Disruptive Technologies: An Expanded View

by

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Abstract

The awareness of disruptive technologies and their potential effects on established firms was recently brought to the forefront of business thinking by Clayton Christensen in his book "The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail". While Christensen's work offers a fascinating view of technology change and the potentially lethal impact it may have on incumbent firms, his perspective on the contribution of technology change on product attributes and resultant firm disruption, appears, in my opinion, to be too limiting. The specific areas addressed by my thesis include:

- The expansion of Christensen's definition of disruptive technologies,
- An expanded understanding of the product attributes and subsequent competitive advantage that may result from the exploitation of an emerging technology,
- The role of market segmentation and technology interaction on the diffusion of an emerging technology and potential disruption of an incumbent technology,
- Inclusion of the potential for the down-market migration of products based on disruptive technologies in addition to the up-market scenario.

The objective of my thesis is to broaden the spectrum of outcomes associated with technology change in order to help firms formulate a more comprehensive technology strategy. A framework for thought is provided regarding the potential outcomes of the exploitation of an emerging technology (possibly disruptive) in the context of product attributes and market influence in which the reader is encouraged to consider his or her own experiences.

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David J. McGrath Jr. Prof. of Management and Innovation

I dedicate this work to my family;

To my wife Nancy,
for her patience with my frustrations,
her support of my endeavors,
her strength in raising three children alone over the past year,
and most of all, her persistent love.

And to my children, Happy, Adrian and Aaron,
that in time they will understand why I was away for the past year,
and that this experience will serve as an example,
that they too must continue to expand their horizons,
unfettered by imaginary constraints.

Table of Contents

Chapter 1 – Introduction

The awareness of disruptive technologies and their potential effects on established firms was recently brought to the forefront of business thinking by Clayton Christensen in his book "The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail"[1]. While Christensen's work offers a fascinating view of technology change and the potentially lethal impact it may have on incumbent firms, his perspective on the contribution of technology change on product attributes and resultant firm disruption, appears, in my opinion, to be too limiting. The objective of my thesis is to provide a broader understanding of the possible outcomes associated with technology change in order to help firms formulate a more comprehensive technology strategy. I will begin this study by providing an overview of Christensen's work.

In the book's introduction, Christensen describes his *failure framework* as consisting of three elements:

The first is a distinction between *sustaining* and *disruptive technologies. Sustaining technologies are those, which improve the performance of established products along dimensions of performance that mainstream customers in major markets have historically valued. Disruptive technologies are those, which generally underperform established products in mainstream markets. But they have other features that a few fringe (and generally new) customers value. Products based on disruptive technologies are typically cheaper, simpler, smaller, and, frequently, more convenient to use.* I will from here on refer to the performance of established products in mainstream markets as *traditional performance* and to the features valued by fringe customers as *ancillary performance.*

The second element is the potential for technologies to progress faster than the market demand, as measured by the traditional performance attributes of a product, and eventually overshoot the market need. This is depicted in Figure 1-1. These product technologies give consumers more than they demand and potentially more than they are willing to pay for This occurrence gives rise to an opportunity for a disruptive technology, which may underperform on the traditional performance dimension today, to enter the market and be fully performance competitive tomorrow.

The third and final element is that the investment by established firms in disruptive technologies is an irrational decision because 1) they are simpler and cheaper therefore offering lower margins; 2) they are typically first commercialized in emerging or insignificant markets – low volume opportunity; and 3) the firm's mainstream customers generally don't want and potentially can't use these products (because of reductions in traditional performance).

To substantiate his thesis, Christensen uses the evolution of the hard disk drive (HDD) industry (14 inch disrupted by 8 inch disrupted by 5.25 inch etc.) as his centerpiece example of disruptive technology and firm failure, and also uses a broad range of examples

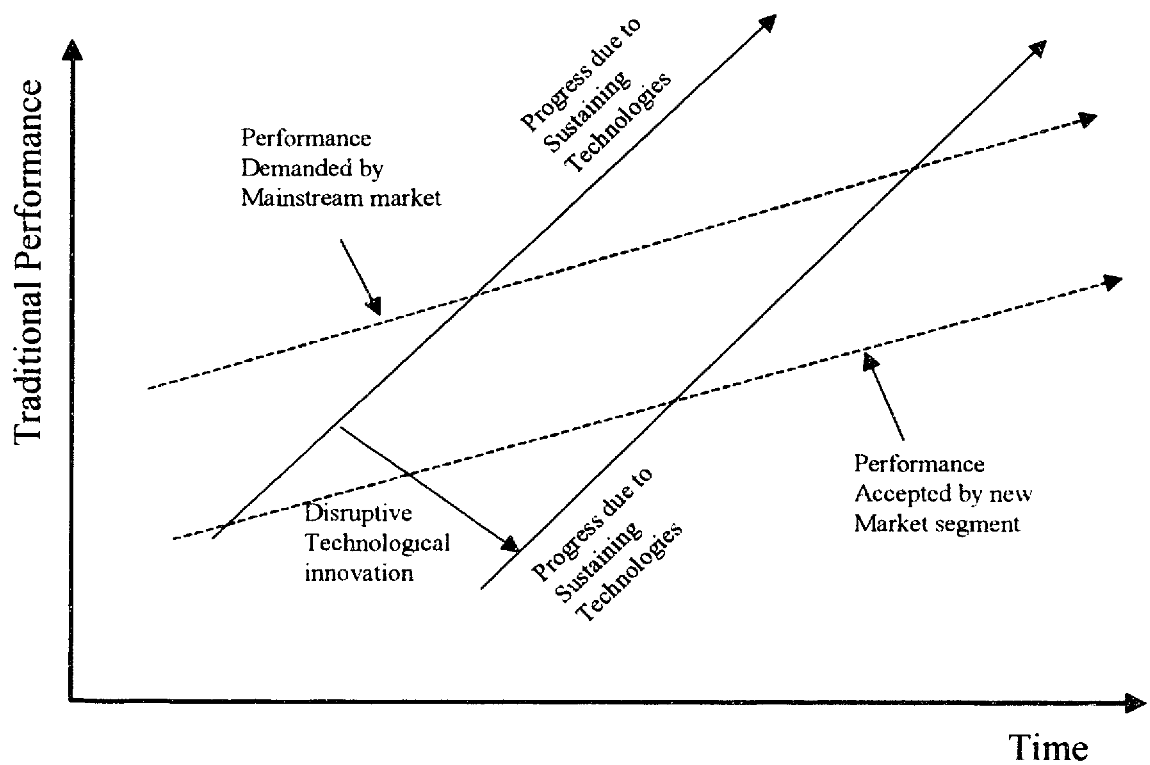

Figure 1-1. The impact of sustaining and disruptive technology change[1]

from the computer industry (mainframe disrupted by minicomputer disrupted by personal computer), the motorcycle industry (over-the-road disrupted by off-road), the excavator industry (hydraulic excavators disrupt cable excavators), and many others. In each case, a new technology resulted in a product that was lower in traditional performance than the incumbent product but was lower cost and offered greater ancillary performance. These products were championed by new entrants and sold in new market segments until the traditional performance was competitive in the mainstream markets allowing the new entrants to displace the established firms. The established firms typically knew of, and in some cases, developed the new technology but their customers were not interested in it and they could not see how to make money by offering it given their organization and cost structures.

While Christensen's insight into disruptive technologies has had a dramatic impact on the formulation of competitive strategy, it is my thesis that disruptive technologies may take other forms. That is, the source of competitive advantage attributed to a product offering based on an emerging technology may display disruptive tendencies outside the characteristics of reduced traditional performance, increased ancillary performance, and reduced cost as used by Christensen to define disruptive technologies.

Christensen also suggests that the ability of a new technology to upset incumbent firms is dependent on the development of a new market segment, outside of the mainstream market within an established industry. While this approach to mainstream market penetration is very sensible, it is my thesis that new technologies can penetrate an established market in other ways and that the approach is dependent on the composition of customer needs within each market segment.

To substantiate my thesis, I will first provide a review from the current literature on the subject of competitive advantage and the relationship between competitive advantage, value chain, technology development, and value networks. Secondly, I will present an argument for the expansion of Christensen's definition of disruptive technologies. With this expanded definition, I will provide a competitive advantage framework that will make it possible to categorize the potential impact of new technologies and I will provide a few cases within this framework and consider their disruptive tendencies on incumbent firms. Finally, from these cases, I will discuss the role of market segmentation, the diffusion of innovation, and the interactions of emerging and established technologies within a market context to provide insight into the disruptive tendencies of emerging technologies.

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[1] C. Christensen, "The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail", Harvard Business School Press (1997)

Chapter 2 – Competitive Advantage

To place disruptive technologies in the proper context, it is necessary to understand competitive advantage, both the strategies which give rise to and the sources from which it is derived, from the perspective of a firm and the firm's product. *Competitive advantage* is that increment of value a firm offers to it customers above that of its competitors thereby providing an opportunity for the firm to capture above industry average financial returns. Porter[1] describes two basic types of competitive advantage, cost leadership and differentiation, from which he defines three generic strategies that may be considered by a firm in order to achieve competitive advantage. Figure 2-1 displays these generic competitive strategies that consist of 1) cost leadership, 2) differentiation, 3A) cost focus, and 3B) differentiation focus. The cost leadership and differentiation strategies seek competitive advantage in a broad range of market segments, and the focus strategies seek cost or differentiation advantages in narrow market segments. Porter's[1] emphasis on generic competitive strategies highlights the need for a firm to make a choice and that trying to be "all things to all people" will often destine a firm to failure in that it will have no competitive advantage at all.

		Competitive Advantage	
		Lower Cost	Differentiation
Competitive Scope	Broad Target	1. Cost Leadership	2. Differentiation
	Narrow Target	2A. Cost Focus	2B. Differentiation Focus

Figure 2-1. Three generic competitive strategies[1]

Cost leadership may be obtained by a firm through economies of scale, proprietary technology, preferential access to raw materials, etc. The cost leader cannot ignore the bases of differentiation and must achieve parity or proximity in these attributes to the competition in order to be an above average performer. The strategy requires the firm to be the cost leader within the industry, not one of several firms, in which case its advantage may be lost. A firm may achieve differentiation by selecting one or more attributes that customers perceive as important, and uniquely position its product to meet those needs. The means for differentiation are peculiar to an industry and may be based on the product itself, the delivery system by which it is sold, marketing, or other dimensions. The firm, which is able to effectively differentiate, is rewarded for its uniqueness with a premium price. In the focus strategy a firm seeks a cost or a differentiation advantage focused on a specific market segment within an industry. The cost focus targets price sensitivity in some segments while the differentiation focus attempts to address the special needs of customers in some segments, both of which are underserved by an industry that is pursuing a broad (mainstream) market strategy.

