PATENT ORIENTATION AND FREEDOM TO OPERATE IN THE MANAGEMENT OF TECHNOLOGY

by

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ABSTRACT

Can firms keep up with the pace of technological change? This thesis explores the idea that firms differ in their adaptive behavior, namely fast response to technological change, based on their relative resource allocation to different patent orientations. This thesis begins with a thorough review of theories of intellectual property, the development and use of patents and patent citations, and challenges in the accurate sampling of patents . Then, from a detailed analysis of patents in the photolithographic aligner industry, the thesis examines the extent to which firm patenting behavior is oriented towards (1) internal technologies (2) customer and supplier technologies (3) competitor technologies and (4) technologies that are assigned to peripheral firms outside of the core industry. It is shown that firms whose patent orientation focuses on internal technological development and competitor technologies are adaptive relative to the pace of technological change, whereas focus on customer of supplier technologies offers no adaptive benefits. These results imply that the patent systems may not just offer economic gains, by protecting internal technological development and establishing barriers to entry, but can also offer organizational gains. In particular, the results suggest that organizations focused on 'freedom to operate' from competitor patents are more adaptive.

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Chapter 1: Introduction

This thesis explores the overlap between intellectual property, particularly patents, and the management of technology. The thesis consists of five chapters which gradually builds up to the idea that differences in how firms manage patented technology has very important organizational implications that impact organizational adaptability and performance. This conclusion is reached after a significant investment in understanding the theories of intellectual property, how patents and patent citations are made, and how to sample patents to accurately represent the technology and industry that is being studied. This thesis is composed of four additional chapters.

Chapter 2 seeks to review a wide spanning literature on important topics in intellectual property rights, and more specifically patent rights with theories of technological development. The chapter begins with an examination of four broad philosophical theories of intellectual property rights, and then expands to describe several of utilitarianism theories as treated by various economic perspectives. The paper then examines the limitations and implications of the core economic theories, as illustrated by the New Institutional Economic framework. Finally this chapter briefly addresses concerns for the use of patent data and statistics in the emerging organizational literature and potential opportunities to develop this into new theories of patenting.

Chapter 3 addresses how the patents and citations are made the implications of this on both the quality of patent data, but more importantly on the ability of firms to use the patent system effectively. The article explores two phenomena not significantly addressed by the theories presented in Chapter 3: (1) the complexities of patent thickets, including issues of freedom to operate and design, and (2) the increasing concern that overly broad, and inadequately novel, patents are issuing from the USPTO. The chapter will examine the role of various actors in the patenting process, and will argue how individual search disincentives may affect the quality of patent citations and the use of patent data. The article will also consider how these individual disincentives may also impact the US intellectual property system as whole, and suggests potential mechanisms by which some of these concerns may be addressed.

Chapter 4 seeks to expose and examine systematic biases that can arise when researchers use inconsistent patent sampling criteria for panel patent data. In particular, this paper will examine how different patents can be sampled, how these different samples overlap, and a preliminary discussion of how these issues can affect the interpretation of management scholarship that relies on patent data.

Chapter 5 develops from the earlier chapters, and asks an important management of technology question: "Can firms keep up with the pace of technological change?" Chapter 5 explores the idea that firms differ in their adaptive behavior, namely fast response to technological change, based on their relative resource allocation to different patent orientations. From a detailed analysis of patents in the photolithographic aligner industry, the chapter examines the extent to which firm patenting behavior is oriented towards (1) internal technologies (2) customer and supplier technologies (3) competitor technologies and (4) technologies that are assigned to peripheral firms outside of the core industry. It is shown that firms whose patent orientation focuses on internal technological development and competitor technologies are adaptive relative to the pace of technological change, whereas focus on customer of supplier technologies offers no adaptive benefits. These results imply that the patent systems may not just offer economic gains, by protecting internal technological development and establishing barriers to entry, but can also offer organizational gains. In particular, the results suggest that organizations focused on 'freedom to operate' from competitor patents are more adaptive.

Chapter 2: A Review of Major Theories, Themes, and Emerging Issues in the Scholarship of Intellectual Property Rights and Patents

This chapter seeks to review a wide spanning literature on important topics in intellectual property rights, and more specifically patent rights with theories of technological development. The chapter begins with an examination of four broad philosophical theories of intellectual property rights, and then expands to describe several of utilitarianism theories as treated by various economic perspectives. The paper then examines the limitations and implications of the core economic theories, as illustrated by the New Institutional Economic framework. Finally this paper briefly issues in the use of patent data and statistics and the migration of this type of data in emerging organizational literature.

2. 1 Introduction to Intellectual Property Rights

The system of intellectual property rights (IPRs) is an institution that is even older than the capitalist industrial society. In 3200BC potter marks on fired pot clay provide a precursor to trademark protection for First Dynasty Egyptian Kings, and in 700-500 BC chefs in Sybaris, a Greek Colony in southern Italy were granted one-year monopolies on the preparation of unusual or outstanding dishes (Grandstrand 2000). Today, this system of property rights has grown to provides a loose cluster of legal doctrines regulate the use of different types of ideas and insignias, and includes protective laws of copyright, patents, trademarks, trade secrets and 'right of publicity' (Fisher 2001). In the United States, the need for a system of intellectual property rights was defined from inception, as

Article 1, Section 8 of the United States Constitution grants Congress the power "To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries."

The early constitutional grant in the United States has resulted in a number of statutes being enacted by Congress including the Copyright Act [17 U.S.C.A. Sec 101-810], the Patent Act [35 U.S.C.A. Sec. 1-376], the Plant Variety Protection Act [7 U.S.C.A. Sec. 2321-2583], and the Semiconductor Chip Protection Act [17 U.S.C.A. Sec. 901-914]. Additionally, the federal government has enacted the Trademark Act as amended [15 U.S.C.A. Sec 1051-1127] and there are state laws regarding trade secrets and of misappropriation of other information (Besen and Raskind 1991). The United States is also becoming increasingly involved in international intellectual property conventions include the Berne Convention for the Protection of Literary and Artistic works, the Universal Copyright Convention, and the Paris Convention for the Protection of Industrial Property. More recently intellectual property issues have become prominent in the discussions on the General Agreement on Tariffs and Trade (GATT) and its property rights component, the Trade-Related Aspects of Intellectual Property (TRIPS).

The increasing importance and recognition of strong intellectual property rights in the United States, ushered in what is considered the U.S. pro-patent era in the early 1980's (Jaffe, 2000). This move was not only because the intellectual property rights (IPR) system began to be considered as a more important element of traditional capitalism, but also because the United States felt a concern that its ability to appropriate returns from research and development was being significantly challenged by several Asian economies, and most especially Japan (Granstrand 2000). It is now becoming increasingly recognized by academicians and practitioners that the economic and cultural importance of intellectual property rights is becoming a fundamental issue in technology development and the economic growth, not only in the United States, but also on a global scale.

As mentioned earlier, the history of intellectual property rights is rich and ancient; indeed intellectual property rights have been around for longer than any theories that have been used to explain them. As Edith Penrose (1951) notes about the patent system, "if international patent laws did not exist, it would be difficult to make a conclusive case for introducing them; but the fact that they do exist shifts the burden of proof and it is equally difficult to make a really conclusive case for abolishing them." Certainly scholars are now more interested than ever in understanding why intellectual property rights are important, and particularly how they impact innovation, technological and knowledge development, and economic growth.

2.2 Four Broad Theories of Intellectual Property

In an excellent review of the theoretical literature, William Fisher (2001) divides the theories of intellectual property into four economic and philosophical theoretical traditions: (1) Utilitarianism; (2) Labor Theory; (3) Personality Theory; and (3) Social Planning Theory.

2.2.1 Utilitarianism

The utilitarianism theory argues that intellectual property rights should be constructed to maximize net social welfare, or more simply the greatest good for the greatest number. Utilitarianism theories have strong economic traditions, and are often examined by either the "wealth-maximization" criterion (Posner, 1986), or the "Kaldor-Hicks" criterion which maximizes social welfare by finding a state in which there is a minimum opportunity for a "gainer" to compensate a "loser" for the "loser's" loss in utility (Kaldor, 1939).

Within the utilitarianism framework there are three general ways that an intellectual property system might enhance social welfare. The first of these, incentive theory, was in part developed William Nordhaus who was concerned with optimal patent durations. Nordhaus demonstrated that each increase in the duration or strength of patents would stimulate an increase in inventive activity and social welfare, while at the same time social welfare was reduced by larger administrative costs and deadweight monopoly losses (Nordhaus, 1969). William Landes and Richard Posner also use this approach with regards to both copyright and trademarks, arguing that copyright provides incentives for creators of intellectual products that are easy replicated to recover costs of their work (Landes and Posner 1989). These same authors also argue that trademarks create incentives for businesses to produce consistently high quality products, as trademarks confer low consumer-cost information about product quality and history (Landes and Posner 1987).

A second way by which intellectual property rights might be considered to enhance social welfare focuses on the optimization of patterns of productivity was brought forth by Harold Demsetz. Demsetz argued that copyright and patent systems signal producers in directions most likely to enhance consumer welfare. Rather than impede public dissemination of technologies, this approach drives benefits as intellectual products are sold or licensed to that part of society that wants them and is willing to pay for them (Demsetz, 1967).

A third approach in examining the social welfare argument is through the rivalrous invention theory. Deived from Yarom Barzel (Barzel 1968; Fundenberg et al., 1983; Dasgupta 1988), this theory argues that uncoordinated and duplicative races towards technology development is a source of economic waste, and therefore systems of intellectual property reduce, or prevent, many groups from trying to reach the same potentially lucrative invention. Similarly, the idea of 'inventing around' a rivals patented technologies is also socially wasteful, and this theory argues that society needs to find ways to dissipate resources so as to prevent this.

2.2.2 Labor Theory

The second common framework, the labor theory approach, derives from the early writings and philosophical traditions of John Locke (Hughes, 1988). The framework suggests that a person who uses resources that are unowned, or held in common, has a natural property right as a result of that person's labor. The critical idea here, as emphasized by Robert Nozick (Nozick, 1974), is that in using the common property, or unowned resources, the inventor does not cause net harm to others, and thus does not cause the commons to be poorer as a result of the inventor's labor and invention. Thus, provided there is no net harm, Nozick argues that the creator is creating a new property that they should rightfully own. However, to the extent that this framework should be used, it suggests that intellectual property protection should neither restrict individuals who create on their own intellectual property without using the knowledge of the previous intellectual property, and that the protection of intellectual property should not be longer than the period of time it would have taken for another individual to develop the intellectual property independently. This approach, while appealing from a philosophical standpoint does not however offer much guidance in the way of developing intellectual property policy or laws.

2.2.3 Personality Theory

The third framework, derived loosely from the writings of Kant and Hegel, is the personality theory framework. This approach argues that intellectual property rights are justified in that these rights protect artifacts which authors and artists have expressed their personality, personhood, or will. As such, it may also be argued that intellectual property rights are important in that they create social and economic conditions conducive to individual creativity and expression (Radin, 1993). Because intellectual property in such a framework is seen as and expression of individual personhood, including one's personal image, mannerisms, and history; highly expressive intellectual activities are more deserving of strong protection, as is a person's 'persona' and image, even though certain of these properties would not necessarily result from labor (Hughes, 1988). While the framework offers us some guidance, scholars attempting to use this framework are highly conflicted (Fischer, 2001). There are also two serious problems in applying these theories. Firstly, the concepts of persona and "personhood" are abstract and very poorly defined. Secondly, there is a problem of what is described as fetishism (Radin 1982), which focuses on the question of which of the tastes of the culture should be indulged. In this, the question asked is how is the individual persona differing from society, and what tastes of society, be it for example nationalistic, nostalgic, or ethnic tastes, that will inevitably need to be defined and understood for intellectual property dispute resolution.

2.2.4 Social Planning Theory

The final framework suggests that a system of intellectual property rights must confer and foster the achievement and planning of a just and attractive culture. This philosophy, of what is best termed social planning theory, is in part derived from a wide group of philosophical and legal theorists including Thomas Jefferson, Karl Marx, the Legal Realists, and classical and modern proponents of classical republicanism (Fisher 2001). Indeed while this emerging and growing tradition is similar to the utilitarian perspective from a technological standpoint, it is dissimilar in that it does not focus on social welfare, but rather on deeper visions of social desirability.

In the construction of social planning theory one of the most difficult choices in directing intellectual property rules is the problem of actually defining a just and attractive culture. In attempting to achieve a just and attractive culture, law and policy makers could focus on issues of improving: consumer welfare, the breadth of ideas and information; the breadth of artistic tradition; distributive justice and the sharing of informational and artistic resources. The law could also focus semiotic democracy, whereby all persons are encouraged to be participatory in shaping ideas and artifacts in the world, aspects of sociability in enhancing 'communities of memory', and policies that promote individual respect (Fisher 1998). Considering philosophical debates are still raging on most of these topics, the ability to derive adequate directions for the altering or developing of intellectual property rights is as difficult in this framework as we have seen in the others.

2.3 Intellectual Property Rights, Utilitarian Approaches, and Economics

Although there are many views and frameworks in which to consider intellectual property, certain views above others have been utilized in practice more frequently. Both the personality theory and labor theory perspectives have been criticized on the fact that they face many difficulties in measuring and defining such things as personal freedom and just society. However, by contrast, utilitarian and labor theory approaches, perhaps as they tend to be more economic and quantitative in nature, are often seen as more neutral, objective, and determinant (Fisher 2001). Indeed, as Fisher argues (2001), all of these arguments are sharply limited. However, as the utilitarian and less frequently labor arguments are used most often in arguments towards innovation, technological change and economic growth, we shall examine those arguments, and particularly those that focus on patents, more closely.

In economic traditions there is a classic view that intellectual property rights allow for a producer to derive a monopolistic price and output as an incentive to elicit desired investment in new intellectual creations. As with the classic understanding of monopoly competition, and consistent with the utilitarian view described earlier, monopolistic pricing is of net cost to society, although the development of innovations and new technology is argued to be of a new benefit to society. However, in recent years the development of a field of research termed the New Institutional Economics (NIE) has begun to question these core assumptions and conventions in the economic literature regarding intellectual property rights. Of particular concern to followers of the NIE is that classical theory implicitly considers products, markets, and intellectual property rights as coextensive (Merges 2000). However, as most recent literature and practice seems to illustrate, intellectual property rights and intellectual products are often far more complex than a single one to one mapping. Indeed as Merges argues, many innovative products have multiple technological and intellectual property components. For example, technological products may have may separate components that are individually or collectively covered by patent rights. Similarly, artistic or expressive products, such as movies or print, may also have multiple copyrights on components such as writings, pictures, and sounds. Indeed, classical theories also need to be expanded for products exhibiting the qualities of previously mentioned intellectual property rights and the use of trademarks. The ideas of NIE are important to consider as we examine the four broad economic theories of patenting.

2.4 Four Economic Theories of Patents

As this article has already made apparent, theories of intellectual property rights are diverse and complex. Historically, within the field of economics, theories of intellectual property have been rife with controversy. As far back as few hundred A.D. policies taken by different Roman Emperors have been diametrically opposed (Granstrand 2000). In modern times, an early economic review by Machlup (1958) recounts a long history of hostility towards a strong patent system, and this view is echoed more recently by such scholars Scherer and Ross (1990), and Thurow (1997). However, other writings, such as those such as Mazzoleni and Nelson (1998) argue that more recently opinion and practice has been in favor of a stronger patent system, so clearly the debate continues. As Mazzoleni and Nelson describe, there are four major broad theories patenting within the economic literature: (1) Invention Motivation Theory;

(2) Induce Commercialization Theory; (3) Information Disclosure Theory; and (4) Exploration Control Theory. As mentioned earlier these all generally fit into the utilitarian framework, that intellectual property rights confer potential economics benefits as well as economic costs.

2.4.1 Invention Motivation Theory

The first of these theories, termed invention motivation theory, is the classic argument described earlier under utilitarianism theory and argues that patents provide motivation for invention, and that in return, costs to society derive from the monopoly rents on the technology (Arrow 1962, Nordhaus 1969, Scherer 1972). However, while there are a few examples of firms and products that have been able to establish near monopoly positions using a few key patents, there is a early body of literature that argues that, with the exception of the pharmaceutical industry, patents are neither effective or necessary to appropriate returns from research and development (Scherer, 1959; Taylor and Siberston 1973, Mansfield, 1986, Levin et al. 1987). More recent studies, across Europe, Japa,n and the United States (Goto and Nagata 1996, Arundel and Kabla, 2001) show that it is a similar situation in the 1990's.

