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Bringing Technology to Market: a Macro View of Technology Transfer and Commercialization

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Abstract. In the past decade, a number of diverse factors converged to propel the issue of technology commercialization and the role of innovation in stimulating economic growth to the forefront of attention in both industry and academe. Universities, in partnership with industry, are playing an increasingly important role in the innovation and commercialization process. This article, which is written in chapter format, examines at a macro level the issues related to technology commercialization, the issue of complexity, the commercialization process, and the challenges associated with commercialization of technology.

Keywords: intellectual property, technology commercialization, technology transfer, technological change, economic growth, disequilibrium, disruptive technology, complexity, technology diffusion, Bayh-Dole Act, fuzzy front end.

1. Introduction

In the past decade, a number of diverse factors converged to propel the issue of technology commercialization and the role of innovation in stimulating economic growth to the forefront of attention in both industry and academe. For industry, companies seeking to commercialize the technologies they develop now face a dynamic set of challenges, attitudes, and values. The marketplace demands better, faster, and cheaper technology products, a product development nightmare for companies trying to survive while staying ahead of their competitors.

Intellectual property has taken on a new and more vital position. Once a cost center for a corporation, intellectual property (IP) has now become a revenue center and essential competitive advantage for those firms that possess valuable IP portfolios. Consequently, firms must now find ways to create value from archived patents to justify the ever increasing expense of new product development. Moreover, companies can no longer survive simply on incremental innovation - improving existing technology. Today companies must seek ways to add radical innovation to their product development mix to stimulate future opportunities before their existing technologies become obsolete. Although thousands of new products reach the market every year, the vast majority of these products fail to make a profit for the companies that created them. Therefore, it is not surprising that 40 percent of major corporations in business in 1975 are not in business today (Foster, 2000). A critical reason for this dismal record is ineffective commercialization processes that attempt to link emerging technologies with existing markets rather than with emerging markets (Stevens and Burley, 1997). Satisfying customer needs today is like trying to hit a moving target.

Universities are playing an increasingly important role in the innovation and commercialization process. They rely heavily on research grants to support their R&D function, but, more and more, government and foundation funders are stipulating that the results of research must have a commercial application, that is, return something of value to society. As a result, universities are faced with the dilemma of how to stay true to their primary mission - to educate, conduct independent research, and provide service to their communities - while simultaneously responding to demands to commercialize their research findings. Although arriving late to the game of technology commercialization, university licensing activity has had a significant impact on the economy. For example, in 1999, commercialized academic research produced more than $40 billion in economic activity, including over $5 billion in federal, state, and local tax revenues; more than 340 new companies started; and more than 270,000 jobs (AUTM, 1999).

Despite more effective tools and knowledge about commercialization, new technology adoption is still a very slow and incremental process with only a mere fraction of all new technologies ever achieving mass adoption. Those technologies that do achieve mass adoption do so only after significant delays (Farzin, Huisman, and Kort, 1997). The Technology Marketing Group (TMG) of Acton Massachusetts worked with a new firm in the chemical industry to develop a technology for use in pharmaceutical research, development, and production (Hruby & Lutz, 2002). The firm assumed that since it was a pharmaceutical company, its initial customers would definitely fall into the early adopter category. After much research, TMG discovered that the lag time for adoption of the company’s new technology was five years; however, since innovators in the industry had not yet adopted the technology, TMG estimated that it would be 10 years before the new firm could sell sufficient volumes of the product. Calculating the return on investment over that length of time resulted in a decision not to pursue the technology. The slow pace of technology adoption is due in large part to the uncertainties inherent in the commercialization process. The more rapidly an invention gets to market, the more likely it is that it meets market needs defined during the development process. Yet, there are no guarantees and perhaps one of the major uncertainties of the process is that so much of the process is out of the control of the entrepreneur or firm.

Given the environment described above, it is no wonder that interest in understanding, refining, and perfecting the commercialization process has quickened. Yet an understanding of the commercialization process and its outcomes at a macro level is still in the early stages.

2. Technology Commercialization from a Macro Perspective

Technological change and its impact on the economy were nowhere to be found in economic growth models until the work of Paul Romer and others in the 1980s (Romer, 1986). Traditional growth models relied solely on inputs of labor and capital. Entrepreneurship was also not found in the neoclassically dominated economic theory of the twentieth and early twenty-first centuries. In neoclassical economic theory, good management is needed to maintain equilibrium. That equilibrium is disrupted by entrepreneurs who recognize previously unrecognized profit opportunities. Traditional economic models considered productivity growth as essential to maintaining economic growth, but several research studies have identified an unexplained, yet substantial residual in the calculation of growth in output of workers. Two studies in particular, the work of Robert Solow and Edward Denison, succeeded in estimating the contribution of traditional inputs (labor and capital) to increases in traditional outputs (productivity). Their conclusions, which were arrived at by different methods, found that more than a quarter of productivity growth can be explained by R&D activity. (Solow, 1957; and Cohen & Noll, 1991). Early economic research also made a link between the pace of technological change and the magnitude of resources devoted to R&D (Baily & Chakrabarti, 1988).

As depicted in Figure 1 (page 325), technological change results from an entrepreneur identifying new, emerging customer segments, new customer needs, existing customer needs left unsatisfied, and new ways of manufacturing and distributing products and services (Allen, 2003). Therefore, R&D alone does not produce opportunity, but it does create an environment that allows profit opportunities to exist (Holcombe, 2001). For example, the former Soviet Union invested heavily in research and development, physical assets, and human capital, which are the inputs required for economic growth. Despite this enormous investment, R&D in the Soviet Union did not lead to economic growth because the economic environment did not support exploitation by entrepreneurs. Therefore, simple investment in R&D will not always lead to growth; growth requires the combination of innovation and entrepreneurship.

Since entrepreneurial opportunity is a critical factor in economic growth, it would be important to understand where these opportunities come from. Holcombe divides entrepreneurial opportunities into two categories: those that derive from the innovative activity of the entrepreneur and those that arise from recognizing a need or gap in the market. In the first case, the entrepreneur as innovator, the entrepreneur is by definition the only one who has the ability to see the opportunity because it derives directly from his or her expertise, knowledge, and innovative activity. The second type of entrepreneurial opportunity is available to anyone with an opportunistic mindset who can spot a gap in the market (Holcombe, 2001, 301). But it requires a market or environment that produces profit opportunities. Three broad categories of factors seem to create profit opportunities for potential entrepreneurs (Holcombe, 2001, 303):

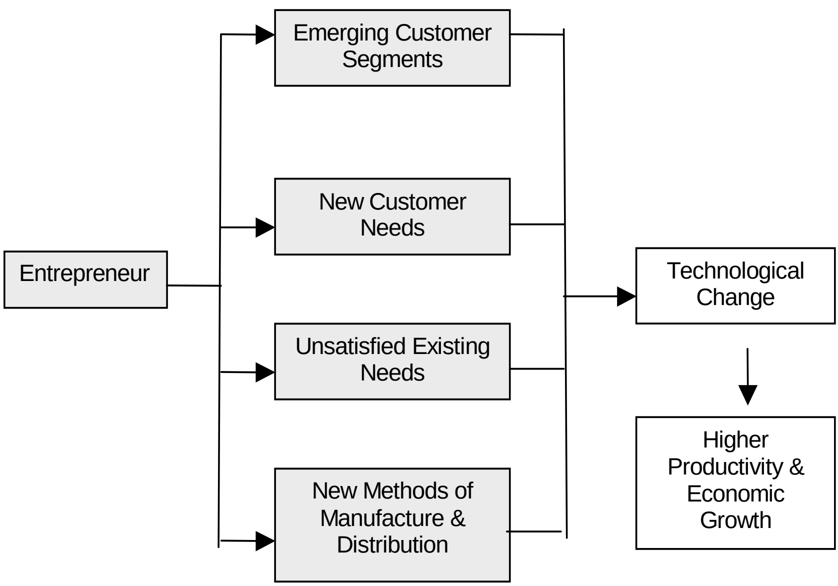
1. *Factors that disequilibrate the market*. Market equilibrium is disrupted when customer preferences change, requiring the reallocation of resources, or when environmental forces deplete natural resources or normal weather patterns are disrupted. For example, as landfills reach capacity, new sites must be found, which provides a new entrepreneurial opportunity. The Internet certainly served to disequilibrate the economy providing new business opportunities that had not previously existed.