2.1 Value Chain, Technology Development, and Value Networks

Now that we've explored the generic strategies of competitive advantage we must understand the potential sources of achieving competitive advantage within a firm. Porter argues that the competitive advantage of a firm can only be understood by looking at the discrete activities that a firm performs in designing, producing, marketing, delivering, and supporting its product. In order to achieve this view of a firm, it is necessary to introduce the framework of the *value chain,* which is depicted in Figure 2-2. The value chain breaks a firm into distinct value activities that are the building blocks through which a firm creates a product valuable to its customers. Porter[1] divides the value activities into two broad types, primary and support activities. Primary activities are those involved in the physical creation of the product and its sale and transfer to the customer as well as after sale assistance. Support activities support the primary activities and each other by providing purchased inputs, human resources, technology, and other firm wide functions. How each value activity is performed will determine whether a firm creates value for its customers through the dimensions of product cost or differentiation. It is possible to determine competitive advantage between firms by comparing their respective value chains.

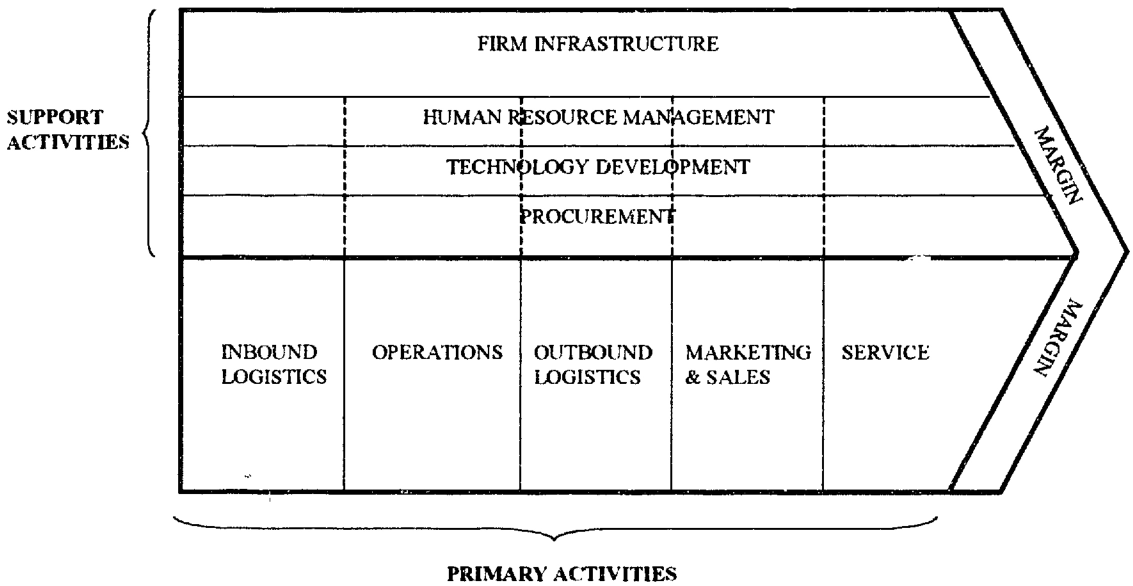

Figure 2-2. Generic Value Chain[1]

In that this thesis is focused on the value activity of technology development, I will limit my discussion to this area of the value chain. Technology development consists of the activities broadly associated with the efforts to improve the product and process. The term improvement refers to the ability of technology developments to enhance our competitive advantage inline with a firm's choice of competitive strategy. Product and process technology development has the ability to support any of the generic competitive strategies, that is, technology development can be exploited to lower product cost and/or enhance product performance attributes to fulfill the needs of the broad or narrow market segments. However, it is critical that the firm ensure that its technology development is not going in a direction that opposes its competitive strategy.

In addition to the ability of technology development to have a dramatic influence on the performance attributes typically associated with product differentiation, certain markets are prone to network effects, that is, the value provided to a firm's customer increases with the number of other users of the firm's product. As such, a market with network effects support a differentiation strategy in which consumers value the product based on its features and find additional value as a result of the number of increasing users. This increased value due to the number of users may come in the form of interoperability with other users (such as word processing software, MS Word) or the development of complementary assets (movies made in VHS format). These network effects are supported by common product standards that may be open (available to all competitors) or closed (proprietary). A firm that owns a standard and is successful at executing a differentiation strategy will find itself in a strong competitive position.

The importance of technology development and the resulting change to a firm's technology has a significant impact on the competitive advantage of the firm. It is therefore essential to understand the types of technology change (innovation) and how they affect the operation of the firm. Clark and Henderson[2] have classified the types of innovation along two dimensions as depicted in Figure 2-3.

Linkages between core concepts and components	**Core concepts:** Reinforced	**Core concepts:** Overturned
Unchanged	Incremental Innovation	Modular Innovation
Changed	Architectural Innovation	Radical Innovation

Figure 2-3. Innovation Type Matrix[2]

The horizontal dimension captures an innovation's impact on components and the vertical dimension captures its impact on the linkages between components. Clark and Henderson[2] believe that incremental and modular innovation is typically well supported by established firms in that these innovations are inline with their existing capabilities. They also have found that radical innovation destroys the usefulness of an established firm's component and architectural knowledge thereby creating a significant challenge in commercializing this technology for the established firm. Architectural innovation, while preserving most of a firm's component knowledge, creates a challenge to established firms because the focus of previous competition has revolved around component refinement based on a stable architecture. Once the dominant design, as defined by the Abernathy-Utterback[3] model of product innovation, has been established, the product architecture is basically fixed and firms cease to experiment and learn about alternate architectures. In fact, these firms are typically organized around their product's architecture and dedicate their resources to improving component technology as a means to gain competitive advantage. Innovation that changes the product architecture represents a major challenge to the established firm due to their knowledge and their organizational structure being tied to the old architecture.

It appears that incumbent firms may best support incremental and modular innovation while architectural and radical innovation may be best aligned with new entrants. I will consider these classifications when I explore the competitive advantage framework in the next chapter.

Within the technology development context, firms view their activities as supporting their product, which is a system comprised of components that relate to each other in a designed architecture. Therefore, a firm may be producing a component-product, which is system that is part of a larger system, or it may be producing an end-product, which is a system that operates within a prescribed environment of use. Christensen and Rosenbloom[4] describe this relationship as *a nested hierarchy of product architectures* and they use as one example the architecture of a management information system (MIS). They define the disk architecture to be nested within the disk drive architecture, which is nested within the mainframe computer architecture, which is nested within the MIS architecture This nesting of product architectures implies the existence of a nested network of producers and markets through which components (systems) at each level of the hierarchy is produced and sold to integrators at the next higher level in the product (system) hierarchy. Christensen and Rosenbloom[4] refer to this nested commercial system as a *value network*.

With regard to the value network, Dosi[5] suggests that value is defined by the dominant technological paradigm in the ultimate system of use in the value network. The metrics by which value is assessed will therefore differ across networks therefore affecting the rank ordering of the importance of various performance attributes of a firm's product.

In regard to consumer markets, the end-user values the end-product based on its ability to satisfy human needs within its environment of use. The attributes of the assembled product are formed by the performance of the component-products, which comprise its whole. This point accentuates the need for all organizations within the product hierarchy to listen not only to their direct commercial customers but also to the end-product consumers (end-users) and observe the changing patterns in the environment of use. An example of the changing environment of use, and subsequent market segmentation, is clearly visible in the computer industry as evidenced by the market progression from mainframe to minicomputer to desktop PC to laptop PC to handheld.

In regard to an industry, Christensen[6] observed that companies are embedded in value networks because their products generally are embedded, or nested hierarchically, as components within other products and eventually within end systems of use. Therefore, a product's architecture and its environment of use will shape the structure of the industry in accordance with the hierarchical relationship of the value network.

2.2 Overview

The intent of this chapter was to introduce concepts based on prior work for accessing the competitive advantage of a firm that operates within a specific industry. I started off by explaining the generic dimensions of competitive strategy available to a firm, and then moved to the value chain of the firm to examine the sources of competitive advantage with a focused discussion on technology development. Within technology development I introduced the innovation types and value networks and their respective influence on a firm and the industry as a whole. These concepts will assist us in the exploration of the characteristics of disruptive technologies to be addressed in the next chapter.

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[4] C. Christensen and R. Rosenbloom, "Explaining the attacker's advantage: technological paradigms, organizational dynamics, and the value network", Research Policy 24 (1995)

[5] G. Dosi, "Technological Paradigms and Technological Trajectories", Research Policy 11 (1982)

[6] C. Christensen, "The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail", Harvard Business School Press (1997)

Chapter 3 – Disruptive Technologies

Christensen's definition of sustaining and disruptive technologies must be questioned in that he defines an outcome of the use of technology in the form of product competitive attributes as we discussed in the previous chapter. This approach is circular in nature, whereby his study has to be correct by the very virtue of the narrow definition he provides for disruptive technology. In contrast, I believe the higher-level context of disruptive technology starts with a firm or group of firms providing a product based on some underlying technology. At some point in time an alternate technology is exploited to introduce a product that overshadows that of the previous product. This occurrence of product change enabled by technology exploitation *may* result in incumbent firms being eliminated by new entrants or it *may* result in an incumbent industry being made obsolete and succeeded by a new industry. This broad view of disruptive technology follows Schumpeter's[2] "process of creative destruction" and its application to the economics of innovation, and agrees with the basic premise of Christensen's treatise, that is, incumbents fail when new technology renders their core product and organizational competencies obsolete.

Based on these viewpoints, I offer the following definitions of sustaining and disruptive technologies; *sustaining technologies* are those that support the current technology paradigm and trajectory of an incumbent product design, in the case of an assembled product, or production process, in the case of a non-assembled product; *disruptive technologies* are those emerging technologies that deviate from the existing technology paradigm that support an incumbent product and result in the replacement of the incumbent product by a new product offering greater value. A disruptive technology may be recognized by a change in the dominant design of an incumbent product, as discussed in Chapter 2, in the case of an assembled product, or a change in the dominant production process in the case of a non-assembled product. A change in the dominate design or process is characterized as a change in product or process architecture in which known components are arranged in a unique way to form a new system (architectural innovation) or in which new components are arranged in a unique way to form a new system (radical innovation) as previously presented in Figure 2-3.

