relative technological capabilities and technological advancement on exit (Multinomial logit results)

A positive coefficient implies that the odds (versus) shut down increase

A negative coefficient implies that the odds decrease

	Survive versus shut down	Sell off versus Shut down	Sell Off versus Survive
Intercept	136.3	196.1	59.7
	(0.21)	(122)	(60)
Relative tech. Capability(t-1)	5.30 *	9.37 *	4.06
	(2.69)	(4.12)	(3.36)
Complementary capability(t-1)	5.38 *	3.60	-1.77
	(2.69)	(3.33)	(2.17)
Pre entry Capabilities	1.22	0.86	-0.36
	(0.86)	(0.90)	(0.42)
Entry Rank	0.17	-0.01	-0.19
	(0.17)	(0.24)	(0.18)
Technological advancement(t-1)	-1.49	-2.02	-0.53
	(1.16)	(1.28)	(0.61)
Relative tech. Capability (t-1)* Technological advancement(t-1)	-0.05 *	-0.10 *	-0.04
	(0.02)	(0.04)	(0.03)
Complementary capability (t-1)* Technological advancement (t-1)	0.05 *	-0.04	0.02
	(0.03)	(0.03)	(0.02)
Competition(t)	0.67	-0.04	-0.71
	(0.53)	(0.80)	(0.62)
Incumbent	2.37 ~	2.04	-0.33
	(1.25)	(1.9)	(1.5)
Industry Growth Rate(t)	4.17 *	2.23	-1.95
	(1.65)	(2.28)	(1.60)
N	133	133	133

*p<0.05 ~p<0.10

In model 1 and 2, omitted case is shut down but in model 3, omitted case is Survive.

Figure 6.19: Effect of absolute technological capabilities and technological advancement on exit (Multinomial logit results)

A positive coefficient implies that the odds (versus) shut down increase

A negative coefficient implies that the odds decrease

	Survive versus shut down	Sell off versus Shut down	Sell off versus Survive
Intercept	-471.20 *	-1627.90*	-1138 ~
	(204.40)	(659.80)	(656.60)
Absolute tech. Capability(t-1)	5.12 *	18.67 *	12.86 ~
	(2.23)	(7.37)	(7.24)
Complementary capability(t-1)	7.13 *	6.68 ~	-7.12
	(3.06)	(3.67)	(^)
Pre entry Capabilities	0.97	0.49	-0.43
	(0.74)	(0.87)	(0.45)
Entry Rank	0.17	0.15	-0.17
	(0.17)	(0.26)	(0.15)
Technological advancement(t-1)	4.62 *	16.45 *	11.65 ~
	(2.05)	(6.71)	(6.69)
Absolute tech. capability (t-1)* Technological advancement (t-1)	-0.05 *	-0.19 *	-0.13 ~
	(0.02)	(0.07)	(0.07)
Complementary capability (t-1)* Technological advancement (t-1)	-0.07 *	-0.07 ~	0.00
	(0.03)	(0.04)	(^)
Competition(t)	0.39	-0.10	-0.41
	(0.50)	(0.92)	(0.77)
Incumbent	2.34 ~	3.62	0.68
	(1.22)	(2.08)	(1.51)
Industry Growth Rate(t)	3.23 *	3.56 ~	0.11
	(1.26)	(2.10)	(1.58)
N	133	133	133

*p<0.05 ~p<0.10

^ implies the standard error is too large

In model 1 and 2, omitted case is shut down but in model 3, omitted case is Survive.

7. Discussion

I found a critical gap in the literature that also has managerial implications – how do firm capabilities affect firm performance as an industry evolves. After examining the issue in detail, I developed a theory to fill the gap and studied the US CT scanner industry in significant depth to test the theory. Qualitative and quantitative analysis demonstrated significant support for the theory. In this chapter, I will examine the implications of the findings.