Not only does research not support the importance of patents in appropriating returns from research and development, there are several other major limitations to the invention motivation theory. Primarily this theory does not make any distinction between the importance of patents to new, entrepreneurial companies, which may arguably need patents for entry and financing (Eisenberg, 1996) or cross-licensing (Teece 1986), and incumbent companies which may not be as reliant on patents to appropriate returns from invention. Also, although the theory argues that the prospect of monopoly rents motivates firms and individuals to invent, it does not demonstrate that indeed this is the case. The classic Nordhaus model (1969) argues that the greater the degree of patent protection, the greater the resources a private firm will devote to pursuing the innovation and the greater the probability of discovery. However, a recent empirical study on 307 Japanese firms by Mariko Sakakibara and Lee Branstetter (2001) on the 1988 Japanese patent reforms shows that the increase of strength and scope of patents showed no increase in research and development spending or innovative output that could be contributed to the reform. A different study (Lerner 2000) across sixty nations over the past 150 years, and over 177 policy shifts, similarly demonstrates that increasing the strength of the patent system had few positive effects on patenting (as a proxy for further innovation), although consistent with Nordhaus (1969), there was greater significance with countries that had weaker systems of rights to begin with.

2.4.2 Induce Commercialization Theory

The second of these theories, the induce commercialization theory, is not entirely independent from the invention motivation theory and the distinction may follow from some of the earlier arguments. The induce commercialization theory argues a distinction between patents as offering incentives to invent, and patents as offering incentives to develop a commercial product. This theory is particularly useful when considering inventive output by smaller firms, universities, or non-profit research organizations, which often do not have the capacity to develop an invention to its commercial potential. In this sense, patents offer property to inventors so that they might approach arrangements with others to develop these inventions. As Mazzoleni and Nelson (1998) argue, the arguments of the induce commercialization theory led to the passage of the

Bayh-Dole act in 1980, which allows Universities to take titles to patents on University developed inventions and license them to external parties for development, rather than let the inventions enter the public domain, or commons. This reasoning argues that such forms of intellectual property protection offer some assurances to external parties that they will be able to appropriate returns from development, rather than compete or invest in development that may be easily imitated by competitors if the invention was in the commons. Similarly, patent protection may help small innovative firms obtain development financing (Lerner 1994, Hall and Ziedonis 2001) which may be even more crucial than having the invention itself.

There is evidence that the Bayh-Dole act significantly increased the extent to which American research universities have marketed, advertised, and gained commercial returns on their inventions (Jaffe 2000). There is also evidence that a large share of large incumbent product innovations were based on inventions from small firms (Mueller 1962, Reich 1985). However, other studies also indicate that many industry patents are not needed to induce development, and other strategies such as a head start on commercialization, or product secrecy, can effectively protect new inventions and technologies (Levin et al. 1987, Mansfield 1986).

2.4.3 Induce Disclosure Theory

The third economic theory of patenting, the induce disclosure theory, argues that the importance of the patent systems is to induce the disclosure of inventions to the commons. Unlike the previous theories, the induce disclosure theory argues that although patents do not necessarily induce innovation, they encourage and provide a vehicle for disclosure, and promote the sharing of technical information, knowledge, driving the potential for future use (Machlup 1958). This type of utilitarian argument is less focused on incentive systems but rather the idea of consumer welfare, and supports earlier philosophical arguments (Demsetz 1967).

The induce disclosure theory, although hardly treated in the literature, is very interesting, but not necessarily that informative on patent policy. Like the previous induce commercialization theory, the induce disclosure theory is likely to be most effective when a particular party cannot develop a particular invention itself, and thus advertises its invention (Mazzoleni and Nelson 1998). Where the theory might have a disconnect with other theories is that is suggests that in the modern world, where companies are the owners of most of the inventions, that companies with inventions that they themselves can develop would not likely patent in areas that they have the ability to innovate and develop in. Indeed there might be some support for this in a recent article (Pitkethly 2001) it was found that companies in Japan often obtain intellectual property, or publish intellectual property, as a means by which they can achieve freedom of action in their core competencies. This practice, not only prevents others from arguing patents around their technologies (as the invention would not be novel under Japanese patent law), but also ensures leverage against competing companies when external patents block product development. Thus, while this practice not explained by this theory, it may be consistent with the view that removing the monopoly incentive from the theory predicts certain phenomena of which there is some evidence in practice.

2.4.4 Patent Prospect Theory

The final theory of patenting is the prospect theory of patenting (Kitch 1977). The prospect theory argues that when there is an initial discovery or broad invention that opens up the potential for many future inventions, termed a prospect opening invention, the development of the prospect is likely to proceed in an inefficient and socially wasteful way. In some sense, Kitch argues that broad patents prevent over-fishing in the prospect pond. Using a similar concept, Kitch expects that in cases where the commons is a newly discovered technology space a tragedy of the commons will occur in technology space if there are no intellectual property rights to prevent too many firms from attempting to appropriate rents from the new technology.

The prospect theory as well as the induce development theory are two of the strongest arguments for offering broad and strong patent protection. However, as argued earlier, strong patent protection has not been shown to increase either research and development incentives, or innovation. It would also be extremely difficult to show that strong patents reduce 'wasteful mining', particularly as patents do not immediately become public. Thus, because of this lag in time between submission and public disclosure, the 'wasteful mining' may have occurred well before the patent issues. Two other problems are argued against prospect theory. First, when technological advances within a prospect are highly connected, for example as subsystems, system technologies can be impeded by cross-licensing difficulties caused by overly broad patents (Merges and Nelson 1990). Secondly, when the initial discovery is very far from a practical applications, particularly one where there may be many broad prospects enabled by such an invention (for example the initial discovery of transistor, or of laser technology, and more recently optical networking, and genetic technologies), the innovative possibilities may too high for any one firm to substantially pursue many of the potential prospects of the technology and thus potential for increased economic welfare might be left on the table if patent prospecting was the dominant innovative force.

2.5 Lessons From the New Institutional Economics

As mentioned earlier, these four broad economic theories of patenting are now conditioned on developments in the New Institutional Economics. As previously mentioned, products and intellectual property rights may affect various components or sub-components of property, and the rights may be of different types, scopes, and durations. The NIE brings in two important concepts, primarily developed in early contract theory (Williamson 1985), to bear on our understanding of intellectual property rights. The first concept is the idea of transaction costs in the transfer of economic assets while the second concept is the understanding that contracts are specific to the assets being exchanged. As alluded to earlier in the various theories, the NIE fundamentally brings to the fore the importance of considering multiple parties and institutions in theories of intellectual property. The consideration of institutions and transactions can occur at various levels including: (1) Pioneer and Improver Transactions; (2) IPRs and New Organizational Forms; (3) IPRs and the Anticommons; (4) Collective Rights, Cross-Licensing and Patent Pools; and (5) Political Institutions.

The importance of understanding the interaction between pioneer inventors and improvers is a critical component of Kitch's prospect theory. Recent work in this area develops models of bargaining scenarios between pioneers and improvers (Scotchmer 1991, Green and Scotchmer 1995) and other model have also been focused on arguments of patent breadth and length (Gilbert 1990). However, although these approaches help us with analytical frameworks, they are very limited in practice as often property rights are dominated by a single party, such as in the pharmaceutical industry, in overlapping subcomponent technologies between firms (Merges 1995), or in large, complex, multi-firm environments (Grindley and Teece 1997).

As Merges (2000) argues, many products encompass multiple components that are supplied, or subject to property rights held by individual firms. As such, the NIE is important in considering how these various physical and intellectual rights are coordinated to achieve all the inputs necessary for production. As we have seen previously, although the total amount of research and development does not seem to be affected dramatically by the strengthening of the patent system (Lerner 2000, Sakakibara and Branstetter 2001), there has recently been a substantial change in the organization of research and development, with more small specialty firms doing an increasing amount of R&D-intensive production (Lamoreaux and Sokoloff 1996). As such, there has been an increasing tendency of large firms to partner with smaller firms in specialized technologies using a myriad of organizational forms. Also, in the last fifty years there has been an increasing reliance on technology and intellectual licensing. The Bayh-Dole act in 1980 assisted in adding Universities and non-profit research institutions as a source of new technologies and intellectual property (Henderson et al. 1998, Mowery, Nelson et al. 2001), and other forms of inter-organizational relationships such as joint-ventures, R&D partnerships, corporate venture capital, spin-offs, and other strategic alliances are now being used to achieve corporate goals (Merges 1995, Roberts 2001).

Recent literature has begun to indicate that there may be a strong relationship between intellectual property rights and organization form (Mowery et al. 1998). In a recent study a firms propensity to engage in 'hierarchical integration', in the form of joint ventures, compared to contracting was examined (Oxley 1999). It was found that when there was weak protection of intellectual property rights, firms were more likely to engage in the higher cost joint ventures, as the costs of regular length contracting increased with decreasing intellectual property protection.

It is however important to note that there is also a significant debate of the use of inter-organizational forms, intellectual property, and the role of antitrust (Kaplow 1984, Gilbert and Shapiro 1996, Gilbert 2000). For example, in the United States, the Sherman Act declares that it is unlawful for any person to "... monopolize, or attempt to monopolize, or combine or conspire with any other person or persons, to monopolize any part of the trade or commerce among the several states, or with foreign nations..", a statement that is well at odds with inter-organizational intellectual property relationships (Gilbert 2000). However, although an extremely interesting topic, the conflicting concepts of intellectual property rights and anti-trust policy are beyond the theories that we will consider here.

Another similar development from the NIE perspective is the idea that transaction costs and coordination problems involved with too many multiple conflicting rights can become so high that innovation and development is stifled (Heller 1998, Eisenberg and Heller 1998). This argument, referred to as the "tragedy of the anticommons" is of a key importance to the NIE framework as it focuses on the transaction as a key variable in the design of intellectual property entitlements. There is convincing support for this issue as certain fast to market technologies, such as in agricultural biotechnology, medical devices, and semi-conductors technologies, are increasingly required to consider large, complex and multi-organizational arrangements to commercialize a technology. A developing body of literature, although very phenomena based, looks at a related issue in considering issues of freedom of action, freedom of design, and more broadly freedom to operate (Philips 1999, Philips 2000, Grindley and Teece 1997). Although not discussed by these authors, freedom to operate can be thought of as the effect another firms patenting on a firm where the transaction cost is so high that coordination and acquiring of intellectual property rights is not feasible. Arguably, there is certainly opportunity to consider the theoretical implications of this phenomenon, which will be further examined in Chapter 5.

While many scholars have accepted the idea of the anticommons, it is unclear if there is indeed a tragedy. Using the NIE framework, the anticommons is really just a transaction cost problem, and in finance terms might just be considered a market imperfection or clearing problem. In some sense, considering that the patent system is a public institution arguably designed to reduce market imperfections under utilitarianism, the anticommons argument is arguably a minor problem to a major fix. In an alternate view to Heller, it has been argued that the anticommons may be a useful impasse that allows society to develop innovative mechanisms and organization forms that lead to higher efficiency transactions and development (Merges 2000). For example, there are now many examples of collective rights organizations in such things as agricultural marketing pools, (Hoffman 1998), oil field unitization (Wiggins 1985), scientific research and universities (Merges 1996), the copyright arena (Rose 1998), as well as patent pools and cross licensing between companies (Grindley and Teece 1997, Pikethly 2001, Lerner and Tirole 2002).

Finally, although this is implicit from brief mentions of the history of intellectual property rights, we must that the system of intellectual property rights is a political process, and that political processes are highly influenced by interest groups (Olsen 1971). For example, scholarship has described gains to political sovereigns that accompany shifts in property rights (North (1989). Other scholarship has shown, through several historical case studies, that major policy changes are often long-term permanent changes that arise from rigorous political discussion, not measured experiments in change (Lerner 2000). There is also empirical research that confirms that inter-country economic development and growth is associated with stronger intellectual property rights (Knack and Keefer 1995; Dollar and Kraay 2000). Building on these early results, scholars have developed new theories on sovereign motivations to grant property rights, arguing that the sovereign has accurate information on economic conditions, and implement property rights as a means by which to increase efficiency and productivity in an economy (Riker and Sened1996).

A somewhat related view is held by a number scholars who argue that the globalization of intellectual property rights is a political process and a means of neocolonialism (Aoki 1998, David et al 2003). These scholars argue that the impact of Western ideological frameworks, as conveyed through international property right conventions, negatively impact developing nations and extract large social costs from these nations (Gana 1996, Oddi 1996, Oddi 1997). Although there are many examples, one of the most telling is by Henry Chakava (Altbach et al. 1995), who argues that while

Africa had 12% of the world's population, it only produced 1.2% of the world's books and controls only 0.4% of the world's copyright industry. By comparison, the United States comprises of roughly of 5% of the worlds population but controls approximately 80% of the world's copyright industry. Indeed, as argued by opponents of global intellectual property conventions, as the first world defines and strengthens its protection around intellectual property, the third world in adopting these policies will only have a more difficult time in catching up and appropriating this property.

2.6 Learning From Patents and Patent Data

The importance of intellectual property is clearly of extraordinary interest to economists and management scholars. As shown so far, although the theories differ, there are strong reasons to suggest that intellectual property regimes affect technological change, economic growth, and the competitive dynamics of products, firms, and organizations. Issues in the use of patent data are described in significant detail particularly in Chapters 4 and 5 of this thesis. However, a brief overview is provided here as it is important to demonstrate the disconnect between theories of intellectual property and patenting and the over zealous use of patent data by economists and other scholars in measurement and the proxies for phenomena in the world around us.

Patent data is one of the most readily available and rich source of data available to economists management scholars. It is vast in both its richness and amount of data, it can be considered international in scope, and it can be examined in multiple fields and time frames. A patent, at some levels, is also fairly trusted source of data as it examined by technological experts, under conditions and standards that infrequently change. To issue patent must satisfy four key criteria: fall in a statutory class (process, machine, manufacture, composition or new use), offer utility, have novelty, and be unobvious (Pressman, 1999); and so despite the diversity of technologies that may be covered by patents, scholars using patent data can be fairly confident that patents within the same general timeframe have been examined using similar standards. Patent fields are numerous, including Inventors and Locations, Assignees (owners), Application Number, Filing Date, Publication Date, US and international industry classifications, Citations and References, Parent Cases and Dates of filing; and also include richer fields such as Claims and numbers of Claims, Field of Invention, Description of Invention, Examples of Invention, and Images.

An excellent review and history of the use of patent statistics can be found in Zri Griliches (1990) survey of economic indicators. In this survey Griliches argues that there are two major problems in using patents for economic analysis: (1) classifications or groupings of patents by technology and user and (2) the problem that patents differ greatly in their technical and economic significance, namely a problem of intrinsic variability.

The first problem of classification is a major issue despite Griliches comment and we will explore this further in Chapter 4. . Often various technologies, defined by patents to be in particular product classes at patent issuance, may eventually develop in other industry or product categories (Scherer 1982, Soete 1983). Another difficulty arises because the Assignee's (owners) of a patent aren't necessarily the same organizations or individuals that have rights to practice the patent. As mentioned earlier patent rights may be transferred under license, acquisitions, or other inter-organizational arrangements, and this is in most cases not captured by patent office data.

The second of these problems is much more serious as the economic impact from innovations associated with each individual patent is highly variable. Because the distribution of the value of patent rights is highly skewed, patent protection is a significant but not the major source of private returns to R&D, and these characteristics vary across technology fields (Schankerman 1998). These results, although rife with assumptions, show that in the various technology fields studied (pharmaceuticals, chemicals, mechanical, microelectronics, and electronics excluding Japan) the mean value of a patent in an industry is approximately equal to, or more valuable than, a patent at the seventy fifth quartile. Indeed the top 1% of patents in the pharmaceutical industry accounted for 12% and 14% of the value in pharmaceuticals and chemicals, and this effect was even larger at 21% and 24% of the value for mechanical and electronic industries.