2. *Factors that enhance production possibilities.* The increase in production possibilities creates entrepreneurial opportunities by increasing inputs and allowing them to be combined in new ways to expand markets. For example, improvements in highways and the lowering of air freight costs extended the market for firms like Federal Express that were able to increase their division of labor and their productivity. Another example is the wider variety of specialized business services that are now available outside of big cities due to reductions in transportation and communications costs. Nationwide financial services firms now can serve customers at a distance through telephone communication and the Internet. These same services cost too much to be feasible in the 1950s.

3. *Entrepreneurial activity that creates new possibilities*. One of the most important outcomes of entrepreneurial activity is to produce more entrepreneurial activity. The act of one entrepreneur opens up new opportunities for other entrepreneurs to act. One example is the microcomputer industry. Xerox developed the mouse, but Apple Computer recognized the commercial potential of this input device and brought it to market. Microsoft, appreciating how effectively the device worked, built an operating system that leveraged that technology. Had the mouse not been developed as an input device, no one would have had the opportunity to develop the

infrared mouse, touch pad, pointing stick, and trackball. So the original idea for the mouse led to new entrepreneurial opportunities.

Figure 1: Technological Change



2.1. Definitions

Since terms related to the concept of technology commercialization are defined in a variety of ways, it would be important to begin by defining some key terms that will be used throughout the chapter.

- *Technology.* For our purposes, Burgelman's, Madique's, and Wheelwright's definition will be employed; that is, technology is "the theoretical and practical knowledge, skills, and artifacts that can be used to develop products and services as well as their production and delivery systems. Technology can be embodied in people, materials, cognitive and implementing a new idea" (Burgelman, Madique, & Wheelwright, 1996).

- *Invention.* The creation of a novel and new idea.

- *Innovation.* Refers to improvements on existing technology or to the exploitation of an invention (Van de Ven & Angle, 1989). Whereas invention is usually a random and unpredictable process, innovation is a manageable process that turns an invention into something with commercial value (Miller & Morris, 1999).

- *Sustaining technology.* These technologies foster improved product performance of established products and comprise the vast majority of technological advances (Christensen, 1997).

- *Disruptive or radical technology.* These technologies bring about a paradigm shift, that is, they obsolete technologies that precede them. Initially they result in poorer product performance, but a cheaper, simpler, smaller, and more convenient application (Christensen, 1997).

- *Technology transfer v. technology commercialization.* These two terms have frequently been used interchangeably; however, it is important to note that technology commercialization has a broader meaning. In general, technology transfer deals with disclosure of inventions, record keeping and management of inventions, evaluation and marketing, patent prosecution, negotiation and drafting of license agreements, and management of active licenses (Allan, 2001). It typically refers to the means by which technologies are transferred from the inventor to the market. Technology commercialization involves a lengthy and complex process that begins with discovery, moves through product development and all its associated issues such as prototyping and intellectual property development, involves business concept development, market feasibility analysis, and business plan development, and takes the concept to a license agreement, acquisition or the start-up of a spin-off venture. In both the university and in large companies, the focus tends to be more on licensing than the start-up of new ventures. Whereas market research is a critical and ongoing component of technology commercialization, the technology transfer practices of most universities and many companies consist of posting intellectual properties on a web site. Many universities, large and small, lack the resources to conduct a full-scale market research or marketing effort (Allan, 2001).

- *Spin-off Company.* A spin-off is a new company formed by former employees of a parent organization and based on a technology that originated in the parent organization and then was transferred to the new company (Carayannis, Rogers, Kurlhara & Allbritton, 1998). In the case of a university spin-off, the technology is licensed from the university.

- *R&D.* R&D is more than simply an inquiry process in the hard sciences; it is a "fundamental process for generating knowledge" (Link, 1999). The National Science Foundation refers to R&D as the "advancement of the discovery of scientific knowledge and development is the systematic use of such knowledge" (Link, 1996).

2.2. Determinants of Technology Commercialization

Many factors work to determine whether a technology moves from laboratory to market and how smooth or bumpy that path might be. Here we look at some of the precipitators of technology commercialization, how the nature of the technology affects the process, how the screening process determines which concepts move forward, and how the ability of the technology to be transferred can affect the commercialization process.

2.2.1. Precipitators of Technology Commercialization

The commercialization process is more creative than scientific. The creative process literature, which dominates the research in creativity, asserts that the purpose of creativity is the production of unique and useful ideas (Deazin, 1999). Another research stream holds the view that creativity is about the generation of valuable and useful products, services, procedures, and processes, which is similar to the purpose of the commercialization process.

In general the commercialization process is precipitated by a discovery or recognition of a market need. The two are quite distinct. The discovery process is about making a connection between two or more disparate ideas to elicit something new. Once that connection is made, a period of exploration and experimentation begins that can result in an invention. By contrast, recognition of a market need or customer pain produces a problem that must be solved. The solution results in a new technology or the enhancement of an existing technology.

We are learning more about opportunity recognition from a growing body of research. While not all of the variables that affect opportunity recognition have been identified or their impact determined, we do know that most people find opportunities in industries with which they are familiar or in which they have experience (Zietsma, 1999). There is also a positive correlation between the number of weak ties (those outside family and friends) an entrepreneur has and the number of opportunities recognized (Singh et al., 1999). Some research has suggested that opportunity recognition involves active, well-planned searches in addition to serendipity (Herron & Sapienza, 1992). Other research has suggested a five-step framework that describes an iterative process with many feedback loops (Hill, Schrader, and Lumpkin, 1999).

1. *Preparation.* Because entrepreneurs bring prior knowledge and experience to the opportunity recognition process, it is idiosyncratic to each entrepreneur.

2. *Incubation.* Incubation is a period of time where the entrepreneur contemplates the solution to a problem.

3. *Insight.* This can be described as the “eureka” moment, when the solution becomes apparent.

4. *Evaluation.* Insight is followed by a process of defining a business concept and testing in the marketplace to determine its feasibility.

5. *Elaboration.* With a feasible concept comes the planning and creation of a company to execute the concept.

Despite research findings, it appears that opportunity recognition is a fairly unique journey for an individual; that is, each individual finds his or her own path to it. Nevertheless, entrepreneurs increase their probability of finding opportunity by 1) increasing their knowledge and experience in an industry in which they are interested; 2) building a diverse network of strong and weak professional ties; 3) developing an opportunistic mindset; and 4) exercising patience as the incubation period may take a long time (Allen, 2003, p.35).

2.2.2. Sustaining Versus Disruptive Technologies as Commercialization Determinants

The type of technology being developed will have an important impact on the commercialization process. Disruptive technologies are those that fundamentally change the way things are done and obsolete previous technology. Some examples are the PC, the fax machine, and the birth control pill. Disruptive technologies are not a simple change from one technology to another, but a radical change at a systemic level with far-reaching implications (Allen, 2003). They are borne from needs that can no longer be met inside current technology parameters. Historically, we saw these cataclysmic changes only once a decade, but today they are occurring almost annually. It is a curious phenomenon that disruptive technologies don’t achieve their full value until they reach mass-market acceptance, which for most is several years. This fact has important implications for the commercialization process.