7.1 Synthesis of research findings

In spite of extensive research on firm capabilities, we do not understand how capabilities affect firm performance as an industry evolves. This is a significant gap in the literature because it points to a potential limit of firm capabilities that has not been studied yet. Since capabilities are important to scholars because they enable firms to achieve their goals, potential limits of firm capabilities are also important to scholars. I also show that this gap is also important to managerial audience because it can guide resource allocation decisions regarding capability development. I alluded to a few examples from industry to show that the answer to this question would enable managers to allocate resources more effectively. I also discussed how effective resource allocation has ramifications beyond the boundaries of individual firms, making it an important topic for all stakeholders.

I hypothesized that in low complementarity contexts, as an industry evolves, the ability of core technological capabilities to drive firm performance should diminish. I argued that in low complementarity contexts, as technology in the industry advances, customer demand for better technology would tend towards satiation. As a result, customers would not value technological advance; customers would not pay for better technology, would not switch suppliers for better technology, and would not replace their previous purchases early to enjoy better technology. This would make core technological capabilities unable to drive firm performance.

I studied the US CT scanner industry in significant depth, from the inception of the industry up to 2002. A qualitative analysis showed that core technological capabilities indeed became less effective in enabling firm performance. A rigorous quantitative analysis using market share and survival as performance measures complemented the qualitative analysis. Across different models and varied operationalizations of key variables, I found consistent support for the theory. A similar result appeared across models for complementary capabilities – they also lose their ability to drive performance. I explained this finding to be a result of demand satiation for superior technology in the previous chapter. Finally, I also found support for the hypothesis that firm performance becomes persistent as the technology in an industry evolves. In the rest of this chapter, I will examine the various implications of this research.

7.2 Performance persistence versus capability gap persistence

This research has significant implications for the resource based view of the firm. The vast literature on resource based view (Barney, 1991; Rugman, 2002; Wernerfelt, 1984) posited that firm resources are valuable, rare, inimitable, and non substitutable. The gap in firm resources arises due to path dependent nature of resource acquisition by different firms. Furthermore, due to causal ambiguity and social complexity, capabilities are difficult to imitate. Rivkin (2000) used a N-K paradigm to model the impact of complexity on imitability of capabilities and found support for this notion. In short, a key implication of resource based view is that firms can maintain sustained competitive advantage due to persistence of capability gap.

However, my empirical research demonstrated that capability gap between firms did not remain persistent but narrowed over time. This finding is in line with the principle of isomorphism (Dimaggio & Powell, 1983) which states that firms become more like each other due to normative, mimetic, and coercive pressures. I measure capabilities by their outputs in a context where firms had incentive to produce outputs in line with the capability.

How do firms experience sustained competitive advantage if capability gap is not persistent? I find support for an alternate explanation – since capabilities lose their ability to drive performance and performance becomes persistent, the mechanism for sustained competitive advantage is not persistence in capability gap but persistence in firm performance.

For scholars, this implication is significant because it proposes an alternate explanation for a long observed phenomenon of sustained competitive advantage. This is a critical contribution to the resource based view literature.

A simple prescriptive result of this research would be for firms to achieve superior performance before customer demand tends towards satiation. However, this is not the only prescriptive output as I discuss in the later sections.

7.3 Demand Satiation

As demand satiation is the prime reason why capabilities lose their ability to drive performance in low complementarity contexts, I discuss this phenomenon in some detail here.

As an industry emerges, it is a result of emergence of demand for the product. Research has shown that the demand for products in the beginning of an industry is in flux; the customers are often unaware of what they are seeking in a product. Literature on judgment and decision making shows empirical evidence against well developed preferences (Bettman, Luce, & Payne, 1998; Coupey, Irwin, & Payne, 1998; Payne, Bettman, & Johnson, 1993; Payne, Bettman, & Schkade, 1999). Evidence shows that often the preferences are constructed rather than recalled. Furthermore, Hoeffler (2003) found that for new to the world technology, customers do not have well developed preferences; over time, customer develop stable preferences, and that the act of decision making leads to stable preferences.