Despite these limitations, patent statistics have been successfully used in many cases. A major finding is that there is a strong relationship between patent numbers and R&D expenditures in the cross-sectional dimension, implying that patents are a good indicator of the inputs to inventive activity across different firms in similar industries (Scherer 1983, Pakes and Griliches 1984, Acs and Audretsch 1989). However, this relationship certainly does not exist between firms in different industries. It has also been found that small firms receive a significantly higher number of patents per R&D dollar, although small firms may have a higher propensity to patent as larger firms may be able to appropriate more returns without intellectual property (Levin et al. 1987, Cockburn and Griliches 1988). In a related body of work, Joshua Lerner (1994) has shown that within the biotechnology industry, firms that held patents with broader scope (as measured by number of International Patent Classes) were valued more highly by venture capitalists. A similar paper (Lerner and Tirole 2002) also showed that firms with venture capital funding had better patents are were more likely to engage in litigation to protect their IP than firms that were not venture backed. Patent data may also be usefully applied to examine R&D spillovers (Jaffe 1988, Jaffe, Henderson and Trajtenberg 1993) who found that firms in technology clusters generally invested more in R&D and for those who we above average, had substantial positive effects on profit and market value.

At the aggregate level, the appearance of an absolute decline in inventive activity, or patenting, particularly in the late seventies was more due to a bureaucratic cycle, as the number of patent examiners dropped temporarily, than due to any technological or economic variables (Griliches 1990). However, the relative decline in patenting compared to the growth in R&D spending (Griliches 1989, Cohen, Nelson and Walsh 2000) is still relatively unexplained, although it may potentially attributed to an increasing quality of patents or in the increased management of patents (Griliches 1989, Hall and Ziedonis 2001).

2.7 Emerging Organizational Scholarship and Patents

Scholarly interest in intellectual property rights and patents is not only of interest to academics with backgrounds in philosophy, history, economics, law, and political science. Recently, a new body of work has begun to emerge with sociological traditions. In the last two years organizational ecologists (Hannan and Freemen 1977, Freeman et al.

1983), have begun to examine patent data with their ecological models. In the organizational ecology approach, the focus is on the nature of the environment as the key determinant of organizational survival. Thus, for any particular firm, forces of adaptation result from both external constraints, such as legal and financial barriers to market entry and exit, labor markets, information availability, legitimacy considerations, and internal constraints such as investment in plant and equipment, information flows, internal political constraints, constraints from history and tradition. Recently articles in this tradition have begun to shift towards using patents to address organizational phenomena such as an event history analysis towards an examination of organizational age on innovation and technology obsolescence (Sorenson and Stuart 2000). Other studies have expanded on these results into other organizational areas (Ahuja 2000, Ahuja 2001, Rosenkopf and Nerkar 2001, Katila 2002), but despite careful analysis these studies tend to complete disregard of earlier economic advances in addressing patent measures, ignore the functions of the patent as an economic right, and do not relate their findings to patent theory.

Several additional studies that do not directly address patent theory have interesting implications to patent theory, particularly in how patent may affect organizations and organizational behavior. Recent scholarship has shown that entrepreneurial firm formation from University inventors is influenced by the importance (as measured by patent citations), radicalness (number of patent classes in which previous patents cited by the patent are found), and scope (as the number of international patent classes to which the USPTO assigns a patent) of the intellectual property (Shane 2001). This article is important as it suggests new mechanisms by which patents can induce innovation by promoting entrepreneurs to bring new products, processes and ways of organizing into existence. The article also further extends the work of strategic researchers in technological change (Tushman and Anderson, 1986) arguing that radicalness of technology influences decisions of independent entrepreneurs to create new companies, and provides support that firm formation from technological change can not be explained without consideration of the individuals who possess decision rights over the inventions (Roberts, 1991). Given that this article provides evidence on the importance of patent scope to technological entrepreneurship, this article could be construed as a policy argument for a stronger patent system.

Other articles that have continued in the organizational ecology tradition have begun to explore technology not as discrete entities, as is identified in most of the theories of patenting, but rather introduces the ideas of technology space (Podolny and Stuart 1995, Stuart and Podolny 1996). Building on sociological theories of the niche, a region of externally given resource space in which an organizational form can persist (Hannan and Freeman, 1977, 1983), the authors also use a network approach to technology (White, 1981, Burt 1987, Podolny, 1993). Using these approaches, the authors define "an organization's niche as its position in technology space as defined by the pattern of technological ties involving its inventions", and use an argument that closely parallels the theory of density-dependent legitimation and competition (Hannan and Carroll 1989). Using patent data, Podolny et al. find that crowding (measured by overlaps in citations) within a niche depresses growth rates, but under conditions of high uncertainty, status (a weighted measure based on the number of times an organization is cited), elevates them. Importantly, the striking results from the Podolny et al. show the importance of a firms location in a crowding/status matrix over time, and lend support the idea that Kitch's prospect theory of patenting may indeed act as Kitch proposes.

Building on ideas of technology space and theories of evolutionary science (Kaufman 1993), technology can also be considered as a complex adaptive system (Fleming 2001). Using patent data, and citations, Fleming argues that radical and incremental invention result from cognitively limited process of recombination, over a technology landscape. However, while importance of this approach to our understanding technological and scientific knowledge; it is arguable that the most interesting aspects of these approaches is unexplored. Indeed, if organizational growth and success are linked to the actual literal positioning of the patents, the concept of the niche and clusters in patents, rather than technology, may be an important place to explore new and broad intellectual property theories. Given the vast availability of patent data and computational power, the opportunity to examine these interesting phenomena within organizational frameworks offers vast new opportunities to understand the role of intellectual property in organizations and their impact on economies.

Chapter 3: Making Patents and Citations: The Role of Search Disincentives on the Quality of Patenting

In the last ten years there has been an increasing focus in the popular and academic management literature on the importance of intellectual property, and in particular patents, in the management of innovation. Some argue that this focus is driven by the recent availability of patent data, an argument evidenced by the increasing use of citation data in academic articles. However, more recently, academics have also shifted from traditional microeconomic views of patents as monopoly rights and have started explore the complexities of patent thickets, including issues of freedom to operate and design, and the increasing concern that overly broad, and inadequately novel, patents are issuing from the USPTO. The chapter will examine the role of various actors in the patenting process, and will argue how individual search disincentives may affect the quality of patent citations and the use of patent data. The article will also consider how these individual disincentives may also impact the US intellectual property system as whole, and suggests potential mechanisms by which some of these concerns may be addressed.

3.1. Introduction to the Use of Patent Citations

In the last decade or two researchers interested in the management of innovation and technological change have been afforded several fascinating opportunities to study the importance of intellectual property rights, and particularly the impact of patents[1] on

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[1] Like most economic articles, the terms 'intellectual property' and patents will be used interchangeably in this article, despite the fact the 'intellectual property' may also include such property as copyrights, trademarks, trade secrets, breeder rights, 'trade dress', mask works, contracted rights etc…

firms and industries. Unlike academics and philosophers who participated in the enormous patent controversies that swept across Europe in the early 19th century (Machlup 1950) management researchers of the present have had the advantages of (1) an open and increasingly dominant (U.S.) patent and technology marketplace, (2) the increasing availability of patent data, (3) a long standing patent system with ninety years of anti-trust history and experience, (4) a twenty year pro-patent era, all combined with (5) massive revolutions in informational, biological, and management technologies.

Not surprisingly, the last few years have shown an increased use of patent data at many levels of analysis. Certain management scholars (hereinafter referred to as "empiricists"[2]) have recently used patent data to perform comparisons of countries and their policies (Lerner 2000; Porter and Stern 2001); comparisons of patents across industries (Granstrand 2000; Hicks, Breitzman et al. 2001); and comparisons across patent classes (Andersen 2001). Similarly patent statistics are being used to study inter-firm linkages (Ahuja 2000; Ahuja and Katila 2001) and inter-industry studies through the examination of isolated patent classes (Podolny, Stuart et al. 1996; Lerner 2000; Hall 2001). Scholars following more economic traditions have commonly used patent statistics at the individual firm level (Henderson and Cockburn 1996; Cockburn and Henderson 1998; Lim 2000) and patent statistics are being increasingly used in studies of entrepreneurship and studies of university level innovation (Henderson, Jaffe et al. 1998; Shane 2001; Shane 2001). There is also an emerging economic and legal literature which use patent statistics to examine individual level phenomena including the examination of

[2] The word "empiricist" is not to suggest that these articles do not have theoretical contributions, but rather that the theoretical contributions are typically not directed towards theories of intellectual property.

federal circuit judge rulings (Lemley 2001) and the impact of patent examiners on patent quality and validity rulings (Cockburn, Kortum and Stern 2002).

Unfortunately, despite the widespread use of patent data, empiricists using patent data infrequently consider the theoretical support for their measures. These empiricists pay little attention to the underlying mechanisms of how patents are granted, if the patents are valid, and if the patents impact the firm. As such, even though patent data is used in a myriad of ways, it is unclear what one using patent data can infer about such measures as knowledge, capabilities, or innovation. After a brief overview of theories of intellectual property, we will return to this disconnect and begin to examine how a richer understanding the United States patent system can influence the way that we might think about studies using patent data and possible mechanisms to better the overall patent system.

3.2 Theories of Intellectual Property and Patent Citations

The difficulty in using existing theoretical arguments to support the use of patent data is substantial, particularly as theories of intellectual property are contested and generally lack substantive empirical support. At the broadest level, scholars have derived many theories of intellectual property (hereinafter "theorists"[3]) which generally fall into four economic and philosophical traditions (Fisher 2001). Three of these theories are quite philosophical and do not lend themselves to straightforward empirical support. These theories include (1) Labor Theory, motivated by Locke, which argues that the inventors use of the commons is not harmful and thus inventors may own developed

[3] Like "empiricists", the word "theorists" is only meant to suggest that the scholarly contributions are directly targeted to influencing the development of intellectual property theories

property, (2) Personality Theory, motivated by Kant and Hegel, which argues that intellectual property is a component of personhood and individual will and, (3) Social Planning Theory, motivated by Jefferson and Marx, arguing that intellectual property fosters a just and attractive culture. The last and perhaps most influential of these traditions, or (4) Utilitarianism, derive from the Kaldor-Hick's economic criterion with promote the idea that intellectual property rights should be constructed to maximize net social welfare, or more simply the greatest good for the greatest number.

Beginning in the mid-nineteen sixties, utilitarianist traditions have been expanded by several different economic theorists. While the classic monopolistic view of patenting (Nordhaus 1969) has had some success in explaining pharmaceutical firm performance, it generally does not address other empirical questions that have shown that (1) patent policy has little effect on patenting (Lerner 2000; Sakakibara and Branstetter 2001) and furthermore that (2) with the exception of the pharmaceutical industry, patents are generally not predictive of firm level performance (Scherer 1959; Taylor 1973; Mansfield 1986; Levin 1987; Arundle 2001). Theories from the New Institutional Economics (NIE) are also similarly limited, but they are currently the most frequently accepted theories available and are broadly defined in four broad frameworks (Merges 2000). Each of these four frameworks relies on different expectations of the welfare returns to both firms and society [Table 1].

Table 3-1: New Institutional Economic Theories of Intellectual Property

	Society faces monopolist but gets…	Firms get monopoly rents but …
1. Motivate Invention	Lots of innovation and some development	They must innovate and develop
2. Induce Development	Some development in addition to already occurring innovation	They must develop
3. Induce Disclosure	Knowledge	Are guaranteed only for a short time (is 20 years short?)
4. Induce Orderly Development	Some developments but only if no blocking	Are efficient and not proceed wastefully

As may be obvious to even the most casual reader of articles discussing intellectual property, many of these NIE theories are quite contentious, although some of these are typically are less so (Table 1: shaded). However, even the less contentious views of the NIE theories, (1) that patents confer knowledge; (2) that patents induce development; and (3) that patents allow efficient and orderly development, will shortly be examined in light of new evidences within the intellectual property literature. What should be apparent at this juncture is a disconnection between intellectual property theories, and the varied levels of analysis at which patent data are used.

3. 3 Limitations of the New Institutional Economic Frameworks

Before we start to consider why empiricists should be weary of using patent data, it will be very helpful to understand the limitations of currently accepted intellectual property theory. As described earlier, much of what is generally accepted in the NIE does not predict or instruct us in regards to two relatively well-known phenomena: (1) patent litigation and (2) patent thickets and freedom to operate.

3.3.1 Patent Litigation, Knowledge, and Firm Efficiency

One of the most believable and argued societal benefits argued by NIE theory is that the patent system allows for the public dissemination of knowledge. Similarly, a widely held view of NIE theorists is that patents allow for orderly, and potentially efficient, development of new technologies. The implications of these theories are not hugely profound, and in a well functioning patent system we might infer from these theories that in heavily patented areas we would find both a high level of competitive knowledge, and a low level of competition in patented product spaces. Unfortunately, what I will argue is there exists a relatively high incidence of US patent litigation.[4] Approximately 1600 lawsuits per year occur (Lemley 2001) which I argue is of sufficient frequency to lay challenge to the fact that (1) adequate knowledge is disseminated to the society (including competitive firms) through patents, and (2) that there exists a mechanism for efficient development of new technologies.

In recent years, particularly since the 1990 *Polaroid Corp. v. Eastman Kodak Co.* decision (Fed. Cir. 1986), patent infringement suits and awards have been increasingly significant and some have had a massive impact on corporations (Table 3-2).

[4] This argument that number of patent lawsuits is large is not common. Authors such as Mark Lemley have suggested that the level of patent infringement suits are extremely low as he estimates that only two percent of patents are ever litigated and less than two tenths of two percent of issued patents go to trial. However, instead of asking what percent of patents go to trial, litigation is more likely a question of infringing products, so it may be more reasonable to suggest that each year 1600 competitor products or product lines are considered by patent owners to be infringing, and that these competitor product lines are significant enough to warrant the expense (generally over $1.5 million) of initiating a patent infringement lawsuit.

Table 3-2: Patent Litigation Awards Over $200,000,000

Amount	Year	Parties	Legal Action	Technology
$1,200,000,000	1993	Litton Industries <-- Honeywell	P.Lawsuit	Electronics
$873,000,000	1991	Polaroid <-- Eastman Kodak	P.Lawsuit	Chemical
$700,000,000	1997	Digital <-- Intel	P.Lawsuit	Computer
$400,000,000	2001	Pitney Bowes <-- HP	P.Settlement	Software
$324,000,000	2000	Cordis/Johnson & Johnson <-- Boston Scientific	P.Lawsuit	Medical
$275,000,000	2000	Caldera <-- Microsoft	Settlement	Software
$270,000,000	2000	Cordis/Johnson & Johnson <-- Medtronic	P.Lawsuit	Medical
$211,000,000	1996	Haworth <-- Steelcase	P.Lawsuit	Mechanical
$205,000,000	1986	Hughes Tool <-- Smith International	P.Lawsuit	Mechanical
$200,000,000	1999	Univ. California <-- Genentech	P.Settlement	Drugs
$200,000,000	1990s	Intel and AMD	P.Wasted	Electronics
$200,000,000	2000	Gemstar <-- Motorola	P.Settlement	Electronics

Source: Greg Aharonian Internet Patent News 10/31/01 at: www.bustpatents.com

What is most unusual about the fact that patent litigation happens, particularly in light of NIE theories, is that not only is patent information reasonably symmetric (a competing firm knows the contents of the patent and can infer reasonably well date of an invention from pre-trial discovery and can adjust its risk accordingly), but that the process has the potential to be tremendously detrimental to infringing firms. Curiously, not only is patent litigation expensive and lengthy[5], the damages may also be substantial. Furthermore, litigation may affect the reputation and share price of the firm, and increase the risk profile, uncertainty, and bankruptcy risk of the firm, all in the context of publicly

[5] For example, in Polaroid Corporation v. Eastman Kodak Co. (Fed. Cir 1986), Kodak and Polaroid enjoyed a long standing alliance which broke down in the 1960s with Polaroid's development of the instant camera. When Kodak failed to license Polaroid's patents, Kodak introduced its own instant camera in 1976, and was sued by Polaroid for infringement of ten patents. Pre-trial discovery lasted between 1976 and 1981 with Kodak producing some 268,000 pages of documentation and Polaroid producing 40,000. A 75 day trial took place over 16 months, when Judge Rya Zobel ruled that Kodak infringed 20 claims of 7 Polaroid patents. The injunction stopped Kodak's instant camera business, leaving it with $200M in useless manufacturing equipment, losses of $600M, legal costs of $100M, and force Kodak to pay over $400M to 28M customers as the film could not be produced under the injunction. Separately Kodak was ruled to pay Polaroid a final award of $909.5M in damages, of which $455.3 was interest. Bagley, C. (1998). Managers and the Legal Environment: Strategies for the 21st Century. St. Paul, MN, West Publishing Company.

available patent information and alternate clearing mechanisms for mitigating legal risk and technology development.