Disruptive technologies have been placed into three categories (Leifer et al, 2000):

1. *Innovation within the markets of existing business units.* These types of disruptive technologies completely replace existing technologies in the same market and with the same customers.

2. *Innovation in the white spaces.* Here the disruptive technology targets the gap between a company's existing businesses and often borrows knowledge, experience, and technology from two or three business units to create a new technology.

3. *Innovation outside a company's current strategic objectives.* These types of disruptive technologies open up new markets that are substantially different from current markets and therefore incur the highest level of risk for the company.

If is often believed that large companies have the highest probability of successfully developing and introducing a disruptive technology, but the reality is that large companies are plagued by the "incumbent's curse" (Chandy & Tellis, 2000). The theory of the incumbent's curse has been studied to a great extent in the research literature. The notion is that because incumbents have invested heavily in the development of their technology, they face inertia and resist investing in any technology concept that might cannibalize or obsolete the existing technology (Scherer, 1980). As a result, most disruptive or radical technology comes from small firms with no sunk costs and no turf to protect.

1. There is no incentive to take on the development of disruptive technologies because they typically don't produce an income for years. By contrast, incremental or sustaining technologies produce a relatively quick return on investment (Conner, 1988).

2. Large firms tend to focus on their core competencies and therefore filter out unrelated information, which may include a potential threat from a small, innovative company.

3. Large firms tend to rely on existing routines and are reluctant to change what has worked previously to support a disruptive technology.

Sustaining technologies, by contrast, are major improvements on existing technologies, generally in the area of performance. Consequently, their adoption rate is almost immediate, and they are profitable much earlier. Most firms rely on sustaining or incremental innovation, often to their detriment, because over time incremental innovations experience diminishing returns and eventually are overcome by a new technology on a different platform.

2.2.3. Technology Screening

Ideas usually come easily, but opportunities - those ideas that have commercial potential - are often more difficult to identify. Successful technology commercialization relies on a screening process to sift through potential opportunities and settle on the most appropriate one. Figure 2 (page 332) presents a screening framework to assist in determining which of many ideas might actually go through the commercialization process.

Development of a new technology opportunity is normally undertaken when it is compatible with the entrepreneur's personal goals and/or the company's strategic direction. It must be demonstrably worth the investment in time, money, and other resources. At this early screening it is critical to view a new technology from the customer's point of view, whether that customer is a potential licensee or a buyer of a finished product.

In doing an initial screen of a potential new technology, consideration of its future economic value will be an important determinant of the decision to go forward with commercialization.

Intellectual property has a legal life, but it also has an economic life; that is, the length of time a patent can generate revenue for its owner. That length of time and the amount of revenue generated is a function of several factors (Allen, 2003, p.40):

- *The probability that competitors design around the patent* and develop a competing product.

- *The probability that the patent is challenged.* This is often done by competitors as a strategy to tie the company up in patent litigation and divert its attention from developing the market.

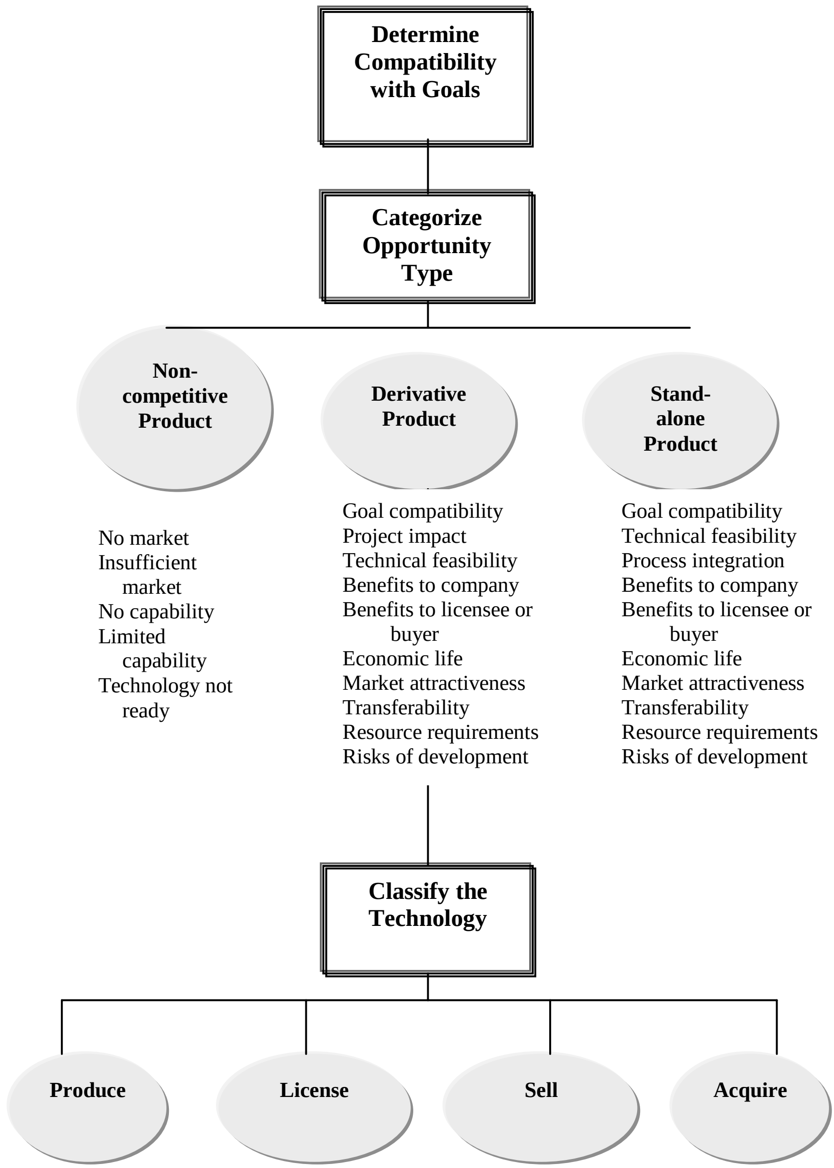
- *The probability that development costs exceed estimates.* The cost of developing a new technology is difficult to estimate with any degree of accuracy. Frequently, developers will estimate on the high side to such a degree that the project never happens because it is judged to be financially infeasible.

- *The impact of new laws on the development of the technology.* A new law can shorten or cut off a new technology's economic life.

Regulations on stem cell research have threatened to end many promising opportunities to cure many diseases. By contrast, environmental protection regulations have spawned many new businesses in the areas of diagnostics and compliance.

- *The escalation of supply pricing or loss of source of supply.* Supply prices are rarely stable, but rather change fairly frequently, sometimes significantly. When that happens, the higher prices can effectively reduce the economic life of the technology by forcing companies to find alternative sources of supply or get out of the business entirely if it no longer makes financial sense. The loss of a key supplier to a catastrophe such as fire or to bankruptcy can also start a chain reaction that could put the company out of business. Understanding the volatility of the industry is important in estimating future economic value. Having a back-up supplier would help in situations where a supplier is lost.

Figure 2: Technology Screening Framework



2.2.4. Determine the Ability of the Technology to be Transferred and the Resource Requirements to Transfer the Technology

It has been suggested that transaction cost economics research might provide the appropriate framework to identify the conditions under which a technology might be successfully transferred (Shane, 2002). The most effective commercialization of university technologies is conducted by entrepreneurs and other economic players who have a comparative advantage in terms of market research, product development, manufacturing, and distribution capabilities and resources. In general, licensing is a way to identify the best players to commercialize a specific technology where markets are free of problems (Teece, 1980). But the market for inventions is imperfect and is characterized by problems of adverse selection, moral hazard, and hold-up. We find adverse selection in markets where low-quality inventions are misrepresented as high quality and potential buyers are unable to discern the difference (Anton and Yao, 1994). This is due principally to problems of disclosure. Buyers will not purchase without sufficient information about the invention, but often once that information is revealed, the invention no longer holds any value for the buyer.