The disruptive technology *may* be exploited by new entrants giving them a product centric competitive advantage over incumbent firms. This advantage *may* result in the incumbent firms exiting this business. To a greater extent, a disruptive technology may render a majority of the value chain of all firms within an industry obsolete resulting in the demise of the incumbent industry. These scenarios make it is possible to visualize the varying scale of impact that the introduction of a disruptive technology may have on the economic landscape. The result simply cannot be confined to the displacement of incumbent firms by new entrants when the impact may be lesser or greater than the firm-centric perspective.

Dosi[3] introduced the concepts of *technology paradigm* and *technology trajectories* in his attempt to account for continuous and discontinuous technology change. He defined technology paradigm as " an "outlook", a set of procedures, a definition of the "relevant" problems and of the specific knowledge related to their solution". Technology trajectory is defined as "the direction of advance within a technology paradigm". Dosi was very critical of demand-pull and technology-push theories of technology change and promoted a more holistic view of technology change which is characterized by a complex structure of feedbacks between the economic environment (markets, governments, etc.) and the direction of technological change. Dosi notes that once established, technology paradigms have a significant exclusion effect, that is, the efforts and imagination of engineers and their organizations are focused in a rather precise direction and blind to other technological possibilities. As economic and social conditions change, they interact with the process of selecting new technologies, with their development, and with their eventual obsolescence and substitution. During these periods of change, the Darwinian process of selection may be observed as new companies attempt to exploit different technological innovations and markets perform as a system of rewards and penalizations thereby making a selection of the fittest. The change from one technological paradigm that has shaped a firm, as described above, to a new paradigm formed by economic and social change presents a significant challenge for incumbent firms.

3.1 Competitive Advantage and its Scope of Possibilities

Incumbent firms may be displaced by new entrants as a result of new technologies that provide the new entrant with a competitive advantage, as defined by the generic strategies described in Chapter 2, and coincidentally create a barrier to entry for the incumbent firm through the use of technology based competencies not present in the incumbent firm. Christensen defined disruptive technologies as a function of the change in the competitive dimensions broadly defined by the generic competitive strategies enabled by technology change. To substantiate my expanded definition of disruptive technologies and bridge the gap between the expanded definition and Christensen's definition I will consider the scope of competitive advantage relative to an existing product. If we consider the dimensions of cost, traditional performance, and ancillary performance, we can construct the matrix presented in Figure 3-1. Assuming cost and price are closely related, the consumer will consider the purchase of a product based on new technology if the perceived value is higher than the perceived value of the incumbent technology, and if the value of the performance associated with the new technology (ignoring psychological affects such as image) is equal to or greater than the price.

It can be reasoned that a new technology worthy of consideration will have an impact on cost, traditional performance, and ancillary performance, and for the sake of simplicity, this change will be limited to an increase or a decrease relative to an existing product without consideration of the magnitude of that change. Market perceived change is relevant to this discussion and its corresponding magnitude will be addressed in the detailed discussion of the specific cases described in this chapter. The matrix in Figure 3-1 presents cases representative of a change in product or process for some groups of competitive advantage factors, as a result of the introduction of a potentially disruptive technology (per the expanded definition). The examples were selected solely on product or process change and some level of market acceptance. The column titled "Firm Disruption" indicates the subsequent exit of some or all incumbents and entrance of new firms to the product area based on the introduction of the disruptive technology.

Repeating Christensen's definition of disruptive technologies: <u>are those, which generally underperform established products in mainstream markets, but they have other features that a few fringe and generally new customers value. Products based on disruptive</u>

technologies are typically cheaper, simpler, smaller, and, frequently, more convenient to use. In the first entry of the possibilities matrix I have entered Christensen's definition of disruptive technologies, that is, cost lower, traditional performance lower, and ancillary performance greater than current technologies used in mainstream market products. The example is the 3.5-inch versus 5.25-inch hard disk drive (HDD) used by Christensen.

Cost	**Traditional Performance**	**Ancillary Performance**	**Cases**	**Firm Disruption**
↓	↓	↑	Christensen 3.5" / 5.25" HDD	Yes
↓	↑	↑	**CD / vinyl album**	Yes
↓	↓	↓	**OSB / Plywood**	No
↓	↑	↓	Low price, focused perf.	
↑	↓	↑	Digital / film camera	?
↑	↑	↑	**Calc. / Slide rule** **Fuel injection / carburetor** **Nonimpact / impact printer** PC / typewriter Mech refrig / ice	Yes Yes Yes Yes Yes
↑	↓	↓	No market viability	
↑	↑	↓	Premium price, focused perf.	

Figure 3-1. The possibilities of competitive advantage due to technology change

The matrix is then expanded by all possible combinations of cost, traditional performance, and ancillary performance, and is simplified by assuming that there has to be a change in each and that the magnitude is immaterial. I have included cases for some categories, wherever possible, in order to substantiate the existence of potential disruptions with a combination of competitive advantage parameters outside that sighted by Christensen. The direction and magnitude of performance change and the qualification of performance as traditional or ancillary has been quantified, in some instances, in a subjective manner. The change in cost has been taken at the minimum cost (price) of the new technology up to the point of technology disruption (if it occurred) or at the present cost (price) relationship. Cost is a temporal issue based on experience curve reductions and a new technology may start out higher priced than incumbent technology but may fall under the price of incumbent technology as a result of production experience.

The matrix illuminates a few areas of interest, most notably the category in which all parameters are greater than the current technology. In addition, the category of lower cost and greater performance (both dimensions) contains a recent disruption of the CD over vinyl LP and tape recording media, and the category of all parameters less than current technology associated with the market relationship of oriented strand board (OSB) and plywood. In the following sections, I will address each of these categories, which appear to contain cases of technology disruptions by investigating the product, firm, and industry dynamics in an attempt to support my thesis.

3.2 Increased Cost and Performance Category

3.2.1 Hand held calculator versus slide rule

In the early 1960's the world's main method of mathematical calculation was performed with a slide rule, mechanical calculator, or paper and pencil.[4] The mechanical calculator was a complicated motor-assisted mechanical machine without electronic parts. They were called calculators rather than adding machines because a complex gear system allowed them to perform multiplication and division by repetitive addition and subtraction. In 1963 Bell Punch Co. LTD and Sumlock-Comptometer LTD of England introduced the "Anita" which claimed to be the first fully electronic desktop calculator that used vacuum tubes and weighed 33 pounds. Since the Anita was about the same size as a mechanical calculator, the major performance advantage was silence (no moving parts) and speed of calculation. In 1964 Sony Corporation claimed to develop the first all-transistorized desktop calculator, the MD-5, and later improved functional operations and operating systems that resulted in SOBAX (solid state abacus) that incorporated important features used in virtually all calculators (i.e. disappearing zeros to the left of displayed digits, floating decimal, rounding off feature, percentage computations and reciprocals). Sony unfortunately could not see its way to profitability in the calculator market and soon after left the business.

Subsequent development of display technologies and integrated circuits led to the 1971 introduction of a "cigarette pack" sized calculator by Bowmar in the US initially priced at $240. It was the lowest priced on the market and one of the smallest. It featured the standard four math functions (+,-,*,/), an eight digit red LED display, and rechargeable batteries. The integrated circuit and the keypad were both manufactured by Texas Instrument (TI) which was solely a parts supplier and not a rival calculator manufacturer. Bowmar's success resulted in the entry of numerous companies into the calculator market in 1972 as demand for the product began to soar. Hewlett-Packard (HP) introduced their first pocket calculator, the HP-35, the first pocket calculator with scientific (transcendental) functions in July of 1972. Soon after the introduction of the HP-35, in 1973, Texas Instruments launched the SR-50 Slide Rule Calculator for $170, well below the HP-35's price. Industrial Marketing[5] reported that: "In January (1971), 300 models were available from 37 companies. Costs have dropped in half from a year ago. Prices could go below $200 this year. The product is still not a consumer-product but its price is getting there." The HP-35 was originally priced at $395, was decreased to $295 in 1973, $255 in 1974, and $195 in 1975 and was discontinued soon after.[6]

During the 1970s numerous slide rule manufacturers existed including the likes of Pickett & Eckel, Sun, Keuffel & Esser, Post, Hemmi, Nestler, Aristo, Dietzgen, Staedtler, and numerous others.[7] Picket & Eckel literature from 1970 provides a matrix of slide rule model versus intended user group, from secondary school up to the professional engineering community. This sales information lists nine of the most popular aluminum rules priced from $6.95 to $29.95. As a result of the introduction of the HP-35 and subsequent competition in the scientific calculator market, slide rule sales plummeted. In

1975 Keuffel & Esser discontinued slide rule manufacture followed by numerous others including Aristo in 1978. The hand held calculator became the defacto means of portable mathematical computation.

The introduction of the scientific calculator, while priced significantly higher than the slide rule, displaced slide rule technology as a result of performance advantages that included greater accuracy and speed of calculation (although I'm sure some slide rule experts would not agree with this) which appear to be the slide rule's traditional performance considerations. The ancillary performance benefits of the hand held calculator over the slide rule include ease-of-use, ease-of-learning, visibility of output (no need to strain your eyes reading slide rule index lines), and greater functionality. The hand held calculator attacked the slide rule in its mainstream market, science and engineering professionals and students, and as a result of falling prices and ancillary performance attributes (most notably ease-of-use and ease-of-learning) rapidly expanded the calculator market into the mass consumer market.

By 1975 student use of the simple four-function calculator was in wide acceptance as the price broke the $20 barrier.[4] Datamation[8] reported in March of 1975: "It is estimated that as many as fifteen million HHCS (hand held calculators) were sold in the US last year. A visit to almost any major department store quickly reveals that the price differential between an inexpensive calculator and an expensive slide rule is quickly diminishing."

The displacement of the slide rule by the electronic calculator resulted in the elimination of the slide rule industry as a result of the comparatively radical innovation (as defined in Figure 2-3) of electronic technology over the traditional mechanical technology employed by the slide rule product. In this example the disruptive electronic technology resulted in overall greater product performance although at a higher price than the incumbent product technology. As a result, we may conclude that the performance demanded by the mainstream market was unmeet by the incumbent product technology and that the introduction of a new product technology, which fulfilled that unmeet need, was valued by the market as evidenced by the support of the higher product price.