Although not well anticipated by leading theories of the NIE, there are numerous reasons why patent litigation might occur. Explanations may include: (1) environmental factors, such as expectations of a weak or inefficient patent system; (2) firm level factors, as companies might be any combination of bad, arrogant, deep-pocketed, risky, or ignorant; (3) team level factors, such as failings in group dynamics or team process; or (4) at the individual actor level, whereby patent litigation might be driven by individual actors, such as money-grubbing attorneys, prestige-seeking inventors, or arrogant CEO's. However, the sheer enormity of the economic impact of patent litigation in the US does suggest that, unlike what NIE would predict, patenting may not necessarily develop high levels of competitive knowledge, and does not necessarily promote a low level of competition in patented product spaces.

3.3.2 Patent Thickets, Technology Development and the Environment

A second major criticism of the NIE theories of intellectual property can be made from an emerging body of literature developed primarily by legal scholars. Simply put, unlike NIE theories that consider a firm and its strategic choices emerging from it ability to obtain its own intellectual property, this new stream of literature appreciates that most firms face environmental intellectual property constraints rather than internal intellectual property opportunities. Early discussions in this area introduce the idea of patent thickets (Merges 1996; Shapiro 2001) suggesting that many firms involved in technology development face thickets of overlapping intellectual property constraints and limited technology development choices. In some cases this view is taken to an extreme and it has been argued that patents may actually deter innovation by creating an "anti-commons" (Heller and Eisenberg 1998). In an anti-commons a large number of owners of even low value intellectual property rights may create untenably high coordination costs such that technology development incentives are eliminated.

Interestingly, concerns about patent thickets and anti-commons are extreme extensions of anti-trust arguments regarding monopolistic competition. In a fascinating history of semi-conductor cross licensing (Grindley and Teece 1997) we are reminded that RCA, IBM, and Bell Labs have for many years been concerned about design freedom, or freedom to operate, terms used to describe not intellectual property ownership but rather a capability to navigate the patent thicket and intellectual property environment. Many recent articles reiterate the necessity of freedom to operate for technology development, not only in the US, but as a core strategy of intellectual property managers in both Japan and the U.K. (Pitkethly 2001). Again, we find the NIE does not instruct us on why there are patent thickets, and why freedom to operate may be a more critical need in intellectual property strategy than monopoly rights.

3.4 Reconsidering the Nature of Patents

Unlike so many other phenomena studied in management literature, a patent is one of the few phenomena that originate at the level of individual or small team, but may rapidly impact the environment. Patents are one of the few tools that can be used by individuals to influence a substantial number of firms and the trajectory of new technologies. Indeed it may be this micro and macro duality of patent that acts as both a challenge to intellectual property theorists, while allowing empiricists free reign over their chosen level of analysis. As will become clear shortly, there is an arguable link between micro-level incentives and environment level effects, which will have implications for how we think about patent data. However, to make this link we must first understand what a patent is and how it is created.

3.4.1 The Structure of Patents and Patent Data

As researchers that use patent data are well aware, there are a variety of services that provide patent information. The structure of patents can be basically broken into seven parts: (1) bibliographic information[6] including the names of inventors, assignees, priority dates, classifications, prior art references[7], and the title and abstract; (2) patent claims information which can be broadly categorized as composition, method, and design claims; (3) the background of the invention; (4) the invention summary; (5) diagrams, figures and drawings; (6) detailed description and definitions and (7) examples and preferred embodiments.

The recent availability of patent bibliographic information from many sources has allowed management researchers to develop many creative ways of using both geographic and citation data to derive a wide variety of conclusions. However, as most attorneys and intellectual property managers would agree, the true heart of the patent is found in the patent claims, which in turn are supported by the bulk of the additional document. Claim information is not necessarily easily linked to brief descriptions in the bibliographic section. Indeed, there may be several structural complexities of patents that

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[6] Historically management and economic literature has, with no exception that I have found, only focused on data available from the bibliographic data of patents, and thus the term 'patent data' used throughout this discussion to more specifically mean bibliographic patent data.,

[7] Prior art references include previous patents or other publications that may impact either the novelty or obviousness of the invention. Prior art is what is used by researchers using citation data and will become and increasingly important concept as this article develops.

might suggest that bibliographic information might not well represent the patent as a whole. For example, as one will find with well-written patents, the claims and language tend towards maximum breadth and scope, with large sections of overlapping and multiply redundant language. Also, the patent is generally written to overcome a variety of patentability requirements, but walks a fine line between appearing to enable others and actually enabling others. Finally, it is also important to note that definitions are frequently written so as not to be standard across patents, nor with cited publications, as this may limit future interpretations of the breadth of the patent because of related prior art. Although these structural issues may raise our suspicion about the quality of patent bibliographic data, there are potentially more significant issues that occur in patent search practices that may be of greater concern.

3.4.2 Requirements for Patentability

The United States patent office has four broad criteria for patentability. The patent must: (1) fall in to a statutory class, such as a utility, method, plant, or design patent; (2) meet a utility requirement, or in simpler terms have a useful purpose; (3) be novel, as evidenced by its ability to overcome prior art, or work that has proceeded the invention; and finally (4) be non-obvious, as evidenced by its having overcome combined prior art in a way that shows an 'inventive step'. The broad definitions of statutory class and the relatively relaxed concept of utility suggest the any hurdles for patentability often rely on arguments made in the context of existing prior art, or more simply evidence of technology practices that have preceded the priority of the applied for patent. As a significant element of the patenting process is reliant on prior art arguments, the search for prior art by various actors in the patent process plays a critical role in how patents develop, what claims issue, and what intellectual property environment develops.

3.5 Prior Art, Patent Search and Patent Validity

The lack of good prior art search has a substantial impact on understanding how new patents fit within the context of the already existing knowledge base. We will explore later how many patents include very little prior art, but even for patents important enough to issue and have their validity challenged, prior art is a frequent problem. A recent examination of federal circuit judge voting in patent validity cases from 1989 to 1996 found that in cases where patents had been found to be invalid, 27% were found invalid for novelty rejections due to prior art, and another 42% were rejected due to obviousness rejections which can arise from the combination of prior art (Allison 2001). However, the opportunity to make patents more resistant to prior-art invalidations is not very easy.

3.5.1 Magnitude of Prior Art

The process of searching for valid prior art when a new technology is developed is not an easy one. The magnitude of the prior art in the patent literature alone is immense. In the US there are approximately 6,300,000 issued US patents, of which 2 million are currently active, and only about 2.5 million are searchable in full text. The US Classification System is also extraordinarily large consisting of some 400 classes, and 136,000 subclasses. The international PCT system, offers approximately 8,500,000 active international patents with 70,000 classification categories. In searching just the patent prior art, which perhaps offers the most accessible technical data available, the task is enormously complicated. For clients willing to pay high search costs ($60-100K), freedom to operate searches require several person-days of manual searching by highly skilled technologists as computer search tools are frequently too slow to parse the required volumes of patent data[8].

Technical prior art available at the Scientific and Technical Information Center of the USPTO is much larger than just the patent database. Not only do USPTO archives contain the official journals of some 77 foreign patent organizations, at 40 million foreign patents, but they also contain some 120,000 physical volumes of scientific and technical books in various languages, as well as 90,000 bound volumes of periodicals devoted to science and technology. Additional sources such as the Library of Congress with 115 million items, the US Copyright Office with 41 million items, the National Library of Medicine with 5 million items, and the National Library of Agriculture with 3.3 million items also suggests the magnitude of the prior art search problem.

3.5.2 General Problems with Prior Art Searching

The difficulty in searching prior art is not just the problem of an explosion of information. Clearly there are search tools that can help us in limiting the amount of information that needs to be parsed so that a searcher would not have to search the whole National Library of Medicine for example. However, even when limited through search tools, the magnitude of information needed to evaluate the novelty of a new idea is enormous. Furthermore, and more limiting, is that a substantial amount prior art is not publicly available or even published in a searchable form. Some of these difficult to access works include the poorly described deposits in the US Copyright office and

[8] Personal communication with Bruce Rubinger, Founder and Director of Global Prior Art. According to Global Prior Art a directed IP search will take about 2 people, 2 days at the USPTO to thumb through approximately 10,000 patents before the complex task of mapping relevant prior art is undertaken.

technologies related to national interests. Other difficulties include the fact that frequently prior art is written in different languages, uses different paradigms and definitions, and much prior art may be intentionally cryptic.

Another major challenge with prior art searching is in regard to the searchers capabilities. In some cases it may be the case that individuals with strong technical expertise may not have the ability to translate that expertise into strong or available search capabilities. As mentioned earlier, so-called 'available' information may be difficult to browse in large quantities, and information systems may make searching too costly or time consuming. It may also be difficult to relate new individual discoveries in some fields to overlapping innovations and prior art in different fields.

Perhaps one of the most difficult challenges dealing with prior art search has to do with the fact that it is a highly probabilistic process. Without doing an infinite search, a searcher cannot prove that all of the relevant prior art has been searched. Instead, and what we see reflected in policy in the USPTO, is that the burden of proof is on the patent examiner as there can be the possibility to disprove novelty in an application.

3.5.3 Patent Validity

It would be difficult to argue that the prior art search process was a substantial problem if there was very little empirical evidence to suggest that the US patent system was in some way impaired. However, there is clear historical evidence that even patents argued at the federal level are largely of a poor quality. In an important patent validity study completed at the US Patent and Trademark Office (Ferderico 1956), it was demonstrated that between 1925 and 1954 only about 30-40% of patents were held valid by a federal court. Similarly, a comprehensive study of all cases between 1953 and 1978 show a similar level of only 35% validity (Koenig 1974). A more recent study of 299 litigated patents in Federal Court from 1989 to 1996 showed that only 54% of patents are to be found valid (Lemley 2001). This later study did find that while there were very few differences between industries in patent validity studies. Pharmaceutical patents were held valid much more frequently than patents in other industries, with an average validity of 73% and although pharmaceutical patents represented only 3% of all validity suits. It might be speculated that this unusually high quality of pharmaceutical patents might be due to some combination of (1) the fairly public and open development process of the pharmaceutical drug industry over this period; (2) an established history of large information databases, established technology search procedures (by highly established chemical classification schemes), and (3) an established history of publishing technical information and conference proceedings in addition to articles and trade press. However, in most other industries the significant noise of invalid patents suggests that the system is very impaired.

3.5.4 Concerns Over Prior Art Quality in Finance and Software Patents

The idea that there is not enough search of prior art at the US Patent Office is not new and has been held by certain practitioners for some time. More recently, and particularly following the notorious *State Street v. Signature Financial Group* decision (Fed Cir. 1998) there has been a flood of business methods and software patent applications, which many argue are of dubious quality. A recent study of all finance patent awards granted through February 2000, 445 in total, examined the quality of patent citations and found that there were only 21 references in total made to works of seasoned financial innovators that included managing editors, founding editors, and advisory editors of top tier finance journals, and Nobel Laureates with financial economics backgrounds (Lerner 2000). Additional cases studies of two US patents in the field, US Pat. No. 5,884,286 and 5,940,810 demonstrated that substantial and easily accessible prior art was missed for claims that cover methods employed five or even fifteen years earlier. Additionally one of the two patents, which focused on financial estimation techniques, contained 19 references to mathematics and only one to a finance article oblivious of literature indicating that the particular technique was in used for twenty years.

Similar disturbing evidence has recently been reported in software patents. As of 1999, the average number of prior art references cited in software implemented business concept patents was fewer than five (Merges 1999). Of these five, a highly recognized and authoritative patent critic Gregory Aharonian finds that three in five are patent citations. This fact is concerning when one considers that software patents have only started to issue whereas prior art documenting the use of software in business practice has existed for a substantial period of time. Equally concerning is that despite Aharonian's substantial and recognized development of a prior art package for software firms to achieve better patents, there was no corporate interest in the materials[9] Additional materials on Aharonian's website[10] go as far as to suggest the utter disdain for patent search capabilities at the USPTO. A quote attributed to one examiner is as follows:

> "So your attorney buddy doesn't want anything that's "not in the PTO" to be PA{Publicly Available}. And the MgMt {PTO Management}. is burning everything they can in the Library. Latest Victim: the Communications of the ACM. USED to be brousable, in paper. Now only in microfilm. Unbrousable. Especially if all the contracted-out microfilm readers aren't working. [Even if they are working, it takes about 5-10X more effort to "turn" a microfilm page and attempt to read the fuzzy image as to do the same with a real PAPER one!]"

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[9] Personal communication, Karl Ruping, Founder IncTank.
[10] www.bustpatents.com December 14, 2002.

And Aharonian attempts to check it out with another patent examiner result in this attributed statement:

> " Don't have to check it out, that' been a PTO "Scientific Library" practice for years, maybe 10 or more years by now. Every journal they can get on microfilm, they take off the shelves and ship to a federal "records center" warehouse. They don't actually burn them, but in practice the result is the same."

It may be clear at this point that at least in some ways the process by which the issuance of patents may be more than slightly impaired. The remainder of this article will focus on the specific mechanisms on why prior art is not search and how this might impact how we think about patent data.

3.6 Search Disincentives and Intellectual Property Management

One of the major challenges that the patent system faces is that many of the expert technologists and firms applying for patents attempt to achieve patents of maximal scope and breadth. As an obvious case, broad patents in any given field with both broad and limited claims are at least as valuable as patents with just the limited claims[11]. This fact creates an individual or organizational level incentive to achieve patents with overly broad scope. Achieving high scope, in turn, naturally conflicts with incentives to do high levels of prior art search which rarely has no effect, as might the case with the most innovative new technologies, but more generally causes the patent office to limit the scope of the patent. While it seems clear that many patents are likely to be invalid, either for obviousness or lack of novelty reasons, there are some incentives for individuals or

[11] A patent contains many claims, of which only some may or may not be valid. Frequently claims are stepped in regards to their breadth so if a broad claim is found to be invalid, more specific claims may still be pursued against the alleged patent infringer.

organizations to get good patents, particularly if the patented invention is broad, potentially valuable, non-obvious and truly novel.

One of the largest individual or organizational level incentives for doing a substantive prior art search is that it reduces the likelihood that others will challenge a patent by introducing prior art that the patent holder did not address in an attempt to invalidate the patent. However, as mentioned earlier, as so much prior art is potentially not publicly available, it is not clear that even the most extreme efforts in the searching of available prior art would necessarily significantly effect the likelihood that a patent will hold up to a validity challenge.

Another potentially interesting argument for individual or organizational level search may be information discovered through intellectual property search may in some ways feed back to the inventors such that more innovation may occur. This idea of search and recombination has been recently examined empirically in two recent articles (Fleming 2001; Fleming and Sorenson 2001), and although there is some support for this, much more needs to be done in this area if these results are to be convincing[12]. However, what is largely questionable about this type of argument, and will be discussed again, is that most organizations are generally organized for what I will term "IP Push", whereby an invention is conceived and IP is developed, rather than "IP Pull" whereby the environment is scanned and IP strategies are developed and supported by new technology efforts.