Moral hazard occurs where, for instance, the buyer refuses to pay for knowledge transferred and that knowledge cannot be unlearned once it is transferred (Arora, 1996). Alternatively the seller may not fully disclose all relevant knowledge in an effort to reduce his or her costs.

Hold-up occurs because of the high degree of uncertainty in the commercialization process. Often, the parties involved in technology transfer must agree to resolve some issues at a future date, because not enough information is available at the time of negotiation.

It is important to note that patents tend to overcome the problems of adverse selection, moral hazard, and hold-up by forcing the buyer to purchase the invention to use it (Anton and Yao, 1994). Patents are also used as a negotiating tool to prevent the parties from taking part in moral hazard and they minimize the problem of hold-up by permitting full disclosure. But, there are many instances where patent strength varies by industry. For example,

- In some industries like software, it is relatively easy to design around a patent (Teece, 1986).

- Some patents cannot stand up to challenge, particularly when their owners cannot defend them.

- In some industries, competitors can legally invent around a patent, particularly if technology is changing so rapidly that patents may be considered irrelevant (Levin et al. 1987).

It is also important to identify the risks associated with the development of the technology. Every project endures two types of risk: technical and market (Smith, 1999). Technical risks come about when developers are unable to produce a product that meets the technical specifications they have designed. Market risks come from misreading the market or failing to meet customer needs. Most product failures are actually due to market risks. The work of Robert Cooper over 25 years and more than 2,000 products has led to six factors that predict new product success (Cooper, 2001).

- A superior and unique product
- A clearly defined product at the earliest stages of development
- Thorough technical and market feasibility analyses
- A well-executed marketing plan
- A well-executed technology plan
- A cross-functional team with expertise in all critical areas

Note that only one of these factors is related to product development; the rest are clearly within the domain of market research. Successfully managing risk (it cannot be completely eliminated) during product development is critical certainly for achieving rapid time-to-market, but also for increasing the odds of securing funding. The amount of equity a company must give up to investors is a function of how much of the inherent risk in the technology it has reduced. Investors will provide funding where they perceive that the inventing team has reduced the technical and market risk to their level of comfort.

Once the initial screen is complete, a technology is typically classified in terms of how it is to be transferred or commercialized. In general there are four categories of commercialization opportunities.

- *Start a company and produce the product.* This route works when the inventor has the expertise and access to required resources to start a company and do an effective job of marketing and distributing the product. These functions may be outsourced and the new company may choose to focus on what it does best, product development, for example. Where it is important to retain complete control of intellectual property (ie. know-how), the inventor may choose to start a company so that the technology can be held captive as a trade secret.

- *License the technology.* Licensing the right to make and distribute a technology is a common route of technology transfer, certainly for universities. This option gives the inventor an opportunity to benefit from reaching more markets than he or she could have achieved alone. Getting to many markets quickly is critical to achieving mainstream adoption of a radically new technology.

- *Sell the technology.* In some cases, an inventor may choose to sell the technology outright, often to a larger company. This is particularly true where the technology is not captive and has no relationship to other technologies the company produces. Another reason to sell is when the buyer has better access to raw materials than the inventor.

- *Acquisition.* Merging with or partnering with another company to share technologies is another choice available to the entrepreneur.

3. The Issue of Complexity in the Commercialization Process

While the entire commercialization process is highly complex, prototype development and manufacturing of a market-ready product involve perhaps the highest degree of complexity. Complexity is a concept that has been studied in fields ranging from biological and physical to manmade systems and organizational structures. In general, there are four categories of complexity: logistical, organizational, technological, and environmental (Khurana, 1999).

3.1. Logistical Complexity

Logistical complexity arises where there are a high number of tasks and/or products. The more inputs and outputs required to manufacture and distribute a product, the higher the degree of logistical complexity. Those inputs and outputs include suppliers, raw materials, distributors, distribution channels, and so forth.

3.2. Organizational Complexity

Organizational complexity can arise from the number of inputs and outputs required by the organization's policies and procedures as well as from layers of management - the hierarchy. Often a high degree of complexity in an organizational structure will actually slow the product development and manufacturing process, creating a competitive disadvantage for the company.

By contrast, the generally flatter organizational structures of entrepreneurial companies often give them a competitive advantage in reducing time to market. Where a company outsources many of its product development and manufacturing tasks to other companies, organizational complexity actually increases because of the need to coordinate tasks across companies whose policies and procedures may not be compatible.

3.3. Environmental Complexity

Environmental complexity includes all those things outside the commercialization process that have an impact on it. The nature of the industry in which a company operates can add complexity to the product development and manufacturing process by requiring the company to deal with multiple suppliers, access complex distribution channels, and satisfy diverse customers.

The work of Michael Porter is often used as a reliable framework for analyzing industry complexity and its impact on the firm. Porter describes five forces that affect every industry and also the profit potential and competitive strategy of businesses in that industry (Porter, 1980): barriers to entry, threat of substitute products, buyer power, supplier power, and degree of competitor rivalry. This author has added technology to the framework to reflect the dynamic rather than static nature of industries over time.

Barriers to entry make it difficult for new entrants to enter an industry. Some of these barriers include economies of scale in marketing, production, and distribution. Another common barrier is brand loyalty, which means that the loyal customer base perceives high switching costs to move to another technology. Overcoming this barrier may mean introducing a superior technology or partnering with a major player to gain entry.

Competition from substitute products, products that perform the same basic function but in a different way or for a different price, can also be a significant entry barrier to new firms. The *purchasing power of the major players* in an industry gives them the ability to force down prices from their suppliers and thus incur costs that are much less than the new entrants must pay. *Suppliers* also have the power to control prices or change quality, particularly if they control necessary raw materials.

Highly competitive industries drive down prices and return on investment. In this situation, price wars and advertising skirmishes are common. To enter such an industry, a new venture needs to define a niche that will give it a temporary monopoly serving a gap in the market. Finally, technology enables business goals and also drives change. Where *technology* is critical to an industry, the industry tends to be more volatile, more virtual than physical, and more intuitive than analytical.

3.4. Technological Complexity

Technological complexity refers to the system and its various technologies. Research proposes the existence of two dimensions of technological complexity: interaction complexity and nondecomposability. Interaction complexity is the result of many interactions among the product components or subsystems. One change in any component or subsystem of the product generally requires redesign and reengineering of the whole product. In some cases, a product cannot be reduced to its individual components without suffering a loss of performance. In other words, the synergy created by the interaction of the components is essential to the performance of the product itself. A similar situation exists with processes. The various steps in a process may have complex interactions such that they cannot take place independently (Weick, 1990; Buchanan & Bessant, 1985). This inability to disconnect processes is known as nondecomposability. For example, the manufacture of picture tubes for televisions is a complex process involving more than 200 production steps and employing more than 24 interacting process technologies including electrical, optical, chemical, and mechanical (Khurana, 1999). Changing any one of these processes will affect the entire system and the ultimate performance of the product.

An inherent problem with complex systems and processes is how often specifications in an engineered design do not match what actually happens when the product is built. Specifications that work in theory or in a computer simulation may still run into problems when the physical prototyping stage is reached because complex processes are, by their very nature, unpredictable. They display episodes of punctuated equilibrium and path dependence. With punctuated equilibrium, the system is relatively stable for periods of time and then experiences a dramatic change. One can ever be certain when a dramatic change will occur. Even smaller, more random changes can frequently lead to radically different outcomes in the future (Bak, 1996). Therefore, to ensure a sound and consistently reliable product, it is necessary to conduct numerous experiments that test all the potential variables that might affect the final outcome. A more sinister problem is that having identified punctuated equilibrium and path dependence in the past does not provide a reliable guide to future events. The commercialization process is not linear, so the future cannot be predicted from either the present or the past.