3.2.2 Fuel injection versus carburetion

The early development of the automobile (dominant design) incorporated as a power source the internal combustion engine (ICE) based on the Otto cycle (4 cycle, spark ignition) and used a carburetor to control fuel delivery. The development of compression ignition by Diesel led to fuel injection delivery systems for compression ignition engines. The advent of WW II led to major developments in the use of fuel injection in aircraft power systems[9]. In 1957 Bendix Corporation is believed to produce the first commercial electronic gasoline fuel injection system for the AMC Rambler. In 1957, Chevrolet and Pontiac offered an optional 'Ramjet' mechanical port fuel injection system. On the Corvette it boosted output to the magic one horsepower per cubic inch, but it was not exactly trouble-free and was often replaced in the field with a big carburetor. In 1958, a limited edition Dodge 361 engine had Bendix electronic fuel injection, but less expensive mechanical injection was offered the next year. Robert Bosch GmbH licensed some fuel injection technology from Bendix and in 1967 introduced electronic gasoline injection into the automotive market with its D-Jetronic system that was installed in the Volkswagon 1600 Model 3 vehicles that were destined for California (which at this time had stringent emission standards)[10]. By 1976 fuel injection was standard equipment on Saab and Volvo vehicles and was being offered as an option on some GM vehicles. The premium price for fuel injection over carburetion was being sighted as $600-700 by these manufactures. GM offered fuel injection as standard equipment on the 1976 Cadillac Seville that had a list price of $12,500[11]. GM's first production vehicles offered with its version of fuel injection, Tuned Port Injection (TPI), was fitted to the sports car segment which included the Corvette, Pontiac Firebird and Trans AM, and the Chevrolet Camaro. GM claimed that TPI increased horsepower, torque, and fuel economy by up to 30% over carburetor systems. Independent laboratories verified these claims with the typical improvement in each area being approximately 35% better than carburetor systems[12].

The late 70s and early 80s saw mounting environmental pressure by US government legislators and increasing fuel efficiency concerns. The auto industry in response to these pressures adopted fuel injection as the primary fuel delivery system over carburetion. Bosch, which was traditionally a manufacturer of ignition and electrical systems (not carburetors), geared up fuel injection system production in its Charleston, South Carolina plant. Walbro Corporation, a manufacturer of carburetors for lawn mowers, weed whackers, and chain saws (not auto parts), entered the automotive fuel storage and delivery business. Pierburg AG, a European carburetor manufacturer, is now a throttle body manufacturer and competes with Walbro in products such as fuel pumps and fuel modules. The GM (Rochester Products Division) and Ford parts operations were also able to shift technologies from carburetion to fuel injection. However, some companies, like Holley, could not negotiate the change in technology and switched from carburetors to transmission control solenoids, emissions valves, and throttle bodies, resulting in a major contraction in the size of the firm[13].

Bill Zielke[14], Sales Director for Delphi Energy and Chassis Systems (previously GM Rochester Products) recalls Rochester Products development of throttle body injection (TBI) during the late 1970s. TBI used a single fuel injector incorporated into the throttle body resulting in the indirect injection of fuel into the engine combustion chamber. This approach eliminated the need for engine manufactures to modify the cylinder head(s) for installation of direct injectors, lowered the number of injectors per application, and allowed the use of a low-pressure fuel supply. The result was a low cost fuel injection system, on par with the cost of a traditional carburetor system, which achieved some of the performance benefits offered by direct fuel injection. At the time Rochester Products was licensing Bosch injector technology. In a move to strengthen Rochester Products technical base, GM merged the Division with the GM Diesel Equipment Group in Grand Rapids, Michigan whose products included the design and production of diesel unit fuel injectors. Rochester Products introduced its next generation of TBI, the Model 700, in the mid 1980s and the product was well received by vehicle manufacturers as a low cost solution to meeting emission standards. By the late 1980s Rochester Products ceased carburetor production and tougher emissions standards introduced in the early to mid 1990s, which TBI could not meet, resulted in direct injection as the dominant design in gasoline fuel delivery systems. Today, GM Rochester Products, now Delphi Energy and Chassis Systems, designs and manufactures a multi-point fuel injection (MPFI) system used by automobile manufacturers around the world.

In 1980 about seven percent of the cars in the US market were equipped with fuel injection which increased to 96 percent in 1990 to approximately 100 percent by 1993[10].

The changing operating environment of the automobile drove the adoption of fuel injection, that is, greater concerns for the environment and fuel conservation. Fuel injection provided the consumer with increased automobile traditional performance attributes of increased engine power, fuel mileage, and reliability along with the ancillary performance attribute of reduced emissions at a price premium over traditional carburetor systems. Fuel injection was a disruptive technology in that it dramatically differed from the incumbent carburetor based technology. Fuel injection represented an architectural change in the fuel delivery system as well as a change to the system components when compared to carburetion. As a result, this technology innovation is classified as a radical innovation according to Figure 2-3.

3.2.3 Non-impact versus impact printers

Personal computer printers prior to 1984 almost entirely used impact technology in which a hammer strikes a piece of metal or plastic type, pressing it against an ink ribbon and transferring its image to paper. Other impact systems replace the type with a matrix of needles whereby hitting the needles in the appropriate patterns, hammers print arrays of dots that look like letters or numbers. This technique is called dot-matrix printing. Impact printers were simple and sold for as little as a few hundred dollars in 1984, but were slow and noisy. Competing non-impact technologies included laser printers that use a laser beam to write text and graphics on a drum similar to those found in a copier and ink-jet printers that spray a fine ink mist from precision engineered nozzles[15]. Laser printers became available in 1979 but their prices, that exceeded $20,000, made them prohibitive to most companies. High printing speeds (in excess of 12,000 lines per minute), near letter quality print, and versatility (page layout, font, graphics, etc.) allowed laser printers to have a performance advantage over competing technologies but limited their application to large mainframe systems due to the high price[16].

In the early 1980s Hewlett-Packard (HP) was not associated with desktop printers. Impact technology was the prominent printer technology and vendors such as Epson, Diablo, and Qume dominated the market. In early 1984 Apple Computer introduced the first desktop monochrome printer, the LaserWriter. HP's Boise, Idaho division quickly followed by introducing its LaserJet printer, which incorporated Canon's LBP-CX print engine, in March of 1984 which could produce 8 pages per minute with 300 by 300 dot-per-inch (DPI) resolution text and 75 by 75 DPI resolution graphics with a list price of $3,495[17]. HP's Vancouver, Washington division then released its ThinkJet ink-jet printer in May of 1984 for $495[15] and was slower than the LaserJet, had lower resolution, and required a special thermal paper to improve print quality. Richard Hackborn, an HP Executive VP said in a 1993 interview with Business Wire, "The HP LaserJet set a new office-printing standard and began winning high praise and customer support immediately. I think it can be fairly credited with obsoleting the daisy-wheel printer."[18] HP has been the center of my discussion because it held between 48 and 62% of the laser-jet market from 1987 to 1995 for which we have data and was not in the desktop printer business prior to 1984. Competitors include IBM/Lexmark, DEC, Panasonic/Matsushita, Apple, Canon, TI, Epson, Okidata, etc[19]. The traditional performance of printing speed and resolution was higher for the laser printer when compared to incumbent impact printers, ancillary performance advantages including quite operation and the use of plain paper allowed the laser printer to displace impact technology at the upper end of the personal computer printer market despite the high price.

At the lower end of the computer printer market, dot-matrix impact technology continued to progress until HP's low-end ink-jet strategy developed. The use of thermal paper and poor resolution prohibited the adoption of the first ink-jet printers. Things changed as described by Hackborn, "It took a little longer with ink-jet, but with the introduction of the 300 DPI plain-paper HP DeskJet in 1988, we began displacing impact dot-matrix printers at the low end. Since 1990, we have seen explosive growth for our DeskJet printers, driven by ever lower prices and the addition of high-quality, plain-paper color printing capability. By 1992, the DeskJet 500 had become the best selling printer in the world in terms of unit volumes."[18] US government data presented in Table 3-1 confirms that the non-impact printer technologies have disrupted the incumbent impact printer technology, first lead by the success of the laser printer and then finished off by the refined ink-jet printer technologies.

Christensen[1] discusses the development of the laser and ink-jet technologies by HP in the context of ink-jet being disruptive to laser technology. His argument is that ink-jet printers are inferior to laser printers in the primary performance attributes of speed and resolution but have improved over time, thereby moving up market, and are displacing laser printers. I believe HP viewed their foray into the non-impact printer business as a disruption to impact printer technology. The introduction of the laser and the ink-jet printers, which came at the same time, was most likely a result of technology uncertainty on the part of HP and resulted in a means to satisfy the market spectrum (the various segments) thereby giving HP a dominant position in a market that it did not previously participate in. The available data indicates that the global laser market has been increasing over time, an estimated 411,000 in 1987 increasing to 2.8 million in 1995[19]. While indeed the ink-jet market has also been increasing in size and most likely is cannibalizing some of the laser printer market. US government data from the 1997 Economic Census[20] displayed in Table 3-1 indicates that US manufacturer shipments of impact printers declined from 1996 to 1997 while both laser printers and ink-jet printers increased for the same period.

	1996		1997	
	US Shipments	Value per Unit	US Shipments	Value per Unit
Impact	899,173	$713	768,436	$660
Laser	1,941,839	$1,002	2,427,245	$1,050
Ink-jet	5,523,120	$239	7,486,107	$202

Table 3-1. US shipments and value of computer printers[20]

The question remains: will ink-jet printers displace laser printers? Or: will both technologies continue to exist in harmony satisfying different market segments? Of course these are both questions with a limited time horizon in that being students of technology innovation we know it is inevitable that a shift in the technology paradigm is lurking in the future ready to obsolete our current printer products.

In closing, the categorization of the innovations discussed in this case appear to be radical in nature, in that, impact to non-impact technologies required a change in printer architecture and components. A comparison of laser to ink-jet technologies also results in the comparative classification of radical innovation due to architectural and component differences. However, the issue of performance and market segmentation is called into play in that the performance demanded by one market segment may continue to differ from that of another requiring the offering of both ink-jet and laser-jet technologies to satisfy the entire desktop market. This of course assumes that ink-jet technology will not be capable of meeting the performance attributes associated with laser-jet technology through sustaining technology advances. The future holds the secret to the outcome of this ink-jet versus laser-jet printer relationship.