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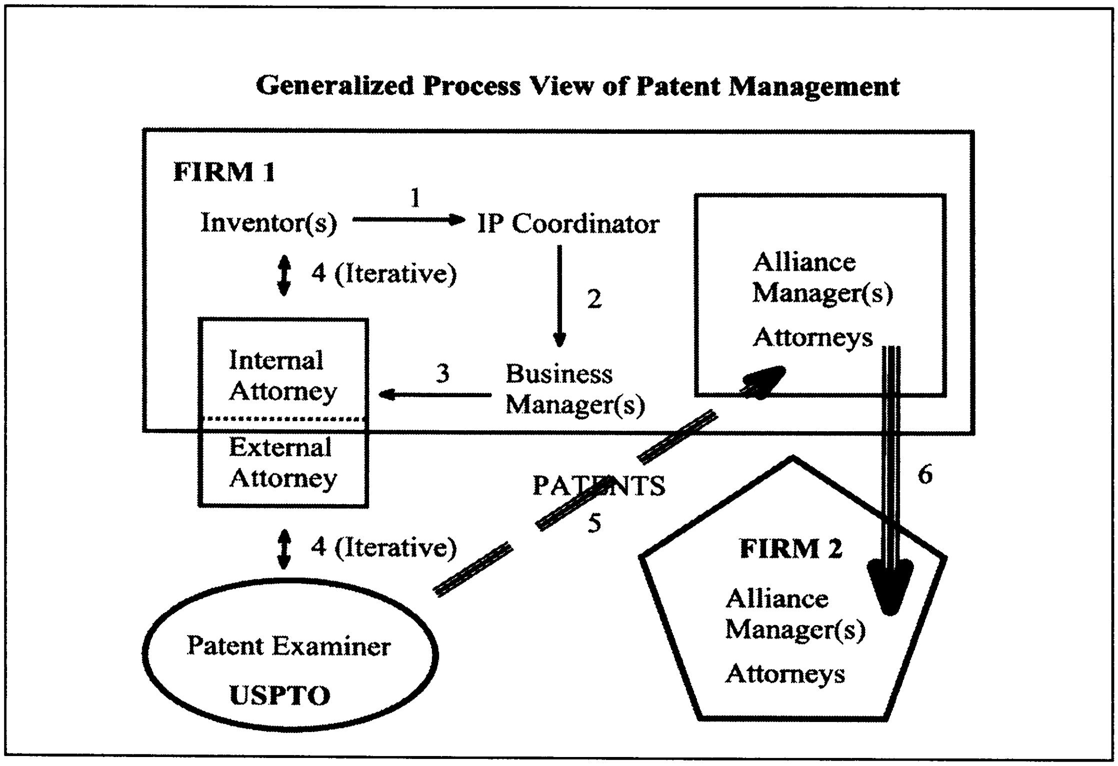
[12] A major limitation of these studies is that Fleming does not control for the idea that the splitting of parent patent applications (as is common practice when patents are examined) may be driving his empirical results. Another recent article by Jesper Sorensen and Toby Stuart "Aging, Obsolescence and Organizational Innovation", ASQ 45 (2000):81-112, shows how such measures may be controlled.

Finally, recent patent litigation, particularly from the *Festo Corp. v. Shoketsu Kinzoku Kogyo Kabushiki Co.,* (Fed. Cir. 2000) case, but also from a number of related cases, suggests that the prosecution history (i.e. the granting process) of a patent may be brought to bear on the ability for the patent holder to exercise the 'Doctrine of Equivalence'. The basic idea under Festo is that if claims are amended because of any prosecution history challenges, the patent holder will not be able to argue infringement under the 'Doctrine of Equivalence' for products or processes which are substantially equivalent to that claimed in the patent, even though they may not be literally infringing the patent. In some respects, emphasis on search may allow for the drafting of more specific patent claims that would be less likely to be altered during prosecution history, and thus the 'Doctrine of Equivalence' may apply, effectively broadening the patent. However, one does not necessarily need to do more search to write great patents\ claims, and concerns of this nature may be dealt with by simply writing more, multiply overlapping claims such that it would be less likely that a claim might be altered during prosecution history.

While there may be some incentives for search at the individual or organizational level, it would be wholly irresponsible for the USPTO to simply grant patent rights to individuals or organizations who claimed that they were the first to invent a new product, process, plant or design. Clearly there is a need for the USPTO to search for prior art to prevent abuses of the system. The USPTO and inventor are not the only players in the patent granting process. Particularly as the patent system is designed to necessarily bring together technical, business, and legal expertise, there are naturally several different types of individuals involved in the patent granting process. Briefly we will examine the various roles of individuals in organizations, from the inventor(s) to the business and legal managers, to the USPTO, and then to other individuals who manage the portfolio of patents (Figure 1) and their various incentives to search for patent prior art.

Figure 3-1: A Generalized Process View of Patent Management



3.6.1 Inventors and Disclosure

The creation of the USPTO is mandated under the US Constitution, Article 1, Section 8 whereby it states that:

> "Congress shall have the power…To promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries…"

Given this mandate, a natural place to start the examination of the patent process is with the role of the inventor.

Since its inception, the philosophy of the USPTO has been to grant patents to the individual(s) who are the first to invent a new product or process[13]. If we assume that the inventors are truly at the edge of the technological frontier, and thus is doing very new work, it is likely that the technology will be a long way from commercialization, or even working, when the inventions potential for patenting and new product development may be realized. Whether the inventors are at a large company, at a university, or independently inventing, the inventor usually has little time to file a patent, particularly as there are frequently competing inventors, publication incentives, or concerns about public disclosure that affect patentability[14]. Also, as the patent document itself is generally a significantly lengthy document the inventor usually has to invest substantially in its development.

The investment in the development of a patent application is not just time and technical effort. Frequently, there is substantial resistance to new innovations in firms, and if the inventor is working for an organization, such as a corporation or university, the inventor may have to champion the invention through the organization for support (Burgelman 1983). If the organization has a dedicated and smoothly operating intellectual property management function, and is pro-patent, there might be substantial infrastructure that allows inventors to move their inventions into the patent process. However, as organizations are keenly aware that patents frequently bestow reputational

[13] The US is unlike most European Patent Offices which offer the patent to the 'first to file' rather than the 'first to invent'. In many ways the 'first to file' grant is a much easier system to administrate and avoids costly 'interference' proceedings (when two patents are in process at the same time and attempt to argue similar claims) that can occur fairly frequently at the USPTO. However, critics of 'first to file' suggest that the process may be unfair, particularly for independent inventors who may not be able to file on new inventions as quickly as larger organizations.

[14] In the US inventors have one year from the initial public disclosure date (generally broadly interpreted) of the innovation to file a patent application after which they lose the opportunity to pursue patent protection.

benefits to the inventor, an aggressive inventor may just be seen as self-interested rather than as contributing valuable potential property to the firm.

There is a difficult situation that occurs when the inventor and the organization do not value intellectual property in the same way. In the simplest of cases, where the inventor does not recognize any value in the intellectual property they are creating, it is fairly likely that the innovations that they are developing will not be disclosed in a formal sense to the organization as a new business opportunity. However, in other cases, where the inventors see themselves as contributing valuable intellectual property, but without ready organizational support, the inventor generally faces the dilemma of either: (1) convincing the organization that the IP is valuable; (2) convincing the organization to allow them to develop it independently (although usually organizations insist on maintaining rights and so this option is usually not attractive); or (3) abandoning the idea altogether. These options facing the inventor likely create an odd selection pressure on inventors and their likelihood of search. Those inventors who would prefer to abandon the idea, and who might be interested in supporting their decision to do so through prior art search, will find it easier to abandon and not search for prior art, than to spend effort searching the prior art for no future reward. On the other hand, inventors wishing to convince the organization that a patent is worth pursuing will be unlikely to search for evidence that would convince the organization otherwise. As a result, it is truly questionable if inventors have much incentive to carefully look for damning prior art.

In more recent years some companies attempting to build large patent portfolios have created specific incentives for inventors based on the number of patents they can get. In these cases, similar to those already discussed, there are strong disincentives for inventors to search for prior art that could in turn limit their ability to patents and effectively reduce their bonuses.

Generally the patent office is aware of the low levels of search of the inventors:

> "Many inventors attempt to make their own search of the prior patents and publications before applying for a patent.... An inventor may make a preliminary search through the U.S. patents and publications to discover if the particular invention or one similar to it has been shown in the prior patent. An inventor may also employ patent attorneys or agents to perform the preliminary search. This search may not be as complete as that made by the USPTO during the examination of an application, but only serves, as its name indicates, a preliminary purpose. For this reason, the patent examiner may, and often does, reject claims in an application on the basis of prior patents or publications not found in the preliminary search."
> USPTO Web Site, December 5, 2001.
> http://www.uspto.gov/web/offices/pac/doc/general/#functions

However, as we will discover shortly, the patent office may also be quite uninterested in careful search as well.

3.6.2 Intellectual Property Coordinator and Technology Managers

The patent process in most large organizations is designed to develop the intellectual property position around internal technologies rather than identify external patent constraints. These efforts to capture the firm's internal technologies are intended to provide the firm with an asymmetric economic advantage or, at the very minimum, allow the firm to own technology that it has invented. Technology based businesses employ individuals to identify, organize and develop intellectual property from technologies developed in the firm. Firms typically attempt to solve the "Rembrandts in the Attic" problem (Rivette and Kline 2000) the issue being that firms do not always realize their full potential in developing and using intellectual property to capture economic value. Intellectual property coordinators and technology managers are charged with identifying defensible new business opportunities, but are typically measured as a cost center. As the vast majority of intellectual property is of relatively low value, but is also of highly uncertain value, these coordinators and managers are driven by performance metrics which emphasize quantity rather than quality of patent output. Managers are aware of the low success rate of individual innovations and therefore develop IP portfolios that mitigate individual technology risk. Therefore, instead of technology managers competing to identify and control the largest deals and opportunities, managers instead competed on metrics that measure the number and costs of patents filed, patents granted, and patents licensed per case manager.

Technology managers who focus on external intellectual property search face a number of challenges that can serve to drive their measured performance down. As discussed earlier, technology search is very expensive given the vast quantity of technical literature available. Patent search activities have two key effects on the manager performance. First, high levels of patent search will increase the costs of patents filed and therefore the manager will be seen as being less efficient per patent then their peers. The second problem of high patent search is that the identification of additional prior art will serve to limit the claims of the patent leading to lower scope and thus a smaller definable business opportunity. Managers are thus likely to do low levels of patent search as it both reduces patenting efficiency and business opportunities that the patent, on its surface, claims to impact.

3.6.3 Internal and External Intellectual Property Counsel

Companies that do large levels of patent filings typically employ both in-house intellectual property counsel and counsel from various external law firms. Internal counsel typically works with the inventors and IP coordinators, or business managers, to define the potential IP and draft the patent application. Internal counsel have the advantage that they can become very experienced in understanding the technologies in their firms, but they can also be less experienced than external firms in dealing with emergent radical technologies. In the early stages of new technology development, technology and business risk will be considered much as much more important and higher than patent risk as some 97% of all applied for patents issue in some form (Lemley 2001). Thus, in the early stages of a patent application, counsel will typically focus on applying for patents quickly, so as to get earlier priority dates or beat disclosure concerns. Counsel will tend not to invest heavily in prior art search because patent quality is not seen as a major issue relative to other risks associated with the technology. For patent applicants there is no U.S. Patent and Trademark Office requirement for prior art search, except that applicants must submit the USPTO all the relevant prior art of which they are aware. The lack of prior-art search requirements, confounded by the legal precedent that subject patent infringers who 'knowingly infringe' to treble damages, create serious disincentives for internal counsel to do significant prior art search.

Experience with external counsel can be mixed. If a client is fortunate their external counsel will be expert in the technical areas in which they are filing, presumably because they have experience with related, although not conflicting, clients and technologies. However, external counsel are not necessarily commissioned because of the specific technical expertise, but may instead be needed because of insufficient internal resources, bundled legal services (particularly for smaller firms), or the need for independent representation. In cases where an organization is developing an intellectual property estate through the use of external counsel one finds that law firms compete fiercely on price when identifying new business with the expectation that they will recoup early costs over the period of the engagement.

Patent prior art search is a very time consuming process and can lead to what seems early on to be outrageous legal bills. In difficult areas of technology, where the prior art landscape is very complex, prior art searches and analysis can cost more than $100,000 which trumps the approximately $10,000 average cost of a normal patent application. We have already examined that prior art can serve to limit the scope of the face of the patent claims, but external counsel typically keep early charges low so as to get the patent applications cheaply. In many cases this concern over early costs can lead to what I call "patent bouncing." In patent bouncing, external counsel apply for the patent without spending time (i.e. legal costs) on the prior art search. The application then bounces through the USPTO in the expectation the patent examiner will pick up prior art that they see as most relevant and reject the application. Counsel then reply to rejections, as is standard, but only deal with prior art that the examiner identifies. This process is extremely costly in the long run for two reasons. First this process shifts the cost of the patent primarily from search to prosecution, and thus removes the valuable exercise of identifying the extent to which the patent enforced. Second, this process runs a greater risk of not identifying the key prior art which could make the patent valueless, or difficult to defend, should it every be litigated. It is not uncommon for key prior art to be discovered many years after the original patent filing.

3.6.4 Patent Examiners

The search disincentives both inside the firm and in the hiring of external counsel is not necessarily a significant problem if the USPTO was effectively in identifying new technologies from those that existed before. However, as a result of the 1990 Omnibus Reconciliation Act and the 1999 American Inventors Protection Act, the USPTO began considering itself more like a private business with a unique customer focus. Accordingly, commissioners from the USPTO would pronounce that they were in the business of making patents and not preventing them[15]. As one examiner attested, there are strong structural and psychological pressures on examiners to issue patents rather than reject applications as the reward systems measure the ability of examiners to get patents out the door. Indeed, it has been shown that even before the patent boom of the mid-1990s, the largest predictor of annual aggregate US patenting is not the amount of commercial US R&D investment, but rather patenting is most correlated to the number of employed examiners in a given year at the USPTO (Griliches 1990).

The patent examiners are very constrained by time. Patent examiners typically have 18 hours to read an application (which can include 70 -200 pages of technical text), read the submitted prior art (which in some cases can be boxes of paper), search and read prior art in accessible databases, compare the prior art to the application, write, read and respond to office actions, and reiterate this procedures. In addition, the examiner can conduct an interview with the application, and will need to ensure that claims and diagrams are in a form with allowance (Lemley 2001). However, allocation of time can be averaged across general patent loads for each examiner, and there are differences in time allowances between different patent groups (Cockburn, Kortum and Stern 2002). The impact of examiner time spent on an individual patent has not been studied in terms of patent quality, but examiners are also less likely to develop prior art issues because an

[15] Comment made by John Doll, Director of 1600 Patent Group at the 1998 Harvard-MIT Hippocratic conference.

examiner can not provide a final rejection. In cases of dispute the applicant can always re-file the patent as a continuation. Given these constraints, patent examiners are unlikely to invest heavily in high degrees of prior art search at least for most patents.

Other structural problems also exist that may affect the quality of patent prior art search. In many emerging new technologies it may be difficult to recruit examiners with the appropriate technical skills to address new technologies. In an examination of early finance patents it was found that extremely low degrees of prior art was cited, that most examiners did not have a sufficient background or educational training in the area, and that obvious prior art was missing from the applications (Lerner 2000). Recruiting top technical talent for the USPTO can not be easy. In the last few years, approximately one third of the USPTO's revenues had been siphoned into general congressional funds rather than being reinvested in the patent system. Perhaps because of this, patent examiners are on lower government pay scales. In 1998 the salaries for most examiners was around $50K and the pay scale topped out at $95K for the most experienced biotech examiners. For equivalent positions outside the USPTO one might expect $75K for a starting technical specialist without legal training, over $130K for starting attorneys, and over $300K for highly experienced attorneys. Also, because the USPTO is structured under the federal government, it limits its applicant pool to US citizens, thus denying itself access to a large group of US trained technical experts that are of foreign citizenship.

Early research examining the impact of patent examiners on patent quality have lead to the startling result that there are no significant differences in patent validity according to examiner experience level suggesting that there is very little evidence of any learning curve for patent examiners (Cockburn, Kortum and Stern 2002). If anything, the authors found that invalid patents are associated with examiners with higher mean levels of experience (both in terms of patent volume and tenure). It was also found that patent invalidity is highly correlated with examiners with higher than average citation rates, suggesting that invalidity is associated with examiners that allow on average too much patent breath. This data taken together may well suggest that younger critical examiners, who reduce patent claims through increased use of prior art, may be selected out of the organization as less critical, more efficient, examiners are promoted.

The belief that the USPTO is unable to do high quality prior art searches is common amongst practitioners and has resulted in papers attempting to explain the rationality of this phenomena. A recent argument, suggest that because there are very few valuable patents (Lemley 2001), or patents that are licensed (Roberts 1981), that prior art search is so costly that the USPTO is 'rationally ignorant' (Lemley 2001). Lemley argues that based on reasonable patent cost data, the cost of search to the USPTO is far greater than the in-depth search and litigation costs faced by industry. Lemley calculates that the current $5B system patenting system saves $1B over a system that is 10% better at patent prior art search. While this may be the case, Lemley does not measure the welfare effects of bad patents such as the social cost of non-entry, standard setting opportunities, or technological trajectories that are driving by dominating portfolios. Thus, when patent examiners avoid appropriate levels of prior art concerns, it is unclear how that effects the overall patent environment.