Some research has suggested that adopting an adaptive strategy provides a variety of options which optimizes outcomes over many different circumstances. More flexibility increases the probability of success (Beinhocker, 1999).

4. The Commercialization Decision - Technology Diffusion and Gap Theory

The market system does not allow for the natural diffusion of technologies to the marketplace. One of the primary reasons for this is that the investment community does not invest sufficiently in basic research largely because there are no reliable methods for accurately assessing risk at such an early stage (Cohen & Noll, 1991, 18). A further problem is that of appropriability, which is the gap between private and social rates of return on R&D; that is, it is unlikely that the rates of return to the investor will match or even come near to matching the returns to society (Jamison & Jansen, 2000). Because most of the benefit of technological advances is passed on to consumers and is not part of profitability calculations, the profit to the inventing company is generally too small to justify a private investment (Mansfield, 1980 & Scherer, 1982). It has been estimated that the private rate of return on investment in R&D is about 25 percent and the social rate of return on R&D is 56 percent (Mansfield, 1986). The appropriability problem often extends to applied research as well where the application does not have a specific value to a particular company.

The "technological gap theory" applies in the U.S. where defined mechanisms for supporting applied research don't exist; consequently, a gap exists between scientific advances arising from academic research and technologies commercialized in the market (National Academy of Sciences, 1992). The Bayh-Dole Act of 1980 has gone a long way toward narrowing this gap by making it easier for industry to participate in the development of federally funded basic research. The Bayh-Dole Act, the popular name for the Patent and Trademark Act Amendments of 1980, radically changed the incentive structure for non-government organizations performing federally funded research. Prior to the act, the federal government retained title to patents generated from its grants. Since it then gave non-exclusive licenses to develop technologies, there was no incentive by companies to do the development because their competitors could also obtain a license on the same technology. With the increase in global competition, however, the government became concerned that most of the technologies developed under its grants were not being commercialized. So Congress pushed through the Bayh-Dole Act, which provides for ownership by universities and others of patentable inventions resulting from federally-funded research. In addition, a series of federal judicial decisions that followed the passage of the act significantly broadened the definition of patentable inventions and strengthened the legal protections of holders of intellectual property rights (Newberg and Dunn, 2002).

4.1. The Role of Intellectual Property in Technology Diffusion

Securing intellectual property protection is a critical element of the commercialization process where licensing and outside funding are being considered. Since the Bayh-Dole Act, the number of invention disclosures and patents filed at universities has been increasing, which has stimulated interest from the investment community (Santoro & Betts, 2002). In fiscal year 2000, 13,032 invention disclosures at universities were reported, up 6 percent from 1999. 6,375 new U.S. patent applications were filed, up 15 percent from FY 1999. In FY 2000, 4,362 new licenses and options were executed, up 11 percent from FY 1999. Ninety percent of these licenses and options to start-ups were exclusive (Pressman, 2002), which is surprising because universities tend to be reluctant to grant exclusive licenses to industry partners. The opportunity cost of revenue streams from other segments of that company's industry or other industries is lost with an exclusive license. Moreover, exclusivity can impede the university's ability to disseminate knowledge - it's primary mission.

4.1.1. Incentives to Invent

Several economic theories form the basis for the rationale behind intellectual property protections. Under the incentive-to-invent theory, without the temporary monopoly created by intellectual property protections, the original inventor would be left open to having his or her invention stolen and produced, often at a lower price, before the inventor could recoup the costs of research and development. With patent protection and the quiet period it provides, inventors, theoretically, will be induced to invent. Some research has not found a relationship between patents and the incentive to invent, but today in more volatile industries like pharmaceuticals, software, and telecommunications, a greater interest in protecting inventions is taking place (Baumol, 1999).

4.1.2. Incentives to Disclose

With formal legal protections in place, inventors are incentivized to disclose their inventions without fear of their proprietary information being revealed until the patent is issued. Disclosure is important to the diffusion of knowledge in a field of study because it prevents the duplication of research effort and moves the field forward more quickly. Without these protections, inventors might retain their inventions as trade secrets to maintain their value. Given that trade secrets are difficult to sell or license because once the secret is disclosed, it loses its proprietary value, new inventions would not be disseminated to the public and technological change would not occur.

4.1.3. Incentives to Commercialize

Most inventors need to work with strategic partners such as manufacturers who incur the expense of setting up for manufacture. The temporary monopoly granted by a patent provides the manufacturer with a quiet period to produce and distribute at a fair price before it needs to find a way to lower costs to compete with other manufacturers who have entered the market (Allen, 2003).

4.1.4. Disincentives to Securing Intellectual Property

Many arguments have countered the notion that intellectual property protections are incentivising to the inventor. One claim is that these protections hurt consumers and end users because they must pay higher prices for patented products than for non-patented products. Another argument posits that if the patent holder does not permit other companies to develop improvements and derivative innovations of the original patent, the patent will never realize its full profit potential (Allen, 2003). The reality is that rarely does a single inventor recognize all the potential applications for a particular technology. A third argument is that typically the initial inventor never realizes a profit from the invention. In general, the second or third mover, who improves on the invention and learns from the mistakes of the pioneer, generally sees more financial rewards from the commercialization process. Finally, patents commonly affect the direction of research. In one study it was found that 60 percent of patented innovations were imitated within four years of their patents and at two-thirds the original innovation’s cost (Mansfield, Schwartz and Wagner, 1981).

4.2. The Role of University-Industry Collaborations in Technology Diffusion

Private industry has played an increasing significant role in university research by encouraging and financially underwriting the costs of research, and this collaboration has increased competitiveness of U.S. firms and improved technological capacity (Newberg & Dunn, 2002). The 1996 Council on Competitiveness, a nonprofit forum of chief executives from industry and academe, established the position that “R&D partnerships hold the key to meeting the challenge of transition that our nation now faces” (Council on

Competitiveness, 1996, p.3). These public/private partnerships increasingly require the participation of universities in the R&D function.

The climate for university-industry collaboration is far more encouraging than in the past. For industry, global competition has forced businesses to turn to universities to find ways to make their organizational processes more effective (Abrahamson, 1996, Micklethwait & Wooldridge, 1996, Pfeffer & Sutton, 2000). Moreover, many companies, in an effort to reduce overhead, have decreased the size of their R&D staff and are using universities to fulfill that function (Cohen, Florida, Randazzese, & Walsh, 1998). An additional benefit is that public policy provides tax breaks for corporate funding of university research and requires university/industry partnerships as a condition of funding.

In the past, collaborations were essentially sponsorships by industry of university research to solve industry-specific problems. Today industry views the university as a source of complementary expertise, knowledge, and resources that are frequently not easily available in the industry environment (Starbuck, 2001). Moreover, university partnerships usually don't carry with them the conflicts of interest so prevalent in industry partnerships. At the same time, industry-university collaborations have also sparked serious criticism that they compromise and weaken the academic mission (Cohen, 1998). One of the main dilemmas is the conflict between the open inquiry principle at universities and industry's desire to restrict the diffusion of information to maintain a competitive advantage. Despite some of the negatives, industry's and the university's share of R&D is increasing while government's share is decreasing (National Science Foundation, 1996).

Four basic models of industry-university collaboration exist (Newburg & Dunn, 2002). They will be reviewed briefly here.