3.3 Reduced Cost and Increased Performance Category

3.3.1 Compact disc (music) versus vinyl LP

The compact disc technology trek is an interesting collection of events that began in 1841 with the great mathematician Augustin-Louis Cauchy who first proposed the sampling theorem. Nearly 80 years later J.R. Carson published a mathematical analysis of time sampling in communications. In a 1928 lecture at the American Institute of Electrical Engineers Harry Nyquist provides proof of the sampling theorem in "Certain Topics in Telegraph Transmission Theory" and in 1937, A. Reeves proposes pulse code wave modulation (PCM). In 1948, John Bardeen, William Shockley, and Walter Brattain invent the bipolar junction transistor at Bell Labs--compact digital circuitry is a reality. Two years later, in 1950 Richard W. Hamming publishes significant work on error correction and detection codes. In 1958 C.H. Townes and A.L. Shawlow invent the laser and in 1960 R.C. Bose publishes binary group error correction codes. That same year I.S. Reed and G. Solomon publish error correction codes to be used in the CD player 22 years later. Also early computer music experiments take place at Bell Labs. Fifteen years before consumers see the first player, NHK Technical Research Institute publicly demonstrates a PCM digital audio recorder with a 30 kHz sampling rate and 12-bit resolution. Two years later, Sony Corporation demonstrates a PCM digital audio recorder with a 47.25 kHz sampling rate and 13-bit resolution.

A hemisphere away, Dutch physicist Klaas Compaan uses a glass disc to store black and white holographic images using frequency modulation at Philips Laboratories. Four years later, in 1973, Philips engineers begin to contemplate an audio application for their "video" disc system. A prototype disc with a 44 kHz sampling rate is run through a 14-bit digital-to-analog converter and exhibits a signal-to-noise (S/N) ratio of 80 dB in monaural. Now a research frontier, Mitsubishi, Sony, and Hitachi all demonstrate digital audio discs at the Tokyo Audio Fair in 1977. One year later, Philips joins with its recording subsidiary Polygram Records to develop a worldwide digital audio standard. In March 1979, Philips demonstrates a prototype compact disc player in Europe. Sony joins the Philips/Polygram coalition after Matsushita declines. In June of 1980, the coalition formally proposes their CD standard. A year later in 1981, Sharp successfully mass produces the semiconductor laser. This step was crucial to delivering a consumer product. In the fall of 1982 nearly 150 years of work comes to fruition and Sony and Philips introduce their respective players to consumers in Europe[21]. The system is introduced in the United States in the spring of 1983 and 30,000 players and 800,000 compact discs are sold that year[22].

Up to this point in time, audio storage was analog in nature and primarily comprised of the use of long playing (LP) records (vinyl). The LP stores its information as an analog groove where variations in its side-to-side amplitude and depth represent the original audio signal. A stylus runs through the groove and the phone cartridge converts the stylus's mechanical movements into an electrical signal that is amplified. The very nature of the analog signal leads to its own shortcomings. In the analog domain, any waveform is allowable; therefore the playback mechanism has no means to differentiate noise and distortion from the original signal. Further, in an analog system every copy made introduces more noise than its parent. This fact is due to both the playback and recording mechanism that must physically contact the media, further damaging it after every pass. Every analog system also carries the side effect that the total system noise is the summation of all distortion and noise from each component in the signal path. Finally, analog equipment is of limited performance, exhibiting: an uneven frequency response (which requires extensive equalization), a limited 60 dB dynamic range, and a 30 dB channel separation that affects stereo imaging and staging[22].

The advantage of the digital audio signal is that noise and distortion can be separated from the audio signal. A digital audio signal's quality is not a function of the reading mechanism or the media in a properly engineered system. Performance parameters such as frequency response, linearity, and noise are only functions of the digital-to-analog converter (DAC). Performance parameters indicative of a digital audio system include full audio band frequency response of 5 - 22,000 Hz, 90+ dB dynamic range, and a flat response across the entire audio band.

The final strength of digital audio is the circuitry upon which it is built. First, due to a large degree of circuit integration digital circuits do not degrade with time as analog circuits do. Further, for all practical purposes, a digital signal will suffer no degradation until distortion and noise has become so great that the signal is out of its voltage threshold that has been made intentionally large expressly for this reason[21].

In short, the traditional performance attribute of sound quality is better for a compact disc compared to an LP (however, audiophiles will debate this statement due to the loss of some harmonics due to the artificially fixed 20 hz to 22kHz reproduction frequency range)[23]. The ancillary performance of increased play durability, reduced handling damage susceptibility, and compact size yields higher compact disc value.

The issue of cost for the CD system deviates from previous examples in that the system is comprised of two components, the player or hardware, and the music media or software (the actual disc with recording). In regard to hardware, Shibata[24] recounts that the first players were designed as full audio components to replace LP players in stereo systems. The high price of the CD player relative to an LP player and the existing LP software libraries owned by individuals limited CD system sales during its introduction. In 1984 Sony introduced the Discman and subsequent introduction of CD radio-cassette players and car CD players enhanced the value of the CD system by allowing the CD to go where the LP could not. Sony, who was also a major supplier of "key components" (such as optical pick-up, laser diode, and LSI) to the hardware manufacturers began to lower prices based on anticipated experience curve effects allowing the reduction in hardware prices. This combination of hardware prices approaching that of traditional LP hardware and promotion of the ancillary benefit of mobility spurred the market for CD systems.

In regard to software price, the compact disc price in 1983 was approximately twice that of an LP. In 1994 the price of a CD was still slightly higher in real terms than the 1983 LP price while the cost to manufacture the CD had dropped well below that of an LP. One explanation is that in the years following the introduction of the compact disc, the large consumer electronics companies like Sony, Philips, and Matsushita bought up the record companies. By the end of the 80s the record industry was more or less owned by the consumer electronics industry. Despite the high prices, unit sales of CDs hit 500 million in 1993 versus 209 million LPs in 1983[25]. US shipments of music CDs in 1998 hit 847 million units at an average price of $13.50 versus 3.4 million units of vinyl records at an average price of $10.00[26]. The advent of the CD made it possible to make money on low volume recordings and as a result increased the breath of music offering thereby earning greater value for consumers. The market has therefore accepted the higher price in return for a greater offering[25].

In summary, the compact disc technology offered greater traditional and ancillary performance than the incumbent analog LP technology while commanding a higher price, in light of the fact that disc costs are lower. This price / cost issue deviates from previous examples in which price and cost tend to track each other relatively closely. This study is more concerned with the price in that it is the metric directly associated with the value consumers place on the new technology. The CD is considered a radical innovation in that the architecture and components are significantly different when compared to the incumbent LP technology.

3.4 Reduced Cost and Reduced Performance Category

3.4.1 OSB versus plywood

Montrey and Utterback[27] have examined innovation in the structural wood panels market leading to the introduction of OSB and waferboard as substitutes for plywood and provide a historical overview of these developments. After World War II, plywood, which had been introduced over forty years earlier, began to be utilized in light frame construction in increasing volumes in North America. The structural flexibility inherent in the plywood panel and its lower overall installed cost resulted in the displacement of lumber as the dominant sheathing material for floor, wall, and roof construction. Rapidly increasing timber prices through the 1970s and early 1980s resulting from shortages of adequate timber to produce the plywood veneer coupled with increasing labor, energy, and adhesive costs resulted in severe plywood price inflation during this period. Known and rapidly developing processes for the production of particleboard and fiberboard had demonstrated the ability to produce flat structural panels that could potentially be a substitute to plywood. These process technologies along with declining plywood quality, abundant timber sources suitable for particleboard fabrication, and new product performance standards provided an impetus to new structural panel development. Three basic product types emerged as plywood substitutes, waferboard, COM-PLY, and oriented strand board (OSB). OSB is of most interest due to its low cost relative to plywood (approximately 40% lower variable cost in the 1980s) and its greater performance compared to waferboard.

OSB is an unveneered structural panel comprised of three layers of aligned strands which are similar to wafers but possess length much greater than width. The strands are basically wafers that have been split across the wood grain so that they are much longer in the natural grain direction than across the grain. The strand layers then alternate direction to give OSB a construction that mimics plywood. The OSB strands are bonded using a liquid phenolic resin.

The OSB alternative offered a lower cost (price) when compared to plywood due primarily to the use of lower cost timber. As a result of these panels being load-bearing members in end-use, the traditional performance measure is strength and stiffness, of which, OSB is slightly less than that associated with plywood. The ancillary performance of the structural panel is weight, dimensional stability, and durability. OSB is heavier than plywood, is more prone to thickness swelling, and OSB durability is slightly less than plywood. In general, OSB ancillary performance is lower than that of plywood.

In 1979 total US plywood production (including COM-PLY) was 23.1 billion square feet, while waferboard capacity in Canada and the US together totaled 844 million square feet. OSB, which was commercially introduced in 1981, had no production in 1979. A 1996 report by Forest Products Journal[28] indicated that COM-PLY panel production that began in the mid-1970s had been reduced to a single plant in Oregon and that waferboard had been replaced in a large part by OSB. OSB production on the other hand has been increasing dramatically. North American production figures[29] presented in Table 3-2 display the growth in OSB production and that the structural panel market became evenly split between plywood and OSB in 1998. In June of 1999 the Engineer News Record (ENR)[30] reported the price of 15/32 inch, 3-ply exterior southern plywood at $380 per thousand square feet while a comparable OSB product at $310 per thousand square feet.

	1987	1992	1996	1998
Soft Plywood	23.3	19.3	21.2	19.7
OSB	3.7	6.7	14.7	19

Table 3-2. North American structural panel production (billion sq. ft.)[29]

The case of OSB and plywood differ from previous cases in that a structural panel is a non-assembled product and that technology innovation is more concerned with the process than the product. The development of new process technologies allowed structural panel manufacturers to produce a low cost, plywood substitute. However, the plywood producers retaliated by making process improvements that lowered their production costs thereby remaining competitive with OSB. The major issue for plywood is veneer timber price and availability, which continues to push plywood into higher value products leaving the market for sheathing, subflooring, and other basic building materials to OSB.

While the advent of OSB process technology has resulted in a product, which appears disruptive to plywood, I have labeled this case in Figure 3-1 to be non-disruptive at the firm level. I believe this to be the situation in that the production of OSB is not exclusive to that of plywood, which becomes a plant investment decision. A wood products firm such as Weyerhauser can decide to be a plywood and an OSB manufacturer in that the production and process technology required for one of these products is plant dedicated, that is, a plant will manufacture one or the other. This allows a wood products firm to avoid disruption by playing both sides of the product game should OSB take a majority of the structural panel market from plywood.

3.5 Overview

In this chapter I began by expanding the definition of disruptive technologies to include technology change that results in the displacement of an incumbent product by a new product thereby resulting in the creation of a new dominant product design in the case of an assembled product or a new dominant process design in the case of a non-assembled product. I then created a three factor competitive advantage framework, originally suggested by Christensen's definition of disruptive technologies, that includes all possible changes in product cost, traditional performance, and ancillary performance. I used a limited sample of case studies to support the framework in which technology change resulted in a product disruption in some cases and in a firm disruption in others. While this competitive advantage framework hopefully allows the reader to broaden his or her understanding of disruptive technologies, it certainly only begins to open the door to a comprehensive understanding of technology change. In the next chapter I will introduce some of the issues of market dynamics associated with technology change and the implications associated with disruptive technologies.