These research findings imply that as customers purchase products, the demand for product features evolves before becoming stable. This is consistent with the literature on dominant design (Abernathy et al., 1985; Anderson et al., 1990; Christensen et al., 1998; Suarez et al., 1995; Utterback, 1996) that shows that the demand for a set of product features is in flux in the beginning of an industry; customer experiment with different designs. Eventually, the demand becomes firm and the expectations of customers from product become clear. At that stage, the direction of capability development also becomes clear for the firms.

However, customer demand is not homogeneous (Adner et al., 2001) and there is a range of product performance that is demanded in the market. Although the demand becomes firm in terms of the features customer look at to evaluate products, customers demand different levels of product performance. Moreover, this demanded product performance is also dependent on the supply conditions; customers cannot reliably predict the level of product performance when their demand would become satiated. For example, back in the early days of digital cameras, customers could not think of 5 and 7 mega pixel cameras because the barrier to cross 1 mega pixel appeared insurmountable with the then dominant CCD technology. Once CMOS technology appeared and made it possible to develop better resolution in consumer cameras did customers even begin to articulate the need for higher resolution. Similarly, in CT scanners, customers needed greater speed and greater picture quality but they could only work with what was available. In other words, as the latent demand is not visible, it would appear that the demand for a product performance actually evolves to higher levels across many industries. Eventually, once customers no longer value higher quantity of a product attribute, the demand shows signs of satiation.

From the above discussion, it is clear that although it is not possible to observe latent demand, there is a level at which customer demand would satiate. Two key factors can affect demand satiation process – complementary capabilities and complementarity.

Complementary capabilities influence the purchase criterion of customers by making some features of attributes of products salient and important. As a result, they can make a new feature valuable to customers or increase the performance level at which demand will satiate. Consider the mp3 player industry. Since the beginning of the mp3 player industry in 1998, customers have valued the disk space, music quality, and ease of use. As Apple satisfied the market's need for these three features, it added photo and video to the Ipod, thereby making consumers replace or switch from other mp3 players. However, other manufacturers of mp3 players also added these features to their players. Similarly, digital camera producers added features such as video recording, voice recording, and so on. Although, this addition of features may stimulate demand and prevent satiation, if competitors can easily imitate new features, it is unlikely that capabilities would drive performance. Consequently, it is not sufficient to add features and create demand for these features to enable capabilities to drive performance. There should be a barrier to imitation whether a real barrier such as patent or a perceived barrier such as capability gap. This was a key difference between digital camera industry and mp3 player industry. However, what enabled Apple to dominate the mp3 player industry was not addition of features that competitors could not add, but it was the use of second strategy of increasing complementarity in the industry.

Mp3 player hard disk size was a key benefit to customers; the ability to carry a music library on the go was a key benefit that made customers trade of the music quality in the first place (mp3 format in its early days was inferior to CD music). By adding podcast network and iTunes store, Apple added complementarity to its product. These interventions made customers increase the size of their music library and thus needed greater hard disk space.

The entire dissertation has been embedded in the context of low complementarity which allowed me to examine a context where external factors do not change the demand in the market place. Complementarity can affect demand satiation and thus provides a boundary for the theory. In high complementarity contexts, the evolution of the complement's technology leads to demand for higher product performance of a focal product. As a result, the customer demand for product performance is contingent on the state of the technology of the complement. For example, in the micro processor industry, the complementarity with computer operating systems and application softwares is very high. As newer operating systems and new softwares emerge, customers demand greater processing power and thus the demand for processing power in microchips does not appear to be satiated after 100% increase in processing power every two years for the last 30 years. As a result, in high complementarity contexts, it is possible that core technological capabilities continue to drive firm performance. When core technological capabilities remain relevant and enable customer switching, the value of complementary capabilities to retain customer must also remain. In short, it is likely that in high complementarity contexts, both core technological and complementary capabilities remain relevant.

From the discussion above, it is clear that potential for capability improvement and the complementarity in an industry can determine firm strategy. If the potential to improve core technological capability is high, a firm would stand to benefit in a high complementarity industry but would not see returns to its potential increase in core technological capability due to demand satiation. Such a firm should attempt to increase complementarity in its industry. On the other hand, a firm with low potential for capability improvement would find low complementarity industry more suitable than a high complementarity industry. Furthermore, such a firm should attempt to destroy complementarity in its industry to sustain a strong position. Apple appears to have followed this strategy successfully. In the digital camera industry, Apple did not possess the ability to infinitely improve its capability for greater resolution. As a result it exited the industry early on. However, in mp3 player industry, it created complementarity early on.