4.2.1. University to Industry Technology Licensing

Licensing university technology is generally the most common form of collaboration where the university grants certain rights of use to its knowledge, generally in the form of a patented invention. In return, the university receives royalty payments. University technology transfer is a result of the Bayh-Dole Act (P.L. 96-517, later amended by PL. 98-620), which incentivized universities to transfer the results of their research. By creating a uniform federal patent policy that allowed universities to retain title to inventions developed with government funding, universities became partners with government and industry to raise the level of innovation and commercialization. Since the Bayh-Dole Act, invention disclosures at universities have increased dramatically. Between 1991 and 1998, invention disclosures increased by 59 percent and new patent applications increased by

164 percent in the same period. The number of licenses executed increased by 120 percent (Pressman et al, 1999). Research by Rogers, Yin, and Hoffmann (2000) determined that the most effective universities in technology transfer are large research universities with more resources, higher faculty pay, and an office of technology licensing that was established early.

4.2.2. Industry-Sponsored University Research

In this model, the university trades its expertise and resources in exchange for industry funding to solve a particular research problem. The funding company may be entitled to right of first refusal to license the technology resulting from the research. In this situation, the university must carefully weigh the risks and advantages of being essentially in a work-for-hire situation.

4.2.3. Spin-off Companies

Some technologies are more appropriate for a start-up company that is spun-off out of the university. In this scenario, the inventor may take a leave of absence from the university to work full-time in the new company for a year or two, then return full-time to his or her research position at the university. Some universities offer incubator facilities on or off campus where researchers can locate their spin-off ventures for a period of time before taking spinning out of the university.

4.2.4. Idea Laboratories

The Massachusetts Institute of Technology's (MIT) Media Laboratory and the University of Southern California's (USC) Integrated Media Systems Center (IMSC) are unique structures that permit multiple projects to coexist as a single research center. Under this model, private companies support the laboratory financially in return for the ability to follow a stream of research and have first right to license any technologies coming out of the lab. Projects within the lab are usually synergistically related; that is, they have value as individual technologies, but integrated, they create many more opportunities for new applications. For example, USC's IMSC focuses on media systems: sound, panoramic video, haptics, streaming, and compression technologies. Together these technologies form an immersive technology platform that permits the development of such diverse applications as the treatment of social phobias and learning disorders, immersive music and video environments, and interactive simulations. The mutual benefit of the idea lab structure is that it provides unrestricted industry support for academic research while at the same time giving private industry access to university talent.

5. Commercialization as a Process

Considering technology commercialization as a process is a way to study individual tasks as part of an integrated whole. A process is a linked chain of interdependent activities that cross many functions to develop, produce, and distribute or transfer a technology from concept to market (Garvin, D.A., 1998). In addition to the engineering and market analysis processes, the overall commercialization process is comprised of research, strategy, decision-making, communication, political, negotiating and selling processes. Perhaps the most studied of these processes has been decision-making beginning with the work of Barnard and Simon that described decision-making as a distributed activity, extending over a period of time and involving several people (Barnard, 1938 and Simon, 1975). Early research attempted to model, without much success the decision process as a sequence of events. Later research concluded that decision-making involves simultaneous activities that occur in different stages rather than sequenced (Witte, 1972). But even a stages approach cannot capture the intricacies of the commercialization process: the scope of interrelated activities, the impact on the whole process of one change at one point, the numbers of people that move in and out of the process at various points, and the impact on resource allocation.

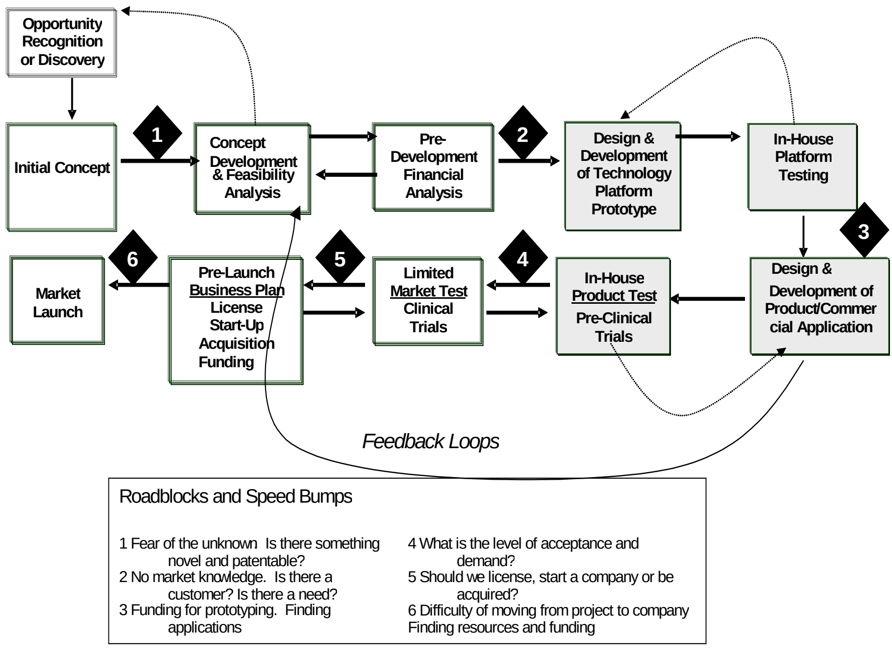
The commercialization process is also a learning process that involves knowledge acquisition, explanation, diffusion, and retention. How knowledge is acquired determines the activities, behaviors, and sub-processes that affect the overall commercialization process from creation through market research, intellectual property protections, product development, and business planning. How that knowledge is interpreted and diffused throughout the process affects everything from time to market to launch decisions. Furthermore, the combination of scientific and technical knowledge with tacit manufacturing and sales knowledge can create a significant competitive advantage for a company. When know-how represents a relatively high portion of overall investment, it is typical to find correspondingly high R&D expenditures (John, Weiss, and Dutta, 1999). Yet another advantageous characteristic of know-how is that it cannot be used up; it is regenerative (Glazer, 1991). The result is that once the cost of producing the first unit is recouped, the cost of replication declines precipitously.

Another aspect of commercialization processes that is often overlooked when discussing how an invention moves from idea to market is the political processes that can derail a project at any point and certainly contribute to making commercialization more art than science. The ability to move successfully through the commercialization process, particularly in a large organization, is often a function of how effective the project champion is in aligning and harmonizing competing interests while simultaneously motivating and securing commitment from everyone involved (Garvin, 1998). This is no easy task, particularly in the development of radical technologies because typically costs are high, outcomes are uncertain, and economically the development of radical technologies makes no sense because the return on investment is many years out if ever.

Some research has found that most technology projects have more than one champion (Leifer et al, 2000). In fact they were able to identify technical champions, project champions, business unit champions, and executive champions. Technical champions are typically the inventors or discoverers who drive the idea forward in its earliest stages. Project champions, by contrast, are the interface between the project, the rest of the organization, and external partners. Business unit champions are those who have the ability to see that the project transitions from project status to an operating unit or start-up venture. The executive champion is the senior executive who can cut through all the barriers and smooth the path to completion. Many a technology has successfully made it through product development only to fail to complete the commercialization process because it didn't have the right champion at the right time to break down the barriers.

In Figure 3 opposite, I offer a framework for studying and explaining the technology commercialization process. It is based on the work of Cooper, 1999, and others and highlights the key issues developed throughout this chapter. While the major components of the framework will be discussed in more detail in later sections, it is appropriate to provide an explanatory overview at this point.

Figure 3: Framework for the Innovation and Commercialization Process



Although the framework depicts what appears to be a linear process, the technology commercialization process is, in fact, iterative with many feedback loops and tasks that may occur in parallel. Throughout the process, one finds several challenges in the form of speed bumps that slow down the process and roadblocks that may send a project in a new direction or stall it indefinitely. In fact, the period between discovery or invention and reaching the market is often called the "valley of death." The valley of death is characterized by a lack of structure, resources, and expertise (Markham, 2002). One of the principal explanations for this period with a high potential for failure is that the technical people often do not understand the motivations and focus of the business members of the team. They tend to have different goals. The primary challenges (there are many more) are listed below the diagram in Figure 3.