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Chapter 4 – Markets and Technology Disruptions

As I have mentioned in Chapter 1, Christensen[1] suggests that the ability of a new technology to upset incumbent firms is dependent on the development of a new market segment, outside of the mainstream market, within an established industry. This new market segment is assumed to be more price sensitive than the mainstream market, it is willing to sacrifice the level of traditional performance as measured by the mainstream market, but requires ancillary performance not valued by the mainstream market. Once the new entrant establishes and gains a foothold in this new market segment, traditional performance improvements made by sustaining technology development allows the new entrant to move into the mainstream market with a lower cost / price product which meets the traditional performance demanded by the mainstream market. The new product and entrant firm then displaces the incumbent product and firm.

Christensen's example of the 3.5 inch HDD overtaking the 5.25 inch HDD begins with the development of the 3.5 inch HDD by the Scottish firm Rodime in 1984 and sales of this architecture becoming significant when Conner Peripherals started shipping product to Compaq computer in 1987 for use in portable and laptop computers. The architecture of the 3.5-inch HDD pushed some functionality into the electronic hardware / software domain and away from that previously performed in the mechanical domain which allowed this new product to be lower in weight and size, and more rugged (necessary for mobile computing) while enjoying a lower production cost. As an aside, the advent of digital electronics has allowed the migration of product technologies from the mechanical domain to the electronic hardware / software domain allowing increased product functionality at lower cost. This recurring theme is evidenced in various assembled products from the automobile to the washing machine and represents a broad technology paradigm shift.

Compaq, founded in 1982, was a major force in establishing the mobile computing market segment that had begun just prior to the availability of the 3.5-inch HDD. Conner and its competitors saw an opportunity to fulfill a need and Compaq was so interested in enhancing their product they helped Conner get in business with a $30 million investment and the purchase of all of Conner's first year of production. The point here is that understanding market segmentation, whether infant or mature, is essential for the success of any technology and its associated product(s). In the case of component suppliers, like the HDD firms, their product is a subset of the final assembled product produced by an OEM. Therefore, the component suppliers' decision to pursue a technology that satisfies the needs of a new market segment is based on the confidence they have in the OEM's market decisions. In addition, that while the cost of the product may have the potential to be lower than incumbent product technologies; price may be higher if the demand for the ancillary performance features is of sufficient value to that market segment. As such, cost and price are not always related as we have seen in the case of the compact disc. To assist in the understanding of interactions between product markets and emerging and established technologies, I will propose a conceptual framework that attempts to map these potential interactions. I will then apply this framework to some of the cases discussed in Chapter 3.

4.1 The Nature of Technology Interaction

Pistorius and Utterback[2] have proposed that the market interactions between established and emerging technologies are multi-modal in nature. That is, the typically classified "competition" (confrontation) between established and emerging technologies is just one dimension of the possible market interactions. There are many cases where technologies interact in a relationship that is not confrontational or competitive and these added dimensions of market interactions must be considered in the formation of an effective technology strategy. Pistorius and Utterback[2] define the following three major interactive modes:

- *Pure Competition,* where an emerging technology has a negative influence on the growth of a mature technology, and the mature technology has a negative influence on the growth of the emerging technology;
- *Symbiosis,* where emerging technology has a positive influence on the growth of a mature technology, and the mature technology has a positive influence on the growth of the emerging technology;
- *Predator-prey,* where an emerging technology has a positive influence on the growth of a mature technology, and the mature technology has a negative influence on the growth of the emerging technology; or where an emerging technology has a

negative influence on the growth of a mature technology, and the mature technology has a positive influence on the growth of the emerging technology.

These three distinct interactive modes allow the formation of a matrix of possible interactions when considering two predator-prey interactions can occur depending on which technology is the predator and which is the prey. The interaction matrix is presented in Figure 4-1.

		Effect of emerging on established tech growth rate	
		Positive	Negative
Effect of the established on emerging tech growth rate	Positive	Symbiosis	Predator (established) Prey (emerging)
	Negative	Predator (emerging) Prey (established)	Pure competition

Figure 4-1. Multi-mode framework to assess technology interactions[2]

This framework gives us the opportunity to expand our views of the market events surrounding the introduction of a new innovation by considering the effects of emerging and established technologies on one another's growth as well as the transitory effects as the interaction between the technologies shifts from one mode to another with time. Pistorius and Utterback[2] suggest that the element of time may be referenced to the three stages of the technology life-cycle or the progression of an s-curve which is often characterized as ferment or fluid stage, growth or transitional stage and the mature or specific stage. I will revisit this temporal application of the multi-mode framework after the introduction of a few additional market concepts.

4.2 Market Segmentation and the Diffusion of Innovation

Kardes[3] provides the following insight into market segmentation, which involves dividing a market into subcategories and pursuing different product or service strategies for each subcategory. There are many ways to segment a market. They include dividing groups of consumers into subgroups of consumers, dividing groups of products into subgroups of products, or dividing groups of situations into subgroups of situations for example. Segmentation is a multi-product strategy, that is, different products for different subgroups and aggregation is a single product strategy, that is, a single product for the entire market. The most important reason for segmenting is consumer preference heterogeneity, or variability in consumer preference. As preference heterogeneity increases, the case for segmentation increases in strength. Segmentation from a preference heterogeneity perspective represents the demand side of the equation. On the supply side of the equation is the sales-cost tradeoff. Product segmentation increases costs for a firm because different manufacturing equipment, skills, and resources may be needed and reduced economies of scale to produce the expanded product offering may result. Therefore, a firm or group of firms must evaluate the sales-cost tradeoff when segmenting a market.

Understanding the preference heterogeneity of a market and the sales-cost tradeoff is helpful in determining whether and how much to segment. To determine how to segment requires an understanding of the dimensions on which consumers differ known as the bases of segmentation. These include: *geographic segmentation* which involves segmenting on the basis of cultural differences among consumers living in different geographic regions; *demographic segmentation* which involves segmenting on the basis of gender, age, education, income, household size, marital status, etc.; *psychographic segmentation* which involves segmenting on the basis of personality characteristics, attitudes, beliefs, or lifestyles; and, *behavioral segmentation* which involves segmenting on the basis of usage situation or usage frequency.

The segmentation of a general market is essential to the successful introduction of a disruptive technology. To use an analogy, it is an essential element of strategy to decompose a war into a series of battles that allow the limited tactical resources of an army to focus its efforts on a manageable event, a single battle, with a successful outcome allowing it to progress to the next event or battle. Market segregation allows a firm, especially a new entrant, to focus its limited resources on a limited population of a market which it believes to be most accepting or in need of the new product technology. This approach, if successful, provides the new entrant with a foothold that it may leverage to attack the next most vulnerable segment. Cooper and Schendel[4] note that a future assessment of technology change and market acceptance must consider the differences in the needs of market segments and relate these to probable improvements in the new technology. They have found that some market segments in a traditional industry are threatened earlier by a new entrant and to a greater extent than others.

Rogers[5] noted that not all individuals in a social system (or market) adopt an innovation at the same time. Rather, they adopt in a time sequence, and they may be classified into adopter categories on the basis of when they first begin using a new idea. Rogers took the bell-shaped curve of adoption frequency derived from the s-curve of cumulative adoption and sectioned it into categories of adopters as shown in Figure 4-2.

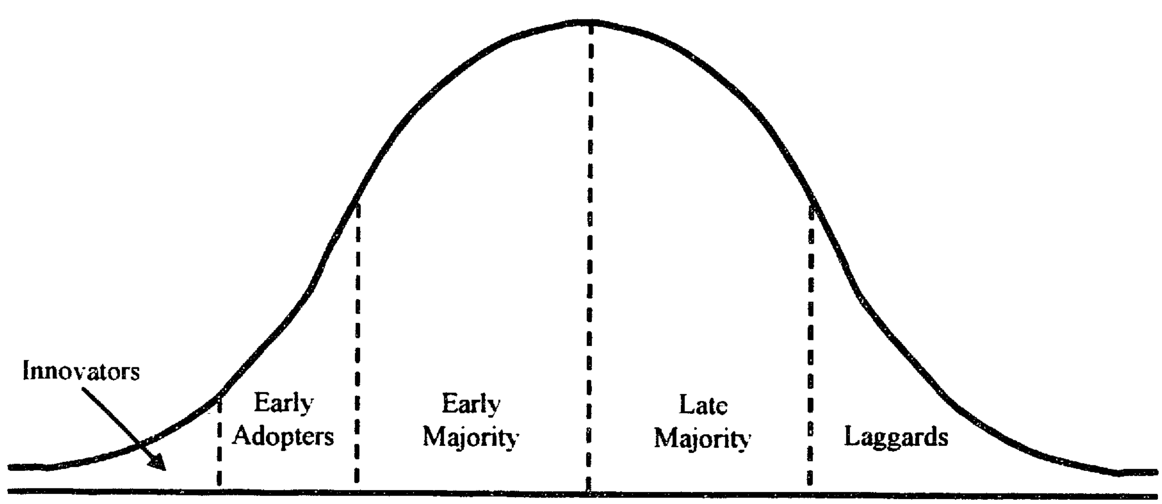

Figure 4-2. The innovation diffusion process and adopter catagorization[5]

The categories are defined as: *innovators* who are the venturesome individuals who are eager to try new ideas while accepting the high degree of uncertainty associated with this unproven innovation. Members of this group are not necessarily respected by the social system; *early adopters* are the group that looks for a more stable innovation than the innovators and are more tied to the social system and are considered opinion leaders. The early adopter is considered by many as "the person to check with" before using a new idea; *early majority* is the group that adopts a new idea just before the average member of the social system. They follow with deliberate willingness in adopting innovations, but seldom lead; *late majority* is the group that adopts a new idea just after the average member of a social system. Their relatively scarce resources mean that almost all of the uncertainty about a new idea must be removed before they feel that it is safe to adopt; and, *laggards* are the final group in a social system to adopt an innovation. They tend to be suspicious of innovation and change agents. Their traditional orientation slows the innovation-decision to a crawl, with adoption lagging far behind awareness-knowledge of a new idea.