3.6.5 Managing Granted Patents and Patent Audits

The patenting granting process, and the structural disincentives for prior art search in the patenting process have resulted in a patent system that, on the surface, appears much broader than it should be. As discussed earlier in this chapter, approximately 50% of litigated patents are held invalid, although what is not clear is what proportion of non-litigated patents are both invalid and effective as deterrents for new markets.

The poor quality of patents makes understanding the legal implications of both internal and external patents very difficult. Although in recent years, companies have become better at understanding their own portfolios, many are still very poor at it. In the semi-conductor industry firms in the late 1980's were described as managing their patents by patent-stack size (von Hippel 1988), and nearly ten years later top firms were still very poor at managing their IP portfolios (Parr 1996). In 1996, 3M did not have a formal licensing office, with a corporate committee making licensing decisions rarely. Similarly, Motorola only had a small staff of attorney's, reporting to company businesses and DuPont, until 2001 allowed each business unit control over its own patents with occasional agreements approved by a central board. In a provocative book, Rivette and Kline (2001) argue that companies have the equivalent of 'Rembrandts in the attic', namely patents that they are unaware have the potential for tremendous value if appropriately enforced. While companies typically disagree with the conclusions of the authors, many firms have initiated IP audits of their own patents presumably to see if there is intellectual property that they are not using.

It is still unclear from the literature (1) how many IP audits are successful at identifying new business opportunities, (2) if these audits result in significant patent cost savings by killing non-performing patents, and (3) if these audits result in some significant percentage of the 1,600 patent lawsuits each year. We do know that many patent lawsuits are brought very late in the technology cycle. In some cases this may be just because the firm wants to maximize the patent impact. For example, many firms wait to sue right before a competitor takes a potentially infringing product to market. However, in many cases, the patented subject matter exists as products for many years, and can even become a de facto standard (such as with both the gif and jpeg image standards), before the patent position is recognized. In of itself, this behavior suggests that both patent holding and patent facing firms can fail to recognize the value, or even existence of important IP, for significant periods of time.

Even if firms are able to aptly identify internal IP, it is significantly more complicated for companies to understand external patent positions (Sullivan and Petrash 2001). Understanding external patent positions is very difficult because companies are both less aware of external technology development and they may also lack the appropriate technical and organizational capabilities to understand them (Henderson 1994). Similarly, firms also face the policy disincentives relate to external searching as firms fear paying treble damages associated with willful infringement of existing product lines. Given the concern that external patent searching can identify patents that block existing product lines, and thus would subject the company to treble damages, there is a legitimate and substantial incentive to not knowing about others patents.

Significant incentives also exist for a firm to represent its patents as both valid and a broadly as the claims describe. In these cases, a firm's ignorance about the external patent market can also allow a firm to represent its position in a manner fully afforded by the patent claims, rather than to disclose constraints posed on the patented technology by other patent holders. In cases of licensing transactions, or cases of infringement, the patent holding firm again has incentives to not understand the existing intellectual property landscape.

3. 7 Implications For the Use of Patent Data

The significant prior art and patent search disincentives across the various functions involved in attaining most US patents tells a compelling story as to why engineers rarely use patents to learn about new technologies (Allen 1977). Many research scholars now admit that patent counts offer a poor measure of innovation (Griliches 1987, Griliches 1990). However, many papers still rely heavily on patent count data (i.e. Sorenson and Stuart 2000, Rosenkopf and Nerkar 2001, Katila 2002 to name a few). But even for those looking at patent citation data, the challenges faced in the US patent system also cause great concern when using patent data for management research. It is a significant question if researchers can trust citation data when the validity rates of patents are so low and the disincentives for search are so high?

Several key studies in the last decade of so have show that the frequency at which patens are cited correlates well with both expert opinion on (1) the value of the patents (Alberts et al. 1991); (2) the likelihood of patent renewal (Harhoff et al 1999); and (3) the linkage between highly patents and the likelihood of patent litigation (Kortum and Lerner

2000). However is the polling of technological experts enough to rank important patents? When we consider the difficulty of search the importance of citations may just be a tautology – inventors confirm that patents that they think are important are ones that they cite. Perhaps citations are based on heuristics of availability (some searches and content is more available than others) rather than on true value of the claims and technology? What is clear in our discussion is that many opportunities for citations are missed given the disincentives for technology search.

Two key studies on the value of patent citations are critical in understanding if patent citation data was useful. To date, very little scholarship has linked patent citations to real measures of value with the exception of the study of patent examiners (Cockburn, Kortum and Stern 2002). In that study the authors found very little correlation between findings of patent validity and the number of received patent citations. Further work needs to be done to confirm these results, but it is a serious challenge to research that relies on measures of citation frequency.

The other study that we argue would be worthwhile would shift the attention from the patents that received the most citations and instead to examine the number of citations that a patent makes. In considering patents as measures academics frequently think that patents act like academic papers. They do not. While the best papers enable new areas of research, the best patents prevent others from further developing the technologies. Similarly, citations within academia are nearly free, or costless, to make within acceptable norms of citing practice, but as we have shown, citations that arise from technology search are very expensive to find and make, particularly as they can significantly limit the breadth of claims. As such, management researchers might well consider studying highly citing patents (not highly cited patents) as we might expect firms to invest heavily in prior art search if the technology was significantly radical that additional citations did not seriously limit the claims of the patent. In the cases of radical technology, where it would be difficult to limit the breadth of the claims through prior art, additional citations would make such a patent highly defensible.

3.8 Implications for Policy

A number of industry observers and management researchers have suggest that the intellectual property system is so broken that is should be dispensed, or perhaps that alternate reward mechanisms should replace the patent system (Merges 1999, Lessig 2001). Rather than offer alternate systems there are a number of policy recommendations using the current system that have not been addressed in the USPTO 21st Century Strategic Plan. I suggest two key and novel policy changes that would substantially improve the current US patent system at a very minor cost.

First, the USPTO does not make accessing patent data particularly easy for either management researchers or firms. The USPTO should make all patents, including those prior to 1975 available in full text, rather than the current difficult to use pictures. A tremendous number of citations originate well before 1975, perhaps some 20% of citations this year (Hall 2001). The USPTO could enhance the way in which patent are downloaded by providing bulk download services to local databases, and could also provide minimum thinker tools so that all the text specific patents could be reduced to different manageable forms. In particular, while the USPTO and a number of data sources (i.e. NBER) have made it easy to identify patent bibliographic information, it is not easy to identify claims information by either bulk download or types of claims. Also challenging, patents do not necessarily list their assignee, or may be identified to shell organizations, making it potentially impossible for even the most effective firms to identify patent holders. Patent bibliographic data should be dynamically updated to reflect existing ownership and licensees to truly reflect the state of the intellectual property landscape.

Secondly, many scholars and firms have identified that overreaching claims of the US patent system have created a massive patent thicket, a so called 'tragedy of the anti-commons' whereby firms are concerned with severely overlapping patent estates making it difficult for firms to commercialize new technology (Eisenberg and Heller 1998, Shapiro 2001). Because the inclusion of additional prior art serves to limit surface patent claims, additional prior art search would be helpful to reduce overlapping claims, and increase the validity of claims. There are several mechanism by which the USPTO could do this at very minor cost. First, the USPTO could make a best-efforts prior art search mandatory for the applicant and allow examiners to ask for reapplication based on examiner perceptions of inadequate search. The USPTO could also require applicants to name the closest competitor patents in the subject class of the application, and could require disclosure of all intellectual property sharing arrangements such as licensing, cross-licensing, alliances and other sharing agreements as a condition of patent validity.

A simple reorganization of the patent system could facilitate these processes. A reorganized USPTO, rather than offer patents through a simple grant process, could design a rejection and appeals process such that examiners could be required to eliminate some fixed percentage of patent applications based on inadequate disclosure elements.

Examiners could then be rewarded based on their ability to reject patent that are not later reallowed though a similarly structured appeals process.

Regardless of the mechanisms by which the USPTO solves the patent search problem, the current system may be well designed for the granting of patents, but is very poorly designed to serve notice to those firms and individuals willing to respect them. Notably ,its messiness also impacts the ability of researchers to measure it's importance and utility, a concern which is becoming increasingly a larger question. Because the intellectual property landscape is perhaps the most dynamic of all governmental regulatory environments, and also because intellectual property is so closely linked technological innovation and thus economic growth, careful attention should be paid to the intellectual property system to ensure an the most efficient and effective use of economic resources and incentives. Without effective mechanisms for the identification of these legal requirements, the system is becoming remarkably burdensome, arguably ineffective, and most certainly wasteful of key economic resources and overall welfare.

Chapter 4: Sampling on Patents as Technology

"There are two major problems using patents for economic analysis: classification and intrinsic variability. The first is primarily a technical problem. How does one allocate patent data organized by firms or by substantive patent classes into economically relevant industry or product groupings?" Griliches 1990.

4. 1 Introduction

It is commonly accepted that technological innovation impacts both organizations and environments. As a broad challenge, researchers in the various fields including strategy and the management of technological innovation have focused a tremendous amount of effort in understanding whether examining organizational capabilities or market competition gives us a greater understanding firm action and performance (Cockburn. Henderson et al. 2000). Several theoretical approaches such as resource dependency theory, neoinstitutional theory, population ecology and evolutionary economics have included technological innovation as an important, and perhaps a key, component of strategy. However, the concept of what technology actually "IS" has shifted over time from view of technology as endogenous to the firm, to a more open systems perspective (Poldolny, Stuart et al. 1996). This shift, while extremely rich in the opportunities it affords, has created a sampling trap: casual definitions of technology have led to the casual measurement of technology and has affected the general comparability of results across studies. In no place is this more apparent than some of the more interesting literature that relies on patent statistics.

The explosion of new patent based indicators in the last ten years has been unprecedented. Prior to the 1990's there had been a thirty year empirical legacy, primarily led by productivity economists, towards measuring patents, productivity and research and development (Penrose 1951, Machlup 1958, Scherer 1959, Nelson 1962, Schmookler 1966, Nordhaus, 1969, Taylor and Siberston 1973]. Unlike today, where a tremendous amount of patent data is computerized, these scholars necessarily examined the patents they sampled and primarily focused on patent count data. Over the years this research has led to great strides made in dealing with this type of data [Griliches 1987 ,Hausman 1984 #], including techniques to deal with the common problems such as classification, time lags, and other concerns intrinsic to patentable inventions. These other concerns, for example, manage data issues caused by the fact that "not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in "quality" in the magnitude of inventive output associated with them." (Griliches 1990).

In the early 1990's, the landscape of patent studies shifted. This may have been do to the availability of a large amount of patent data in computer form or perhaps to the expanding literature in sociology, particularly population ecology, (Podolny 1993, Podolny and Stuary 1996) and network studies (Powell 1990, Powell 1996). However, the explosion was fueled by two critical papers from the previous economic traditions. In 1990 it was shown that citation based patent count indicators could be associated with an independent measure of the social value of innovation (Trajtenberg 1990) and, a year later, that patent citations could be used as indicators of industrially important patents as perceived by technology experts (Albert, Avery et al 1991). Interestingly, the literature did not develop along these classic economic productivity lines, but rather scholars began to focus on new ways to examine the links between patent citations and other avenues of scholarly interest (Table 1).

Table 4-1: Examples of new applications of patent citation data

Author	Tradition	Year	Topic
Jaffe, Trajtenberge, Henderson	Economics	1993	Geographic localization of knowledge spillovers
Podolny, Stuart, and Hannan	Population Ecology	1996	Niches, crowding and status
Mowery, Oxley, Silverman	Strategy	1998	Technology overlap and collaboration
Henderson, Jaffe, Trajtenberg	Strategy	1998	Generality and originality in University patenting
Powell	Network	1999	Network position and performance
Sorenson and Stuart	Population Ecology	2000	Aging, obsolescence and organizational innovation
Shane	Entrepreneurship	2001	Importance and radicalness of patent on new firm formation
Rosenkopf and Nekar	Organizational Behavior	2001	Boundary spanning in organizations and technology
Fleming	Technological Innovation	2001	Technology search and component combinations
Powell	Network	2002	University-Industry Relations
Katilla	Technological Innovation	2002	Product search over time
Sorenson and Fleming	Technological Innovation	2001 Mimeo	Publication in science and innovation diffusion

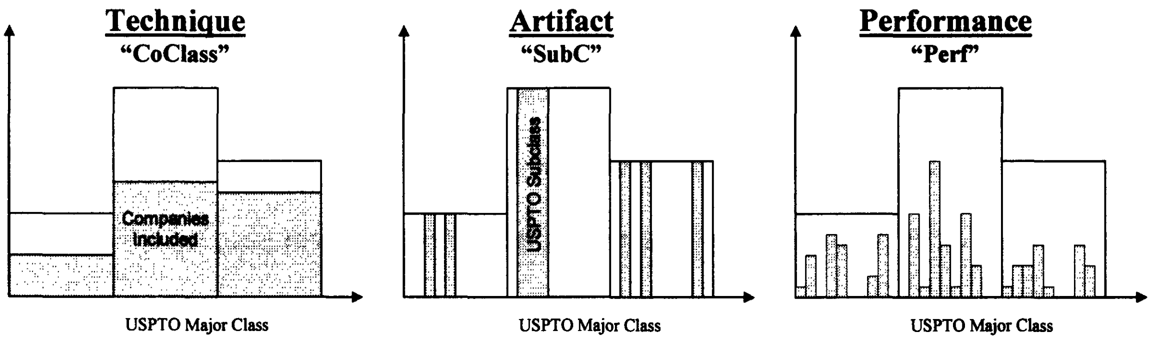
The vast breadth of intellectual interest in technology in recent years is wonderful development for those who see technology as a key component of management scholarship. However, hidden under the vast flurry of new results and ideas is a dangerous combination of overlapping indicators, varying methods of patent sample selection, and for the most part, biases in conceptualizing technology in a way that is frequently neither explicit nor explored. For example, two recent papers (Rosenkopf and Nekar 2001 and Katila 2002) rely on inferences and measures of backward lags in patent citations (Sorenson and Stuart 2000) but sample patent data very differently from the previous paper without considering that sampling effects may actually be driving some of the age results. Similarly, the latter (Katila 2002) borrows a concept of technology boundary spanning from the first (Rosenkopf 2001), but the measure was altered as their method of picking which patents to include for study likely made it very difficult to construct the same type of measure.

This chapter seeks to expose and examine systematic biases that can arise under three different sampling criteria for panel patent data. In particular this paper will examine how different patents can be sampled, how these different samples overlap, and a preliminary discussion of how these issues can affect the interpretation of management scholarship.

4-2. Sampling on Technology – Background and Hypothesis

A review of the empirical patent literature suggests that there are basically three generalized ways by which management scholars have typically used and sampled patent panel data: (1) by the techniques of the firm or group of firms, (2) by technological artifacts, and (3) by product or performance linkage (Table 2). A fourth method of sampling, by the temporal landscape of the patents (Fleming 2001) is uniquely focuses on a cross-sectional dataset and will not be considered in this paper. These broad approaches are described as follows:

Figure 4-1: Sampling Patents on Technology



Pick an industry and identify companies of interest. Take all the patents of these companies for the period of study and eliminate any patents from USPTO classified major classes (>400) that seem unlikely to generally fit the industry of study.	First identify the sub-components of the technology of interest. Then, match the sub-components of the technology to USPTO patent sub-classes (>110,000) and take all the patents from the sub-classes that match.	Patents are read and then included if they fulfill criteria for linking to product or performance. Before reading, sample by using free-text searching and companies of interest. Read and resample using citations until convergence (ie. all back citations cited 2x times).

4.2.1 Sampling Technology as Techniques of the Production Function

The idea of taking all the patents for any particular firm in a firm year and attempting to use those patents as an economic indicators has the richest history of all empirical patent literature. This sampling process is fairly simple. A scholar simply selects a group of companies (or organizations) for comparison, usually by selecting a particular industry or organization type and gathers all the patents assigned to those organizations over the period of interest. Given that in the last 25 years that the United States had been the biggest market for most new technologies, and that much research suggests that foreign companies patent in the US regularly, it is common to restrict the sample to US patents. As is frequently the case, the scholar also slightly limits the patents to several of many broad patent classes (there are approximately 400 in the US Patent Office) so as to minimize the some of the errors that are thought to arise when, for example, companies get a few patents that have nothing at all to do with their business interests. This later task frequently reduces the sample size by only a small percentage of the originally available patents.