5.1. Discovery and Opportunity Recognition - the Fuzzy Front End

The innovation and commercialization process is precipitated by a discovery or recognition of a need. This discovery usually results from exploratory research that originally had no specific goal or outcome as its purpose. In fact, radical new technologies depend on exploratory research that may have preceded their development by years. The challenge at the discovery stage is to determine if the invention is truly novel and capable of being patented. Whether or not the invention has commercial potential is often not apparent early on, particularly in the case of a radical or disruptive technology for which there is no precedent.

While any technology that ultimately reaches the market is born of either a discovery or a recognized customer need, many invented technologies never go beyond these early stages because no commercial application can be found. Alternatively, one core technology may produce many possible applications, each with a different value proposition and a different customer. The challenge then is to determine which application should be pursued first. The Valley of Death exists because of the difficulty of making connections between technology in the laboratory and customer needs in the marketplace.

Most new projects fail at the beginning rather than at the end of the process (Khurana and Rosenthal, 1998). The discovery stage is part of what is frequently referred to as "the fuzzy front end," those activities that take place prior to the more formalized processes of feasibility analysis and product development. While much research has focused on the more formal aspects of the technology commercialization process, little has been done about looking at the most effective practices in the fuzzy front end of the process. The FFE is characterized by experimentation, bootstrap funding, and a high degree of uncertainty. It is generally comprised of five elements (Koen, Ajamian, Burkart, Clamen, 2001):

1. *Opportunity Recognition.* Here the firm (alternatively the entrepreneur) identifies opportunities that it wishes to pursue that are in alignment with its business goals. Opportunity recognition may entail a formal process or a more ad hoc, informal process.

2. *Opportunity Analysis.* Here the opportunity is held to the first level of scrutiny, which may be more or less intense depending on the attractiveness of the opportunity.

3. *Idea Genesis.* Here the idea is worked into something much more concrete. At this point, potential customers (if markets exist) may be brought in to provide input. Again, this may be a formal process or more informal.

4. *Idea Selection.* Since ideas are generally ubiquitous in creative environments, a screening process needs to be in place to select those ideas worth of continued study and application of resources.

Screening at this point in the process is far less rigorous than in the more structure part of the commercialization process.

5. *Concept and Technology Development.* At this point, a business case is developed for the technology concept that includes some initial and broad estimates of market potential, customer needs, funding required, competitor analysis, technology risks, and so forth.

Some research has found that the proficiency of the FFE is directly correlated to a high level of innovation and not to a high level of proficiency in the product development process. That is, companies that have effective processes in the FFE tend to experience higher levels of innovation (Koen, Ajamian, Burkart & Clamen, 2001). It is difficult to go forward with a project or secure the necessary resources and commitment where market, technological, and competitive uncertainties exist. Uncertainties in the commercialization environment include emerging technologies, changing customer needs, shortened product life cycles and the impact of outsourcing and partnering with external organizations. To succeed at this stage in developing a robust product definition requires accessing information and feedback from potential customers and others in the value chain as well as internal sources of feedback in the form of engineering, R&D, manufacturing, and marketing. One of the key goals of the FFE is to reduce the level of uncertainty so that the new technology can move into the more formalized new product development (NPD) phase.

It is important to note here that radically new or disruptive technologies follow a different path in the FFE as they generally do not have identified markets in the early stages. Their market opportunities are usually unpredictable or emerging so conventional strategies for market identification and research are not appropriate. As a consequence, the FFE for radical technologies is especially fuzzy.

5.2. Feasibility Activities

Invention and innovation are followed by a period of general feasibility analysis, both technical feasibility of the invention and market feasibility. These tasks typically proceed simultaneously and result in a well-developed and compelling business concept and business model. In addition, the first estimates of the cost to produce a prototypical design are developed as well as an initial plan for pricing. The decisions made at this stage in the process are critical because from this point forward the costs increase exponentially and the project becomes more focused, so fewer changes are permitted. The roadblocks at this stage typically revolve around lack of market knowledge and ability to identify and test a particular market, an unforeseen technical problem, or the ability to fund the development of the prototype. Feasibility analysis is part of the whole design process. The design process then is both intentional and evolutionary, coming about from a series of refinements and iterations. Design "grounds a particular innovation in its particular time and place" by defining it with specific meanings and values (Hargadon, 2001). The design is robust when it can immediately and effectively position an innovation into a world that is familiar to the customer while maintaining sufficient flexibility to allow for future evolution (Eccles, Nohria, & Berkley, 1992).

Effective design strategy calls for a combination of familiar features, new features, and some features that are kept hidden. Achieving a robust design is more difficult with a radical innovation where the benefits are usually not yet recognized or appreciated. For example, in 1999, TiVo launched the digital video recorder in the United States, which allows the user to program, record, and replay television programs in a digital format. TiVo's developers faced many challenges because for the company to survive in the short term, there had to be rapid adoption of the technology so the company could recoup the enormous development costs. To achieve rapid adoption, TiVo had to show customers that TiVo exploits the very familiar television and VCR. So the product was introduced as an advanced generation of VCRs. Over the long term, however, TiVo believes that its technology will replace existing technologies while leaving customer habits unchanged so it must be able to evolve beyond current familiarity with the VCR (Hargadon, 2001). TiVo intends to change the way television is broadcast and viewed. Because it contains a modem and a computer, TiVo, which runs on an open-source Linux operating system, can evolve far beyond the capabilities and scope of a VCR. In an effort to avoid confusing customers and to keep some capabilities hidden, TiVo minimized the ability to record TV shows without commercials. Of course, it also did this to pacify the networks that it needed to provide scheduling (Lewis, 2001). The bottom line is that TiVo walks a fine line between relying on familiar functionality and distinguishing itself from existing technology, so its adoption rate has been slow.

5.3. Product Development Activities

The next stage in the process focuses on prototype design and development and in-house product testing. In the case of a radically new technology, the platform or base technology is developed and tested; it then serves as the foundation for a family of products based on the core technology. Each of the derivative applications of the core technology will also need to be developed, tested for technical and market feasibility, and refined. The challenges at this stage center on determining if there is sufficient market demand and who the first customer is likely to be.

Once the product passes in-house testing and is suitably market ready, it is usually tested in a limited market to check for final bugs and to ensure that the correct first customer has been identified.

5.4. Commercialization Activities

In preparing to launch the new technology, the main speed bump is the critical decision of whether to license, start a company, or be acquired by a larger firm. In any case, a business plan needs to be developed that will detail the launch strategy and transition the project to a fully operational company. The biggest stumbling block at this stage is the transition because starting and running a company requires a very different set of skills than running an R&D project.

Successfully crossing the Valley of Death requires a champion, whether that be the entrepreneur, the inventor, or the corporate venturing champion. Someone must take the lead in driving the technology and its associated business concept forward in a timely fashion.

6. The Challenges Associated with Commercialization

There are many challenges associated with the commercialization process. At the University of Southern California, we did a study to determine the key challenges that face researchers as they attempt to make their way through the process. We found that these challenges are 1) fear of the unknown, 2) lack of market knowledge, 3) funding the prototype, 4) determining how to commercialize, 5) transitioning from project to operations, and 6) the role of failure.

6.1. Fear of the Unknown

In the discovery stage and the fuzzy front end of the commercialization process, it is difficult, if not impossible, to determine economic impacts from a fundamental discovery like quantum theory, wave mechanics, or magnetic resonance. Yet universities and industry alike employ the yardstick of economic impact to make decisions about intellectual property protections, funding development, and so forth to reduce risk and ensure their funders that their investment is well placed.