I believe, in concept, the existence of a relationship between market segmentation and the diffusion of innovation. In Christensen's[1] description of the innovation cycles associated with the HDD industry each new HDD was driven by the development of a new computer system that created a new product market segment based on psychographic and behavioral factors. During the creation of the new computer system and the subsequent market segment, such as the desktop personal computer or the laptop, it is easy to visualize individuals representative of the early portion of Rogers[5] diffusion curve working with the new computer system, inclusive of the new disk drive. It is a natural opportunity to package a new component with a new system that is serving a new market segment. The diffusion process starts a new in the new market segment somewhat isolated from the mainstream or established market segments whose constituents are typically dominated by the early and late majority. Once the new market segment passes the product into the early majority category and traditional performance increases, the component innovation is safe to move into the established market segments.

However, it also is possible to consider established market segments somewhat aligned with the diffusion curve categories. To simplify this relationship let us reduce the diffusion curve into two groups, the leading edge, the innovators and adopters at the beginning of the curve, and the trailing edge, the late majority and laggards at the end of the curve. Now consider the automotive industry and the hi-performance or sports car segment. This segment typically represents the leading edge of the diffusion process in that they are interested in performance gains provided by component innovations and are less sensitive to the risks associated with their early use. In the luxury segment there exists a desire and an expectation to be first with a new feature and a willingness to pay for being first, another leading edge group relative to certain types of innovation. In fact the fuel injection system discussed in Chapter 3 was first introduced in the luxury and sports market segments and was then slowly diffused into other market segments.

It appears that a relationship may exist between market segmentation and the diffusion of an innovation. In Christensen's[1] theory of disruptive technology, the establishment of a new market segment acts to channel the new product to the leading edge of the diffusion process. Once the innovation reaches the early to late majority of the new market segment it is ready to compete in the established market segments, or as he describes, the product moves up-market. In my expanded view of disruptive technologies, I present a scenario in which higher performance and priced innovation is introduced into established market segments and the product moves down-market. Diffusion of the product innovation, in the case of fuel injection started with the luxury / sports segments and migrated into the other established segments, and in the case of hand held calculators started in the scientific community and expanded the overall market by creating new segments which included the mass consumer market, again, in a down-market progression. Cooper and Schenel[4] discuss the down-market progression of the ballpoint pen which was originally more expensive than the fountain pen but continued development resulted in the "throw-away" pen which opened up new market segments.

In both the Christensen and the expanded view of technology disruption an understanding of the link between market segmentation and diffusion of innovation appears to be a prerequisite to the successfully introduction of an innovation. The creation of a new market segment is crucial to the successful diffusion of Christensen's disruptive technology theory and the existence of a market segment willing to experiment (leading edge of the diffusion curve) is crucial to the successful diffusion of at least one theory of the expanded view. This conclusion is based on subjective market observations and more objective data is required to substantiate this potentially strategic market relationship.

4.3 A Technology and Market Interactions Framework

I will now propose a framework that attempts to consolidate the concepts of technology change and market interaction as discussed previously mapped over the life stages of innovation. Afuah and Bahram[6] have mapped the stages of innovation as a function of the value-added chain in what they call the hypercube of innovation. In addition, Daghfous and White[7] have mapped the stages of innovation as a function of enterprise information, market applications and, product / process in order to produce a multi-dimensional model of innovation outcomes. My proposal is to construct a 3x3 matrix in which the vertical axis is the emerging (potentially disruptive) technology life-cycle broken into three stages, ferment, growth, and maturity. I use "emerging" technology to represent the arrival of a new technology that may or may not result in the disruption of an incumbent technology (the point at which sales of the new exceed that of the incumbent). The horizontal axis is a combination of market segmentation and technology diffusion concepts such that the first element is a new market segment (assumed leading edge on the diffusion curve), the second is an established leading edge market segment (just one for simplicity), and the final element is an established trailing edge market segment (again, just one for simplicity). This matrix is depicted in Figure 4-3 for the scenario in which an emerging technology enters a new market segment.

In the first market scenario (see Figure 4-3), an emerging technology is assumed to enter a market through the creation of a new market segment. When an emerging technology enters the market through a new segment it is believed it will hold a symbiotic relationship with the incumbent technology. In the case of the 3.5-inch HDD, the existence of the portable computer market allowed the 3.5-inch HDD to have a symbiotic relationship with the laptop computer. The existence of the laptop helped the 3.5-inch HDD to grow (from ferment to maturity) and the existence of the laptop helped the 3.5-inch HDD to grow (from ferment to maturity). The growth in 3.5-inch HDD volume spurred sustaining innovation allowing the 3.5-inch to attack (predator) the 5.25-inch HDD (prey) associated with the leading edge market segment of the desktop personal computer (most likely low-end products in this case). The 3.5-inch HDD then continued to move up-market into the trailing edge segment, most likely the high-end desktop products competing with and eventually displacing the 5.25-inch HDD from the personal computer market. During the growth phase of the 3.5-inch drive and its subsequent move into the desktop market, 5.25-inch drive manufacturers became the predator by reducing price through sustaining innovations in design and process that lead to pure competition in which the clear winner has been the 3.5-inch HDD. The point at which the 3.5-inch drive entered the leading edge market segment it turned from emerging to a disruptive technology. Although not highlighted in the figure, the 3.5-inch drive holds a symbiotic relationship with the more mature desktop personal computer technology. The existence and growth of the desktop helped the growth in the 3.5-inch drive and the lower cost, greater reliability of the 3.5-inch helped the desktop to grow.

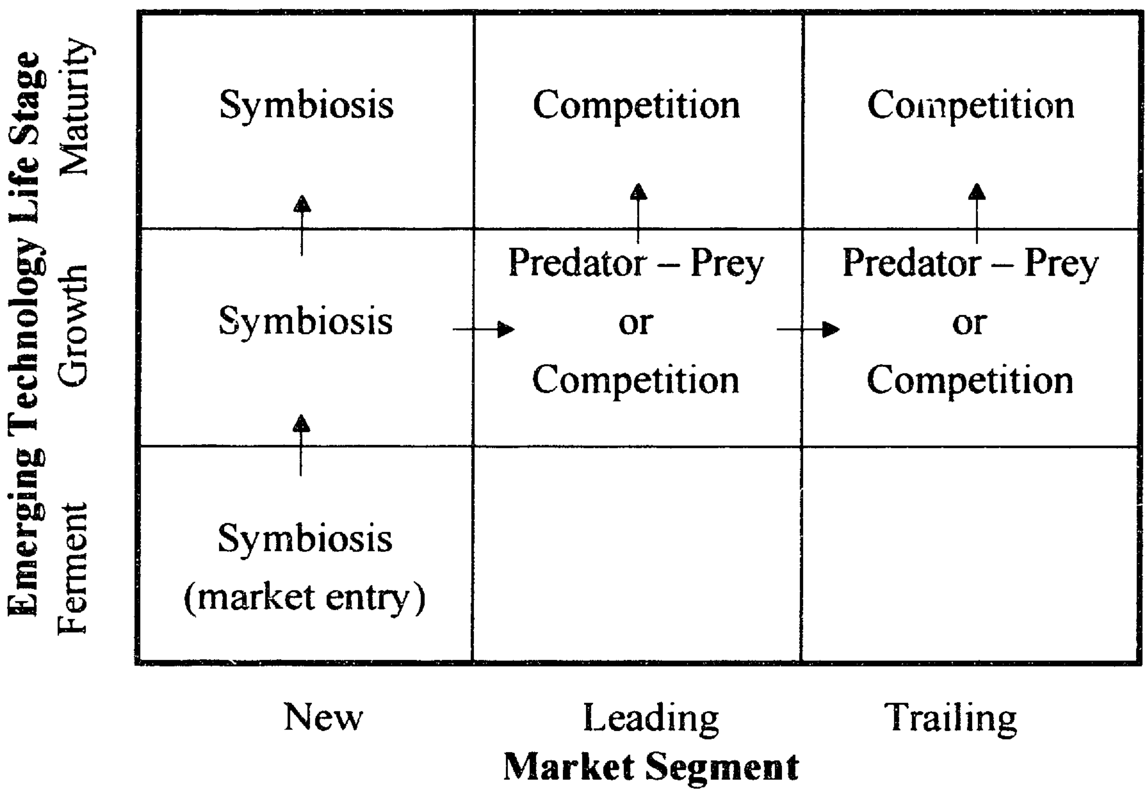

Figure 4-3. Technology and market interaction matrix
Scenario 1 - entry through a new market segment

In the second market scenario (see Figure 4-4), an emerging technology enters the market through an existing leading edge market segment. In this scenario a new market segment is not created. I believe this scenario is applicable to the OSB versus plywood case. OSB (predator) entered the market in the light frame construction, sheathing sector (structural panels for floor, wall, and roof construction) attempting to displace plywood (prey). I speculate that within this sector, OSB most likely targeted the low-end applications as the leading edge market segment and plywood most likely gave way believing OSB would not be a real threat. As OSB continued to take market share from plywood it began to move up-market into the high-end or trailing market segments. Plywood at this point shifted strategy and became the predator by aggressively improving manufacturing operations to lower cost and improve quality as sighted by the Forest Products Journal[8]. Twenty years after the introduction of OSB, the two products compete in the structural panels market with OSB continually eroding plywood's market share as a result of the higher cost of timber used in the manufacture of plywood. Plywood manufacturers are countering by working to reduce raw material prices through new forestry techniques and are shifting some emphasis to higher value markets as reported by Wood Technology[9]. While the market has not stabilized, time will tell if OSB wins the competition or if both products will continue to share the market. Although not highlighted in the figure, OSB structural panel products hold a symbiotic relationship with the more mature light frame construction technology. The existence and growth of light framed construction helped the growth in OSB panels and the lower cost of OSB has helped make housing more affordable and therefore grow.

Cooper and Schendel[4] observed that a new technology often invaded the traditional industry by capturing a series of market segments (they call submarkets) in that the technology offered performance advantages for certain applications. They sight the case of General Motors in diesel-electric locomotives which first invaded the submarket for passenger locomotives, subsequently the submarket for switcher locomotives, and then freight locomotives, which was the major submarket representing 75% of industry sales.