The discussion above points to an understudied area in the literature – how do firms change complementarity in their industry? Complementarity as a dimension of firm strategy would not only add to the literature but also help managers make better strategic choices.

7.4 Capabilities, satiation and Industry stability

This research has some interesting implications for industry stability literature too. The literature on industry stability (Klein, 1977; Klepper et al., 1990; Utterback, 1996), shows that industries often tend towards greater market share stability over time. Scholars have associated this tendency of industries towards greater stability as an offshoot of degree of innovation in an industry.

In line with the discussion on core technological and complementary capabilities, I argued that technological capabilities affect performance by creating utility for customers and by inducing customer to switch supplier. I also observed that complementary capabilities do not induce customers to switch suppliers but enable firms to retain existing customers. The key difference between the two capabilities is the degree of observability; customers and non customers can observe technological capabilities of a firm by observing the product performance but non customers cannot observe the complementary capabilities of a firm since this data is not publicly available. When these facts are observed from the perspective of tendency of industries towards greater market share stability, an interesting question arises.

Why do industries tend towards greater market share stability when core technological capabilities have a destabilizing impact on industry while complementary capabilities have a stabilizing impact? Since core technological capabilities induce customers to switch they also increase market share changes; since complementary capabilities enable firms to retain customers, they also reduce market share changes.

This research results answer this question as follows: As technology in a low complementarity industry evolves, it satiates demand for greater product performance. As a result, core technological capabilities no longer induce customers to switch, thereby losing their ability to increase market share instability. This is a capabilities based explanation for tendency of industries towards greater market share stability over time.

7.5 Shortcomings of this research

I achieved strong and supportive results in the quantitative section of the dissertation. The results remained consistent and robust when using relative and absolute capabilities, and when using survival instead of market share as the measure of firm performance.

Although this research makes a strong contribution to capability theory, it has some limitations which must be considered along with the robust results. First, a single industry study is less desirable than a multi industry study as generalizability of a multi industry study is usually higher than of a single industry study. Nevertheless, robust results in a longitudinal study of a single industry should be viewed as encouraging first step towards future research on the same lines. Second, due to a moderate number of firms within the industry, the sample size is moderate rather than large. Although the sample size is moderate, the significance level of results and consistent results across different operationalizations, show that there are strong reasons to believe the results.

Furthermore, the results of research are heavily dependent on the construct validity of the variables used in the research. In chapter 4, I had commented on the construct validity of dependent variables and the key independent variables. I had also given several reasons why there is sufficient reasons to believe that the construct validity of the key independent variables is sufficiently high. However, since there is a single source of data for core technological capabilities variable, it is appropriate to examine if the construct validity of this variable would remain high at all stages of industry evolution. In short, one must consider whether it is possible that the strong coupling between capabilities and product output can become weaker to an extent that the product output may not demonstrate the true capabilities of firms.

As demand satiation appears and customers begin to make price performance trade-offs could it be that some firms decide to produce at less than their capability levels? The answer to this hypothetical question can often be a maybe which can weaken the significance of results. As a result it is important to consider the details of the context of research to judge whether this issue could affect the results. In the CT scanner industry, when customers began to make price performance trade off, if some firms decided to not produce scanners to their maximum capability then one can question whether technological capabilities really became weaker drivers of performance.

There were three reasons why even when customers began to make price performance trade-offs, firms still gained from manufacturing some products at their maximum capability level.

First, although segmentation appeared in the industry, a firm with high capability would still benefit from competing in a small niche where its high capabilities allowed it to sell more profitable products. In short a firm with higher capability would gain from playing in a small high end niche because such niches are more profitable. In fact, firms continued to produce products at their capability level due to this. The qualitative analysis chapter showed that even later on firms continued to produce higher technology products even when only a smaller number of customers wanted such products. Since the technology of CT scanners was important to hospitals to demonstrate to patients that they had state of the art facilities, a small number of hospitals continued to buy high end scanners. This created sufficient incentive for firms with high capabilities to produce some products to manifest their true capabilities.