University researchers in particular, and industry researchers to some degree, tend to be so focused on their work that they often fail to disclose their discoveries to the university's office of technology licensing (OTL) or even to their departments until they are about to publish in a research journal and or present at a conference (Allen, Maya, and Valencia, 2002). At that time, they realize that they have not yet protected the IP and seek last-minute help. Along the way they have been open to discussing their discoveries with colleagues and others without the protection of non-disclosure agreements or provisional patents because of their naturally collegial relationships. However, this desire to share information leaves them vulnerable to having their research commercialized by someone else. Moreover, researchers often do not know how to disclose their inventions in a manner that makes the market potential and benefit to the university clear to the OTL, which must typically make a rapid decision whether to file a provisional patent application or not. Furthermore, researchers are often not familiar with the OTL's decision-making process and criteria for submitting a patent application. Consequently, they grow angry and discouraged when they are denied the university's services for filing a patent.

Working on the patent application, even with the aid of a patent attorney, is a daunting and time-consuming task for which most researchers have no patience. They variously perceive the patent process as long, arduous, arbitrary, and capricious, and are frustrated by the detail and attention to wording that is associated with a patent application. They also face having to educate the patent attorney in their technology so that the attorney understands the invention enough to prepare the patent application, leading to comments such as "I should have written it myself." They are also unaware of the importance of thinking ahead to potential applications of the technology in areas outside their area of expertise. As a result, they make it easy for someone to take their technology and patent it for a new use, thereby potentially denying the inventor and the university their rightful royalties.

6.2. Lack of Market Knowledge

Researchers, in general, have had no experience researching markets and testing potential customers. They tend to focus on the technological challenge without consideration of its need in the market. Consequently, there is a significant gap between science and technology requirements and market-level requirements. Industry solves this problem by bringing potential customers into the product development process at the earliest stages, even as early as the fuzzy front end. Universities often tap the expertise of their business schools employing qualified students to undertake market feasibility analyses.

6.3. Funding the Prototype

It is not uncommon for researchers to come to the end of a grant period with no strategy in place for funding the commercialization portion of the product development process. This lack of follow-on funding leaves them vulnerable to pressured decisions and to undervaluing their technology to secure quick financing. Furthermore, a researcher’s idea of an effective funding presentation generally focuses too much on details of the technology, which the researcher understands, and pays little attention to the customer, the value proposition, or the business model, which is of primary interest to the funding source. The result is an inability to secure funding.

6.4. Determining How to Commercialize: Start-up, License, Acquisition

Researchers generally do not have sufficient business exposure to allow them to see the breadth of potential options for commercializing their technology. In general, they will identify applications in industries with which they are familiar, but usually not any applications outside that industry. They typically do not have the time or the interest to network outside their areas of specialization. They also tend to assume that letting the OTL license their technology is their only option, so they often don’t consider finding their own licensee or strategic partner, or starting a new venture to commercialize the technology.

6.5. Transitioning from Project to Operations

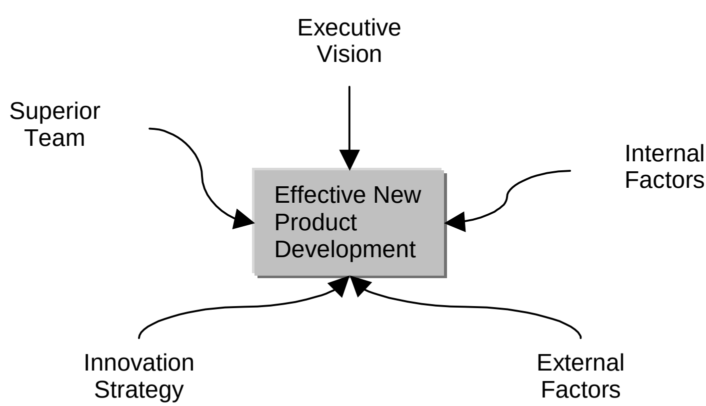
It is only in an ideal world that new technologies move from project status to operations easily with a product ready for manufacture and manufacturing ready to produce the product. Part of the problem stems from the fact that most development projects go through several iterations, changes based on feedback from the test market. Having satisfied the early adopters, the team is often faced with a completely new set of challenges from the mass market customer (O’Connor, Hendricks, and Rice, 2002). These modifications often affect manufacturing procedures and slow the manufacturing launch.

To improve the ability of a project team to move successfully to an operations status, the Industrial Research Institute, in conjunction with a group of academic scholars devised a tool, the Transition Readiness Assessment Form (TRAF), for assisting transition teams in assessing what remains to be done to prepare for full operations and who is accountable for what. Those filling out the form consider two issues: (1) whether or not any work to address a particular section of the TRAF is required and (2) the extent to which that section is relevant or important to the project's success (O'Connor, Hendricks, and Rice, 2002). Key findings from companies using the tool were lack of manufacturing and sales readiness, lack of resources for the launch phase, and lack of partner and human resource readiness.

6.6. The Role of Failure

Much of the research literature has looked at which factors are essential for new-product success. It is generally believed that five factors contribute to effective new-product development as depicted in Figure 4 (Connell, Edgar, Olex, Scholl, 2001).

Figure 4: Essential Factors for Product Deveopment Success



Executive vision suggests that top management support and commitment to the new product development process will facilitate its success. An appropriate innovation strategy will match activities to goals. With radical technologies, a learning-based strategy is appropriate, while for incremental innovation, a stage-gate approach with milestones is important (Lynn and Akgun, 1998). In addition, putting together a superior, cross-functional project team will ensure the execution of the innovation strategy. The correct organizational structure is also critical to facilitating communication, knowledge-sharing, and reporting functions. External factors that affect successful NPD are economic, regulatory, environmental, political, and social in addition to industry forces such as the supply chain, competition, and customers. Absent these factors, failure would seem to be the outcome, but some research has found that this is not always true (Connell, Edgar, Olex and Scholl, 2001). Sometimes the critical factors can work against a project, but through the exceptional efforts of a superior team, the project can still succeed. At other times, a single factor can be the downfall of a project that otherwise would have been successful.

Today, it is common for companies to claim that they are market driven, that their research and development match corporate strategic interests. Unfortunately, this attitude frequently leads to new product failure because there has been no prior exploratory research that would position the technology ahead of the competition (Beall, 2002). In general, exploratory research takes place in new or novel arenas. For example such well-known inventions as glass light bulbs, heat-resistant Pyrex glass, and ultrapure glass-based optical fibers are the result of exploratory research. In fact, Hyde’s discoveries of silicones and chemical vapor deposition in the 1930s and Stookey’s discovery of ceramics in the 1950s contributed to the development of many products that we take for granted today. Important discoveries are typically random and unexpected; if they are not embraced for their potential value, a new technological opportunity may be lost until someone else chances upon the discovery. That is why the FFE is so important; the willingness to take advantage of a laboratory surprise can lead a team in a whole new direction. Unfortunately, exploratory research is often discouraged by holding such scientists to short-term return-on-investment criteria and by a premature focus on applications.

7. Conclusions and Implications

The process of taking an invention from idea to business concept and then to market is embedded with a unique set of challenges and opportunities that occur in an uncertain, volatile, and demanding environment. Products today must be developed faster, prototyped earlier, and brought to market in record time. In many respects, it is easier for small entrepreneurial companies to accomplish these daunting feats than it is for large companies to break away from their inertia to do it. But in all cases, a thorough knowledge of the commercialization process and the challenges that might derail a project along the way are critical to commercialization success.

In a new environment where industry and academe are both being pressured to improve their ability to bring the results of government-funded research to market, it is important to identify, analyze, and improve on the commercialization processes that currently exist, particularly with respect to those processes in the fuzzy front end. Most private companies and all colleges and universities are faced with limited resources to direct toward these efforts, so it is critical that any choices made be the right ones. The emphasis on innovation and technology commercialization is not a fad that will go away in a relatively short period of time. Rather it is a vital component of economic growth. Investment in R&D and the support of an environment that encourages entrepreneurship will fuel economic growth for a long time to come.

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