This technique is naturally subject to certain biases. Primarily, this technique tends to gather data for companies that the scholar is aware, namely large companies with large patent portfolios. Thus, this technique frequently leaves out the patents of small companies, companies who are operating under the radar, important institutions such as universities, non-profits and government organizations, and fails to pick up patents from independent inventors. Also, the reality that companies with large patent portfolios are typically highly diversified gives rise to the concern that the patents would look different between, for example, a high performing company operating primarily in mature markets and a high performing company operating in newer markets.

By sampling on company and then major class, or "CoClass" sample, we argue that the resulting sample considers technology as the new techniques of the firm (Mokyr 1990). Building on evolutionary economic theories of the firm (Nelson and Winter 1982), Joel Mokyr argues that the while a firm has standard procedures or routines that it expresses, there is a greater knowledge that firm possesses towards producing particular good which it may not enact. Namely in evolutionary terms, we could think of the products that a firm develops (or expresses) as it phenotype, while the conceptualizations, or knowledge, of how to produce a product as its genotype. Unlike normal events in living systems, organizations may add to their genotype, without necessarily affecting their phenotype, though investment in research and development. Thus, ignoring for a moment all the intrinsic difficulties we face with patent data, we would expect a sample constructed in this way to correlate well with input measures such as research and development activities much more so than with output measures such as sales. It is not surprising then that patent count studies sampled by CoClass have consistently correlated extremely well (corr. 0.85 to 0.95) with R&D inputs (Scherer 1965, Griliches 1987, Griliches 1990) and not directly with productivity measures such as sales (Trajtenberg 1990).

Proposition 1: Patents sampled by CoClass will have higher correlation with firm level R&D expenditures than other patent samples.

4.2.2 Sampling on Technology as Artifacts

Another patent sampling method has its roots in the early economic analysis of patents (Schmookler 1966). when an attempt was made to sample patents based on sub-classifications and then to link the sub-classifications to different industrial classifications. More recent technological studies (Rosenkopf 2001) have carefully linked product sub-components in one industry to US patent sub-classifications (of which there are approximately 110,000). In this particular case, the analysis was restricted to top patenting companies, but as a general method, selection on specific subclasses is a fairly easy method of collecting patent data.

This technique for sampling patents is also subject to certain biases as well, but very different concerns show up here than in the CoClass technique. Unlike CoClass, this sampling method broadly picks up the various forms of organizations. However, it is critically reliant on breaking up the system of interest into components, and in any given linked the technological system, both the components of the system and the classification scheme have changed over time. In some sense this concern might be reduced by the consideration that the USPTO regularly reclassifies patents and is continuously updating the classification system. However, another concern exists that while patents may be in the same classification by the USPTO, the organizations are often not in similar industries[16].

By sampling on patent sub-classification, or "SubC", we argue that the resulting sample considers technology as artifacts which focus primarily on the continuity of technological change (Basalla 1993). Any casual reading of patents in patent subclasses frequently gives the reader a sense that while the technologies appear to be related on the surface, they are frequently very different technologies, meant to address very different products in very different industries. For example, we can find a number of computer interface peripheral devices Subclass 345/156 in as early as 1891, while three patents classified under Mouse 345/163-165 are issued before the first mouse patent to Douglas Englebart. We are reminded of toothpaste tubes and manure spreaders falling in the same primary sub-classification (Scherer 1965), rat poisons in the same sub-classification as cancer medications, and countless other examples exist. At some level the sub-classifications make sense, namely that the technological artifacts share similar physical or conceptual features. Even though there were no computers in 1891 there were still things that you could push to give some kind of output, and there were devices before the mouse that were linked by a cord to a computer. Similarly, toothpaste tubes and manure spreaders are both dispensers, and at a chemical level, poison and medications can have very similar structural properties even though they address very different industries and uses. If we believe that patent examiners classify technologies by their similarities as artifacts, is it unclear how these sub-classifications might be best used to clusters sets of patent citations to learn about the capabilities of companies and their position in the

[16] For greater discussion see (Griliches 1990)

environment except to the extent that the SubC sample overlaps in part with CoClass sample measures.

Proposition 2: Patents sampled by SubC will have very low correlation with both R&D and firm level sales compared to other patent samples.

4.2.3 Sampling on Technology as Use and Performance

A final method of patent sampling for panel data is conceptually what we normally think of when picking patents, but in reality very hard to do and fairly dependent on the criteria of the researcher. In this case, patents are found not only by their company, class or subclass, but by free text searching, citation analysis, and final sorting by an expert reading and evaluating the relevance of the patent to a particular product class or set of performance characteristics. Studies of this sort are very rare in academia (perhaps Basberg 1982 and Trajtenberg 1990 used this approach), although this is the predominate mode of patent searching in industry. Of course, such datasets are not easy to come by, and are frequently undocumented, but are perhaps the best linked to the abilities of a firm or industry to move forward in a given product or market.

By sampling on products or performance characteristics, or "Perf" we argue that the resulting data set builds on existing theories of technological change that consider technology as neither a technique or artifact but rather a capability which alters performance along a particular technology trajectory (Utterback 1974, Abernathy and Uttterback 1978, and Tushman and Anderson 1986). This conceptualization of technology is generally more likely to represent a firm's position within a particular product market or industry over time, although it may misrepresent their overall capabilities across markets. We therefore predict:

Proposition 3: Patents sampled by Perf will have high correlation with firm level sales compared to other patent samples.

4.3 Implications of Patent Sampling on Technology Measures

The recent explosion in the use of patent data with careless attention to patent sampling and concern for what the authors are measuring is of practical concern to the understanding, reliability, and replicability of management scholarship. There are a multitude of issues that could be addressed through careful patent scholarship, although two stand out as amongst the most important. To do adequate scholarship in the management of technology there are two basic questions about the technology that are so trivial they are typically taken as obvious. The first of these questions asks "is the technology is related to the productive capabilities of the firm?" The second of these questions asks "is technology is new or not? "

Through our discussion we will show that these seemingly trivial questions are very difficult to answer using patent data and are critically reliant on the quality and nature of the patent sample.

4.3.1 Testing Technological Boundary Spanning Across Samples

Our first question focuses on if the technology is related to the productive capabilities of the firm. Recently scholars have argued that boundary spanning activities can give us useful measures towards predicting the impact of a particular firm's technologies in within and beyond a particular technology domain (Rosenkopd and Nekar 2001, Katila 2002). These authors argue that considering the antecedents of patents, as measured by backward patent citations, allow us some ability to predict at some level the future impact of the technology, as measured by future patent citations. This might make sense in some cases, for example, some companies add a lot of prior-art to patents that they might consider litigating to "bomb-proof" the patent against prior-art invalidations.[17] However, the vast majority of patents are not litigated and frequently this strategy is not pursued until the patent is already in the courts. Unfortunately, despite this small effect, there is little guidance in the literature on how we might measure boundary-spanning activity in technology[18]. Evolutionary models do not provide us with and clear way to address this question as they are generally focused on the similarities of technology through measures such as niche overlap (Podolny 1996), or interdependency (Fleming 2001). Similarly it is unclear what differences in artifact classification mean for organizations hoping to exploit technology.

By creating a Perf sample , combined with the other two samples, it is possible to test if patent technological boundary is robust to sampling differences. Like Rosenkopf and Nekar one can construct a a SubC sample, and also like Kitala 2002 one could develop a similar CoClass sample. Because these different samples are constructed differently, the use of within citations to predict the proximity of technology will not produce consistent and robust results across samples.

Proposition 4: Replicating the methods of Rosenkopf and Nekar across samples will not product robust results

4.3.2 Testing Technological Age Across Samples

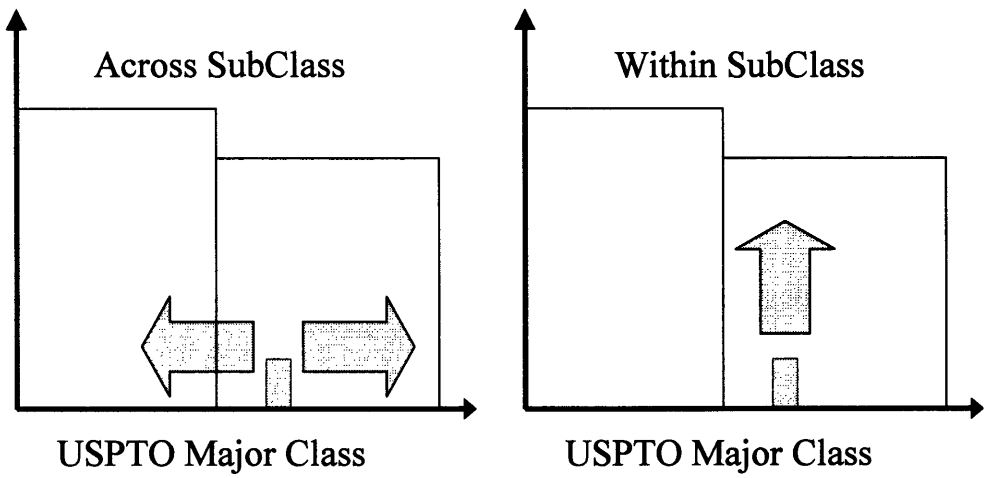
The second question focuses on the issue of if the technology is new or not. Following foundational work in the population ecology tradition (Stinchcombe 1965, Hannan and Freeman 1977) several scholars have given consideration to the nature of

[17] Personal communication with Ian Cockburn

technological age towards achieving environmental fit (Hannan 1998, Sorenson and Stuart 2000, Katila 2002). One piece of scholarship (Sorensen and Stuart 2000) argues that there are two seemingly different effects due to organizational aging processes. In one direction, experienced organizations become more efficient at executing routines, but in the other direction the fit between organizations and their environments deteriorates with age. Using a patent sample of the CoClass type, the authors use cox models of firm patent rates to find that while older firms innovate at a higher rate, arguably their fit with the environment declines as firms exploit existing competencies (measured as the rate of self-citations). Subsequent work (Kitala 2002) builds on these results using a CoClass sample, as well as within competitor measures of technological boundary spanning activities to argue that while old intra-industry knowledge hurts, old extra-industry knowledge promotes innovation.

In this case, while the papers have sampled using the same general method, the results of both the foundational and following article are deeply reliant on measures of backward citation age and self-citation measures. The three samples can be used to test if these effects are more driven by patenting behavior (i.e. propensity to patent) rather than actual innovation effects. Consistent with arguments that firms become more efficient in executing routines over time (Nelson and Winter 1982) large firms, who frequently have large intellectual property budgets and experience in intellectual property litigation, may be more likely than small firms to engage in patent thicketing activities, or expanding patent portfolios around similar or substitute technologies. Patents arising from thicketing behavior based on a particular technology span multiple sub-classes rather than appear in the same sub-class (Figure 4-2).

Figure 4-2 Thicket Effects on Patenting



These patents are likely to have younger within citations than others as they are more likely to be incremental in scope and more likely to be variants on recently discovered technologies. As such, samples more likely to contain "thicket patents" will generally be younger for a given firm in a given year. This leads us to hypothesize:

Proposition 5a: Patents citations to patents within CoClass will have younger back citations, controlling for firm application year, than patents sampled by SubC or Perf.

Proposition 5b: Patents citations within Perf will have younger back citations, controlling for firm application year, than patents sampled by SubC.

4.4 Methods and Technology Sample

To study these effects we develop a Perf, SubC, and CoClass sample of optical photolithographic aligner patents. An optical photolithographic aligner is a sophisticated piece of capital equipment used in the manufacture of solid-state semiconductor devices. These pieces of equipment transfer very small intricate patterns to the surface of the silicon wafer in a transfer process known as lithography. This transfer process is extremely precise and difficult making the performance of the photolithographic aligner the critical element in the manufacture and competitive capabilities of semiconductor manufacturers to whom the aligner was sold[19]. Typically the aligners represented 30% of the cost of a new semiconductor facility.

In many ways the photolithographic aligner industry is a wonderful industry to study the role of patents in complex technologies. At a first cut, the industry has been heavily studied and primary data have already been collected (Hendeson 1988). With data from 18 firms that data includes 468 firm years. Also, the period from 1960 to 1990, where the industry experience tremendous growth, is ideal for collecting quality panel patent data as it precedes the patent explosion of the 1990s while providing a large portion of patents in electronically available format. Sampling over this period also allows for the collection at least ten years of forward citation data for each patent included in the sample. Finally, as the technology is primarily in the mechanical arts, patent grant to application lags are very short (2.25 years), mimicking technology cycles (approximately 2.5 years).

4.4.1 Perf Sample: Technology as Product Performance

To develop the initial photolithography patent data set we began by developing a "Perf" data set so that the other two samples could be derived. Patents were examined that explicitly described technology towards increasing the performance of photolithography equipment or process for the manufacture of semiconductors, including

[19] See Henderson 1988 for additional technical details.

substitute technologies such x-ray lithography, ion-beam lithography and others[20]. Patents were read and included if any substantial feature (abstract, background, summary of invention, examples and/or claims) explicitly targeted improving the performance of lithography (particularly alignment mechanisms, masks, pellicles, devices, optical systems, lenses, radiation sources, chemical compositions, and vibration isolation tables and devices). Patents were not included if they only employed lithographic technologies that were 'known in the art' or 'standard' as frequently mentioned in the read patents, and patents were not included if they only dealt with the design of specific semiconductor features, wafer bonding, wafer types, particular semiconductors or their methods of fabrication, or post-lithography etching technologies .

The "Perf" sample was constructed first by identifying companies with a known commercial interest in manufacturing photolithographic aligners prior to 1990, or companies who frequently published peer-reviewed technical articles on photolithography between 1975 and 1986 (data from Rebecca Henderson, 1988 PhD dissertation). Companies with small patent portfolios had their entire portfolios read (136 included of 431 read, 1969-99). Companies with large patent portfolios were full text searched on the USPTO (410 included of 1182 read, 1975-90). Also read were all patents with the words 'photolithography' or 'microlithography' in their title or abstract (215 included of 224, 1975-99). From this set of 738 patents, we examined the top 51

[20] We could not simply choose subclasses as did R&N as the technology is not well categorized at the USPTO. This may be because the technology draws on a large group of important antecedent technologies such as photography, xerography, transparency and EM radiation projection, motion pictures, magnetic tape, precision manufacture, precision bonding, microscopy, optics, device micro-fabrication, specialty chemicals and chemical deposition, etching and plotting, and vibration dampening to name a few. It is the author's opinion that this feature is more common than not as many of these linkages were not obvious until a detailed review of the patent literature. It is also the authors experience that this is more the norm than not, and that this idea is described in the early expert literature on patents (Schmookler 1966, Griliches 1990).

companies (cited >=9x times, at 8x we would have to include an additional 12 companies) that were most cited and repeated the process for an additional 26 companies (199 included of 905 read, 1975-90). Finally with a set of 925 patents, all patents that were cited at least two times were read, added to the set and the process repeated. At the end of this process 4266 patents were read, and we were left with a final set of 1749 patents assigned to 238 firms. Of this set approximately 1500 patents were granted before 1990.

4.4.2 CoClass Sample: Technology as Technique

The "Perf" data set, as well as a baseline knowledge of key players in the photolithographic aligner industry, was used to generate the "CoClass" sample. This sample included 45 firms across 5 key major classes (representing 69% of the Perf sample), for patents granted 1969-1990. Firms were added if they had substantial photolithography patents (>7 patents in the Perf sample), or if they were dedicated producers of photolithographic equipment. Five firms were removed from our dataset as they were primary producers of technologies that had potential photolithographic applications but whose patents were primarily directed towards other businesses (see Appendix 4-1 for additional details).