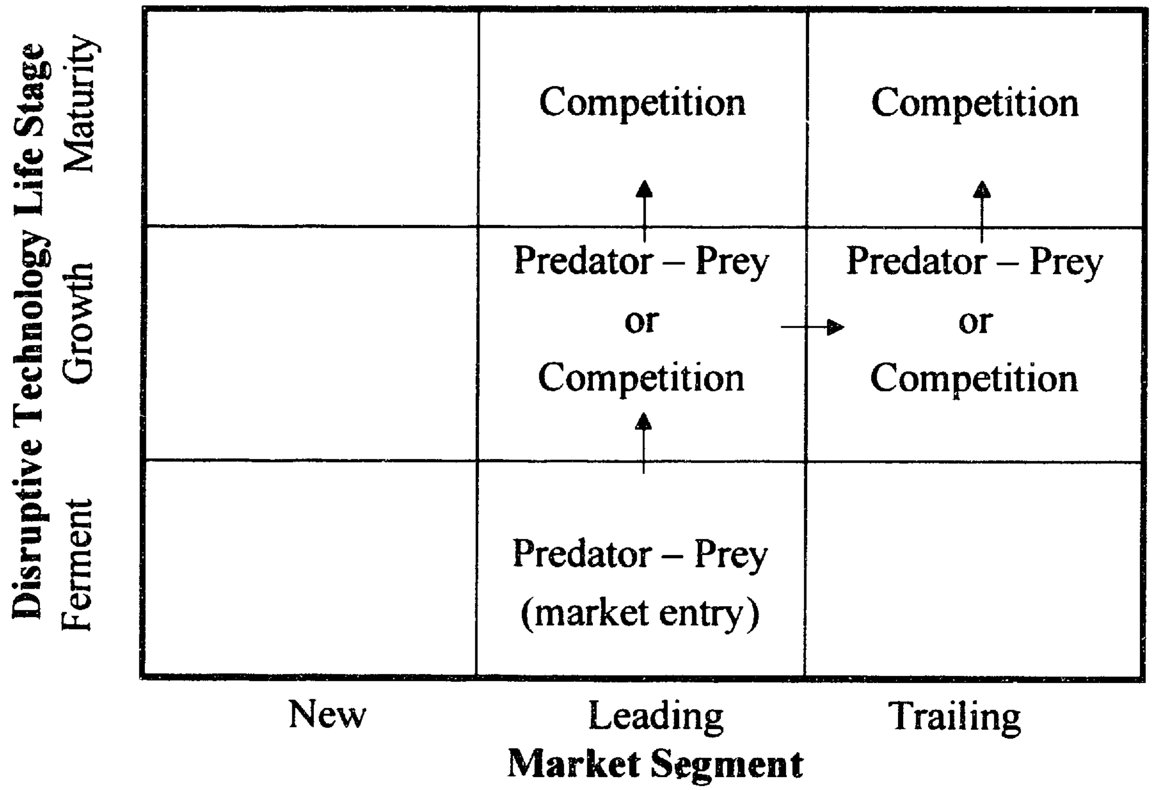

Figure 4-4. Technology and market interaction matrix
Scenario 2 - entry through a leading market segment without new segments

In the third and final market scenario (see Figure 4-5), an emerging technology enters the market through an existing leading edge market segment and not only penetrates the existing market but creates new market opportunities. I believe this scenario is applicable to the electronic hand held calculator (HHC) versus slide rule case. The HHC grew out of the efforts to replace the mechanical (desktop) calculator with an electronic calculator as previously discussed in Chapter 3. It is unclear at which market segment the HHC (predator) entered, but it is certain that in a short amount of time the slide rule (prey) was annihilated. The higher price of a calculator relative to a slide rule during this period allows us to conclude that this market segment had to be able to place higher value on the HHC performance attributes to justify the higher cost assisted by a desire to be at the leading edge of its use. As the price of the HHC fell due to sustaining product and process innovations the HHC moved into a new market segment comprised of the general consumer who was typically performing mathematical calculations by hand. The HHC had a symbiotic relationship with the consumer, the easy use and low price increased the HHC's growth and the HHC's growth increased the ability and desire of the consumer to perform mathematical calculations. Today, most people own more than one HHC.

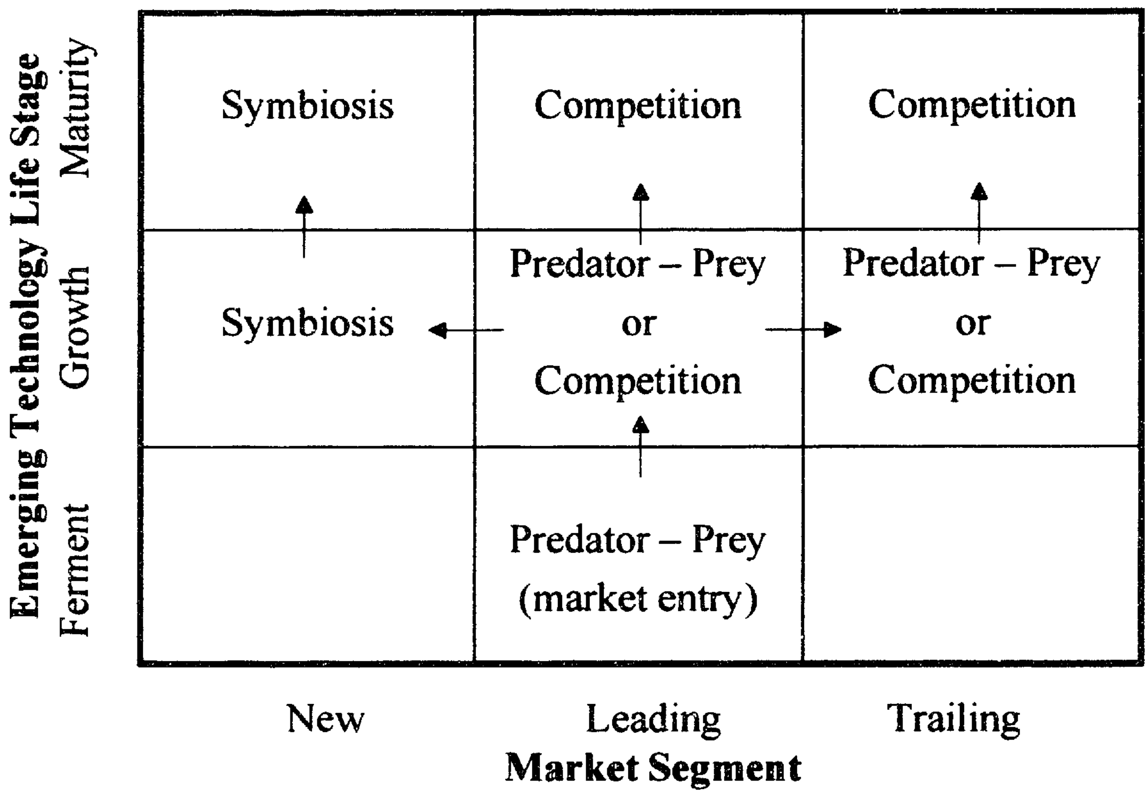

Figure 4-5. Technology and market interaction matrix
Scenario 3 - entry through a leading market segment with new segments

4.4 Overview

In this chapter I introduced a conceptual framework that integrates the interactions of an emerging and established technologies with market segmentation and innovation diffusion. While these interactions are very dynamic and more complex in real time markets, this framework attempts to provide a means to think about the introduction of a new technology and to apply scenario analysis to the possible outcomes of technology change. I have presented three scenarios that include: 1) the entry of an emerging technology through the creation of a new market segment with the subsequent move into the established market segments; 2) the entrance of an emerging technology through an established market segment and subsequent progression into other established market segments, and; 3) the entrance of an emerging technology through an established market segment and subsequent progression into other established market segments and the creation of new market segments. In these scenarios I have provided instances of down-market progression in addition to the up-market progression of emerging (may be disruptive) technologies described by Christensen[1].

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Chapter 5 – Conclusions

Clayton Christensen's work in the area of disruptive technologies has made a major contribution to the understanding of the process of innovation and the consequences this process has at a microeconomic level. The observations presented in my thesis indicate that an expansion of Christensen's work may be appropriate in the areas of: 1) the definition of disruptive technologies; 2) the competitive advantage associated with an emerging technology; and 3) the interactions of emerging and established technologies in the product marketplace. I present the following items for consideration:

5.1 Technology Disruptions and Competitive Advantage

As defined by Christensen, *disruptive technologies are those, which generally underperform established products in mainstream markets. But they have other features that a few fringe (and generally new) customers value. Products based on disruptive technologies are typically cheaper, simpler, smaller, and, frequently, more convenient to use.* I believe this definition is too narrow thereby limiting our understanding of technology change. I propose the definition to be expanded as follows, *disruptive technologies are those emerging technologies that deviate from the existing technology paradigm that support an incumbent product and result in the replacement of the incumbent product by a new product offering greater value. A disruptive technology may be recognized by a change in the dominant design of an incumbent product in the case of an assembled product or a change in the dominant production process in the case of a non-assembled product.*

Christensen's definition of disruptive technologies focuses on three factors, low cost (typically cheaper), low traditional performance (underperform established products in mainstream markets), and higher ancillary performance (typically simpler, smaller, and frequently more convenient to use). These factors are found in the elements of cost leadership and product differentiation that provide a firm with a competitive advantage. Using Christensen's factors, we may say that a consumer of a product will make a value based decision on his purchase which is a function of price, traditional performance, and ancillary performance. A consumer will choose one product over another if he perceives the value of one product to be higher than the other. As such, I have proposed a framework that considers all possible changes in these factors for a new product based on an emerging technology and have provided cases in which these changes have resulted in the displacement of an incumbent technology by an emerging technology. This "disruption" has occurred as a result of consumers assigning a higher value to the product based on the emerging technology, not on a specified change in the direction of the product factors.

5.2 Technology and Market Interactions

The market implications of technology change has also been raised within Christensen's definition of disruptive technologies when he refers to "...a few fringe (and generally new) customers...". His case studies provide examples of emerging technologies supporting new products that are introduced in a new market segment within an established industry. The pioneering firms then move up-market into existing markets and displace the incumbent products and firms. I have proposed that an emerging technology can enter the market through an existing market segment, provided that one of the existing segments finds value in the product and its constituents are at the leading edge of the diffusion process. In addition, sometimes an emerging technology will move down-market, such as that demonstrated by the hand held calculator case. Finally, the interaction between an emerging and established technology is not always one of immediate dominance, that their interactions change over time and that they may coexist in a competitive state as displayed in the OSB case.

While these conclusions are based on the somewhat subjective observations of select innovation events and subsequent market and firm dynamics, I believe an expanded view of disruptive technologies is in order. The rigor associated with a more objective substantiation of this thesis will be reserved for the later works of academics, should they see it fit. I hope this work has provided the reader with a broader perspective on disruptive technologies and that he or she considers other scenarios that may lead to technology disruption.

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