Second, firms with higher capabilities would benefit from producing some products at their maximum capability to develop a reputation for high quality. Such products allow a rub off of the high quality reputation on to lower end products. As a result, although most buyers wouldn't buy the top of the line scanners, high speed and resolution would give an aura of superior quality to all products of a firm. This created additional incentive to produce to the maximum capability level.

Third, at the margin, if firms didn't get returns from additional investment in technological capabilities such firms would not invest further and thus the product output would continue to be a good indicator of firm performance. I observed that firms are still trying to increase the number of slices per scanner although most hospitals are unable to buy such scanners. Currently, the top of the line scanners are so expensive that they surpass the annual capital budgets of most hospitals. To buy such as a scanner a small number of hospitals need to combine capital budgets across different departments such as Oncology, Radiology, Neurology, and Bariatrics.

The above reasons minimize any doubts about the construct validity of the technological capability level. At the same time, no future research can blindly assume that this would be the case in every context. As a result, scholars need to pay as much attention to their construct validity as I have paid in this research.

Finally, one must also raise the question about ease of imitation and its impact on the construct validity. If technology stops evolving, and knowledge spill over allows imitators to launch comparative products then wouldn't the product output be a bad proxy for technological capabilities?

The notion that an imitators somehow has lower capabilities than innovator has a logical flaw; if the ability to produce a product at a technological level is a result of technological capability, then the very fact that an imitator produces such a product, it is a result of underlying capabilities. If such capabilities were absent then imitator should not be able to product such a product. For example, Apple was not the innovator in the MP3 player industry but it could develop its capabilities as manifested by its continuously improving products. More recently, Microsoft has developed an MP3 player to compete with the iPod. But without some technological capabilities, would Microsoft have been able to product the player? Similarly, Amazon has come out with an E-Book reader that is similar to the E-Book reader that Sony developed does not show that Amazon has lower technological capabilities. If the technological attribute of a product has already satiated customer demand then the imitator will find that such imitation does not allow it to gain market share (as Microsoft has seen so far). But the product output would in no way show more capabilities than the imitator has. In short, even when demand satiation takes place and knowledge spillover leads to ease of imitation, the imitators may find it easier to build technological capabilities (that innovators built with a lot more effort) the technological capabilities would still be manifested by the product output.

7.6 Contributions and Implications for managers

There are important implications of this research for Scholars and managers. For managers, this research offers insights on efforts in capability development. It shows that if firms find themselves in low complementarity industries, they should track customer satiation to guide resource allocation efforts in capability development. On the same lines, if firms find themselves in high complementary contexts, they should plan to invest heavily in capability development. Furthermore, this research points to the fact that firms should consider ways of changing complementarity in their industry in line with their ability to improve their capabilities.

7.7 Contributions and Implications for scholars

For scholars, this research contributes to innovation literature, evolution literature as well as to capability literature. This research shows how the relationship between capabilities and performance, especially between technological capabilities and performance, changes as an industry evolves. It also shows how capabilities and their evolution explain the phenomenon of tendency of industries towards greater market share stability. Furthermore, it has given an alternate explanation for sustained competitive advantage.

Other than the above contributions, this research has contributed to a small but growing demand side literature in which significant potential exists. While most of the innovation literature has been a supply side literature, recent work by Adner and his colleagues (2002; 2001) and Christensen and his colleagues (1997; 1996; 1998) have been notable additions to the demand side literature on innovation. Demand side research on innovation has shown potential to enrich our understanding of innovation. For example, Klepper's (1996) work on product life cycle used supply side arguments to explain how the dominant mode of innovation would move from product innovation to process innovation as the industry evolves. Adner and Levinthal (2001) used a simulation model to show how different results can arise when using demand side arguments; they show that product and process innovation do not occur sequentially but rather occur concurrently.

Although I use the notion of product innovation and demand satiation in the same way as Adner has used it in the past, I raise a hitherto unanswered question. Moreover, I add to empirical research on demand side literature on innovation.

My demand side explanation of limits of technological capabilities not only adds to the literature and complements the existing supply side literature, but also shows some research avenues for the supply side view of innovation. It shows that supply side arguments must be considered from the lens of complementarity in an industry which has been underemphasized in that literature. Under which conditions would the notion of product innovation coming to an end find support when complementarity in an industry is high?

In short, this research adds to the demand side innovation literature, complements the supply side innovation literature and also shows future potential in examination of supply side literature in the context of complementarity in the industry.

Furthermore, this research shows avenues for important future research. First, scholars can test these propositions in different industries to further strengthen the capability literature. Second, it shows that there is potential for future research on how firms can change complementarity in their industry. Third, as internet enables non customers to get a better sense of complementary capabilities of firms, it would be meaningful to investigate whether emergence of internet would result in increasing returns to investments in complementary capabilities. Finally, it would be worthwhile to investigate the effect of capabilities on performance in a high complementarity industry.

In summary, this research adds to the capability literature by examining the conditions under which capabilities will affect performance and offers managerially relevant insights. It also opens up an interesting question of complementarity as a dimension of firm strategy.

7.8 Pragmatic resource allocation

After examining the question of resource allocation and conducting the research, we should now be able to answer the original question I had raised at the beginning of the research: What should Apple and Satellite radio players do to respond to the competitive threats?

When viewed from the perspective of this research, iPod is an example where the context's complementarity has been increasing. Originally MP3 player segment had low complementarity with any other products, but over time, Apple has successfully increased the complementarity of the segment through iTunes software and its music and video store. With the ease of purchase of single songs and videos, the need for higher hard disk capability has increased. With podcasting becoming popular, again the need for greater hard disk on MP3 player has increased. Nevertheless, the context of iPod cannot be considered that of strong complementarity. This is so because there is no specific complement whose technical advancement is resulting in decrease in utility from iPod. Moreover, there is little indication that hard disk space is driving replacement of iPods. As a result, Zune's competitive threat does not make a compelling case for Apple to allocate investment into hard disk capabilities. This is exactly how Apple responded – it introduced a 160GB iPod but put massive investments into the communication capabilities and launched the iPhone. As a result, while it had to drop prices in response to Zune's entry (during the last few years hard disk prices have come down significantly), it was able to charge a significant premium on the iPhone. So far, Zune has had little impact on the MP3 player segment while iPhone has been extremely successful with over 1 million units sold within the first few months.

Satellite radio industry also had a similar decision to make in response to the HD radio threat. Compared to the traditional terrestrial radio, High Definition radio has a significantly better sound quality. Furthermore, some stereophiles have complained about the quality of satellite radio sound. However, there is no evidence that high definition radio has better sound quality than satellite radio or that this sound quality is the key attribute that customer desire. Satellite radio has found customers because it provides bigger music selection without advertisements. Satellite radio industry however faces competition from iPod in a more meaningful way. Customers can carry their entire music collection and listen to it in their cars (or anywhere else). This makes iPod a bigger threat to satellite radio than HD radio. A bigger collection of music is unlikely to make satellite radio more attractive to the customers. As a result, satellite radio companies need to invest in new capabilities such as streaming video, weather forecasting, and GPS navigation to provide a complete platform for automobile travelers. Such a direction would appropriately handle the iPod threat. It would also increase the penetration of Satellite radios and make these companies profitable.

The fact that in both the cases above, the answer was to invest in new technical capabilities does not imply that this will always be the case. The fact that both the examples belonged to low complementarity contexts was a bigger reason to expect that demand satiation would occur and thus a need for new capabilities to improve performance.

In high complementarity situations the answer could be different. For example, in the microchip industry, AMD and Intel will have to continually invest in chip technology in order to successfully compete. It is clear that if one of them stops investing in chip technology it will lose market share to the other.

This shows how this research helps practitioners in better resource allocation decisions.

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