4.4.3 SubC Sample: Technology as Artifact

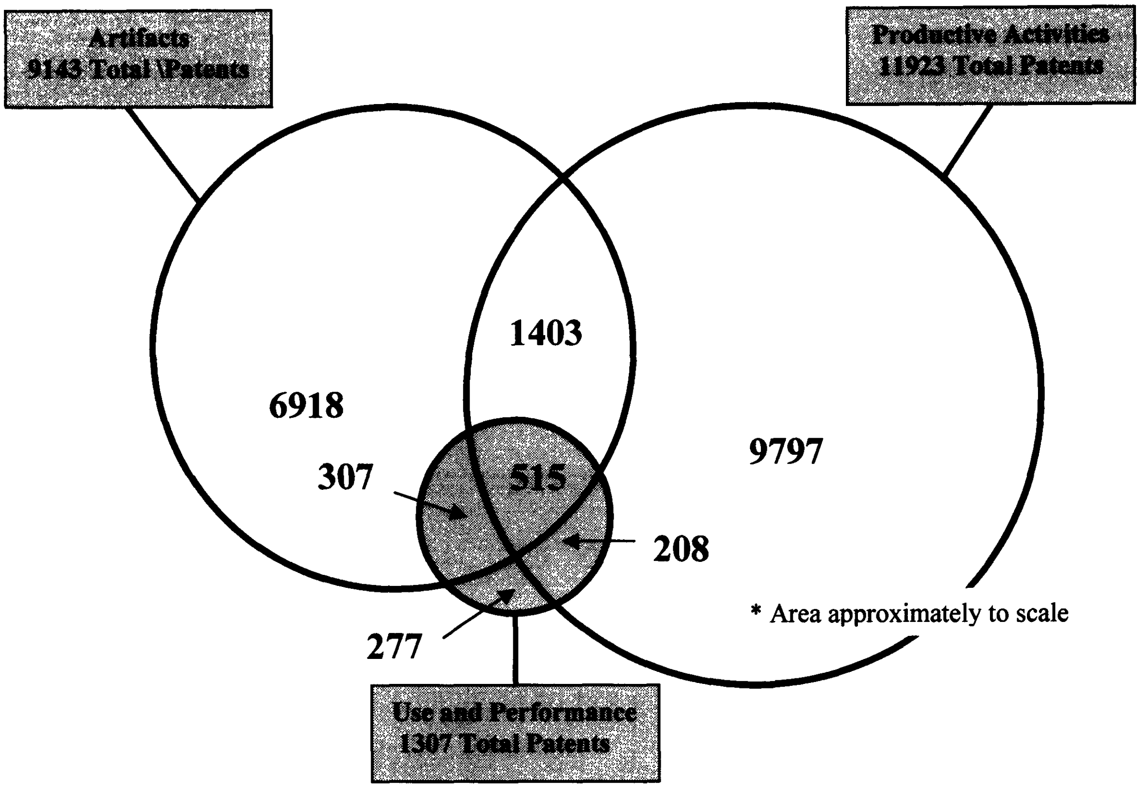
The "Perf" data set was also used to match as closely as possible with the Rosenkopf and Nekar study (2001) where patents were pulled from approximately 35 unique subclasses. As mentioned earlier, the patent classifications are not necessarily very useful for determining where key patents are found for a particular technology of product. Examining the "Perf" sample it was discovered photolithography patents are scattered across numerous patent subclasses, the bulk of which are not specifically tailored to the product category (in fact the largest number of patents are found in subclass 355/53 “Photocopying / Step and Repeat” suggesting that those looking for photocopying patents will similarly pick up photolithography patents).

Using the “Perf” dataset, the most popular primary subclasses (n = 1749) were compared with the most popular total subclasses for all the 1749 patents (n = 9683). Comparing the most popular 48 primary patent subclasses (subclass named >=5x, approximately accounting for 40% of the primary subclasses) with the most popular 49 normal subclasses (subclasses named >=30x, accounting for 30% of the primary subclasses), we found that 29 matched, and an additional 7 were added as they fell within obvious numbering ranges (see Appendix 4-1 for additional details).

4.5 The Extent of Overlap in Patent Technology Samples

The resultant three patent samples (Figure 4-3) have very little overlap although efforts were made to ensure that patent samples were constructed following procedures that are described in leading technical articles.

Figure 4-3: Why Not All Patent Samples are Equal: Patent Samples 1968-1986*



These samples presented in Figure 4-3 are sufficient to examine the various ideas presented in this chapter although this data has not yet been fully employed to test the propositions of this paper. However, preliminary analysis on Proposition 4 presented in this chapter suggests, as one might expect from Figure 4-3, that measures of boundary spanning activities are not consistent or robust when different patent sampling techniques are employed. Similarly, evidence from Chapter 5 of this paper suggests, as one might expect, that there are some differences on technology age depending on the sample construction and different within-sample citations. As Proposition 5 suggests, different samples are likely to pick up different levels of strategic activity within that sample, and these differences in firm activities likely influence the technology age of within sample citations.

4.6 Discussion:

This chapter, although very preliminary, attempts to identify and consider several issues not previously examined in the technology or strategy literature. The first question is whether the classification of patent data is not just a mundane "technical problem" as is often treated as the case (Griliches 1990) but rather a critical consideration that can seriously affect research outcomes, both in productivity measures and in the examination of technology. A second question which this chapter poses is if it is useful to draw strong boundaries when categorizing technology, or if more general boundaries are more appropriate for examining capabilities and environmental fit. Finally, the paper addresses the compelling issue that sampling any sort of population, including patents, has serious research implications and design of patent samples needs to be explained explicitly to ensure research integrity, reliability, and replicability.

Appendix 4-1: Development of the Perf, CoClass, and SubC Samples

In the significant literature using patent data, much attention has been given to how patent data is used while very little given to how patent data is collected. For papers concerned with the patent environment, or technology landscape, biases due to sample collection may omit critical patents and key firms such that such that key features of the environment are not represented in the sample. For example, sampling on large firms may leave out some of the most important patents to the industry. Similarly, sampling on patent subclasses may omit highly critical important patents that are primarily classified elsewhere, while including patents with no relevance to the industry of study. Sampling concerns may also restrict the types of variables used in a study. An obvious example: if a study builds a patent sample by using patent sub-classifications it cannot use sub-classifications as a general measure of the relatedness of the various patents.

Because of these challenges, we collect three different patent photolithography samples. The first of these samples "Perf "is similar to an expert sample, where patents are included based on whether their claims and technology coverage propose to increase the performance of the photolithography. This sample is in practical terms very hard to construct. The second of the samples "CoClass" is developed in a manner similar to most economic studies. Patents are identified by identified companies of interest and then culled slightly by eliminating major patent classes that seem highly unrelated to the industry of interest. This sample tends to over sample patents based on industry, particularly as large firms often patent in more than one industry and under sample based on technology. The third of these samples "SubC" is constructed by matching key component technologies with patent sub-classes to develop the patent sample. This type of sample tends to over sample on technology, as many technologies with the same sub-classification are not applied in the same industries, and under sample on the industry as some firms key to the industry will not necessarily patent under the chosen sub-classes.

The performance sample, or Perf, was constructed by initially identifying companies with a known commercial interest in manufacturing photolithographic aligners prior to 1990, or companies who frequently published peer-reviewed technical articles on photolithography between 1975 and 1986 (data from Rebecca Henderson, 1988 PhD dissertation). Companies with small patent portfolios had their entire portfolios read (136 of 431 read patents were included for the years 1969-99). Companies with large patent portfolios with the words "photolithography" or "microlithography" in the full patent text were also read (410 of 1182 read patents were included for the years 1975-90). Also read were all patents with the words 'photolithography' or 'microlithography' in their title or abstract (an additional 215 of 224 patents were included for the years 1975-99). Removing duplicates, this resulted in 738 patents, we examined the top 51 companies that were most cited and repeated the process for an additional 26 companies (199 of 905 read patents were included for the years 1975-90). Finally with a set of 925 patents, all patents that were cited at least two times were read, added to the patent set and the process repeated until convergence. At the end of this process 4266 patents were read, and we were left with a final set of 1749 patents assigned to 238 firms. Of this set approximately 1500 patents were granted before 1990.

The key company sample, or "CoClass" was generated by using the Perf data set as well as baseline knowledge of key players in the photolithographic aligner industry from trade press, interview notes (Henderson 1988), and technical papers. This sample included 44 organizations across the top five major patent classes (representing 69% of the Perf sample), for patents granted 1969-1990. Firms were added if they had substantial photolithography patents (>7 patents in the Perf sample), or if they were dedicated producers of photolithographic equipment. Five firms were removed from our dataset, as they were primary producers of technologies that had potential photolithographic applications but whose patents were primarily directed towards other businesses.

For CoClass the 44 organizations included (and their number of photolithography patents) were:

ASM LITHOGRAPHY B.V. (3); AT&T CORP. (127); CANON KABUSHIKI KAISHA (76); COMPUTERVISION CORPORATION (22); EATON CORPORATION (14); EATON OPTIMETRIX, INC.(3); (ELECTROMASK, INC.(2); FUJITSU LIMITED (31); GCA CORPORATION (20); GENERAL ELECTRIC COMPANY (26); HAMPSHIRE INSTRUMENTS, INC. (9); HEWLETT-PACKARD COMPANY (15); HITACHI, LTD (64); HUGHES AIRCRAFT COMPANY (17); INTEL CORPORATION (7); INTERNATIONAL BUSINESS MACHINES CORPORATION (194); KARL SUSS KG (3): KASPER INSTRUMENTS INC. (12); KULICKE AND SOFFA INDUSTRIES INC. (9); MASSACHUSETTS INSTITUTE OF TECHNOLOGY (17); MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD. (18); MICRON TECHNOLOGY, INC.(3); MITSUBISHI DENKI KABUSHIKI KAISHA (12); MOTOROLA, INC. (17); NEC CORPORATION (8); NIKON CORPORATION (45); NIPPON TELEGRAPH & TELEPHONE CORP. (17); OPTIMETRIX CORPORATION (19); PERKIN-ELMER CORPORATION (68); RCA CORPORATION (54); SHIPLEY COMPANY INC. (4); SIEMENS AKTIENGESELLSCHAFT (17); SVG LITHOGRAPHY SYSTEMS, INC. (4); TAIWAN SEMICONDUCTOR MANUFACTURING CO., LTD. (4); TEXAS INSTRUMENTS, INCORPORATED(28); THOMSON-CSF (31); TOSHIBA CORPORATION (15); U.S. PHILIPS CORPORATION (35); UNITED STATES OF AMERICA, ARMY (11); UNITED STATES OF AMERICA, DEPARTMENT OF ENERGY (6); UNITED STATES OF AMERICA, NAVY (6); VARIAN ASSOCIATES, INC. (6); VLSI TECHNOLOGY RESEARCH ASSOCIATION (2); WESTINGHOUSE ELECTRIC CORP. (21).

The five firms not included in CoClass (and their number of photolithography patents) were:

CIBA-GEIGY CORPORATION (11); E. I. DU PONT DE NEMOURS AND COMPANY (7); EASTMAN KODAK COMPANY(10); FUJI PHOTO FILM CO., LTD (15); FAIRCHILD CAMERA AND INSTRUMENT CORPORATION (8)

We restricted the CoClass patents to five major patent classes as listed below. These patent classes account for 69% of the patents in the Perf data set. The top 5 classes were chosen as the additional classes seemed less relevant than the first five to photolithography and raised the concern of collecting too much noise given the additional benefit of including these classes.

Class	No. Patents	Class Name	Running Total	
430	453	RADIATION IMAGERY CHEMISTRY: PROCESS, COMPOSITION, OR PRODUCT THEREOF	453	Included
355	238	PHOTOCOPYING	691	Included
438	206	SEMICONDUCTOR DEVICE MANUFACTURING: PROCESS	897	Included
250	143	RADIANT ENERGY	1040	Included
356	115	OPTICS: MEASURING AND TESTING	1155	Included
378	63	X-RAY OR GAMMA RAY SYSTEMS OR DEVICES	1218	Not Used
216	56	ETCHING A SUBSTRATE: PROCESSES	1274	Not Used
359	53	OPTICS: SYSTEMS (INCLUDING COMMUNICATION) AND ELEMENTS	1327	Not Used
318	34	ELECTRICITY: MOTIVE POWER SYSTEMS	1361	Not Used
427	31	COATING PROCESSES	1392	Not Used
428	27	STOCK MATERIAL OR MISCELLANEOUS ARTICLES	1419	Not Used
219	23	ELECTRIC HEATING	1442	Not Used

We also used the Perf data set to develop our SubC sample in a manner that matches as closely as possible with a sub-classification sample study (see Rosenkopf and Nerkar 2001). The "SubC" sample is constructed from patents found in 37 unique patent subclasses. We could not simply choose subclasses as the technology is not well categorized at the USPTO. This may be because the technology draws on a large group of important antecedent technologies such as photography, xerography, transparency and EM radiation projection, motion pictures, magnetic tape, precision manufacture, precision bonding, microscopy, optics, device micro-fabrication, specialty chemicals and chemical deposition, etching and plotting, and vibration dampening to name a few. It is the author's opinion that this is a typical issue that plagues patent data collection as many of the technology linkages were not obvious until a detailed review of the patent literature was conducted. It is also the authors experience that this is more the norm than not, and that this idea is described in the early expert literature on patents[21]. Indeed, examining our Perf sample we found that photolithography patents are scattered across numerous patent subclasses, the bulk of which are not specifically tailored to the product category. Considering that the largest number of photolithography patents are found in subclass 355/53 "Photocopying / Step and Repeat, we can presume that those looking for photocopying patents will similarly find our patents plaguing their sampling strategy.

Patents have one primary sub-class designation and may have additional sub-class designations. Using our Perf dataset we compared the most popular primary subclasses (n = 1749) with the most popular total subclasses for all the 1749 patents (n = 9683). Comparing the most popular 48 primary patent subclasses with the most popular 49 normal subclasses, we found that 29 were matched, and added an additional 8 as they fell within obvious numbering ranges,

The "SubC" photolithography sample was constructed from the following 37 unique subclasses:

SubClass	Number Patents	Title	Total in Subclass
204/192.32	48	Chemistry: Electrical and Wave Energy/ Sputter etching	794
216/67	37	Etching a Substrate Processes/ Using Plasma	1254
250/491.1	37	Radiant Energy/Means to Align or Position an Object Relative to a Source or Detector	427
250/492.1	40	Radiant Energy/ Irradiation of Objects or Material	894
250/492.2	145	Radiant Energy/Irradiation of semiconductor devices	1367
250/548	65	Radiant Energy/Controlling web, strand, strip, or sheet	830
355/43	41	Photocopying/Including reflector between original and photosensitive paper	337
355/53	190	Photocopying/Step and repeat	1421
355/67	41	Photocopying/Illumination System or Details	978
355/71	31	Photocopying/Including shutter, diaphragm, polarizer or filter	1147
355/77	52	Photocopying/Methods	1601
356/400	64	Optics:Measuring and Testing/With Light Detector	785
356/401	88	Optics:Measuring and Testing/With Registration Indicia	862
378/34	60	X-Ray or Gamma Ray Devices/Lithography	449
378/35	61	X-Ray or Gamma Ray Devices/ Pattern Mask	344
430/191	36	Radiation Imagery Chemistry/And monomeric processing ingredient	613
430/192	48	Radiation Imagery Chemistry/Polymeric mixture	888

[21] See early writings of Schmookler, or Griliches, Z. (1990). "Patent Statistics as Economic Indicators - a Survey." Journal of Economic Literature 28(4): 1661-1707.

430/22	46	Radiation Imagery Chemistry/Registration or Layout Process Other Than Color Proofing	688
430/270.1	80	Radiation Imagery Chemistry/Radiation sensitive composition or product or process of making	2460
430/271.1	34	Radiation Imagery Chemistry/Identified backing or protective layercontaining	1058
430/272.1	37	Radiation Imagery Chemistry/Silicon containing backing or protective layer	399
430/296	135	Radiation Imagery Chemistry/Making electrical device	941
430/311	93	Radiation Imagery Chemistry/Electron Beam Imaging	1317
430/312	80	Radiation Imagery Chemistry/With formation of resist image, and etching of substrate or material deposition	672
430/313	102	Radiation Imagery Chemistry/Including multiple resist image formation	1229
430/314	64	Radiation Imagery Chemistry/Etching of substrate and material deposition	788
430/318	44	Radiation Imagery Chemistry/Metal etched	577
430/319	44	Radiation Imagery Chemistry/Named electrical device	550
430/321	37	Radiation Imagery Chemistry/Optical device	882
430/322	35	Radiation Imagery Chemistry/Forming nonplanar surface	610
430/323	114	Radiation Imagery Chemistry/Including etching substrate	1038
430/324	48	Radiation Imagery Chemistry/Including material deposition	592
430/325	94	Radiation Imagery Chemistry/Post image treatment to produce elevated pattern	1525
430/326	103	Radiation Imagery Chemistry/Pattern elevated in radiation unexposed areas	1276
430/327	47	Radiation Imagery Chemistry/Processing feature prior to imaging	626
430/329	33	Radiation Imagery Chemistry/Including heating	555
430/5	178	Radiation Imagery Chemistry/Radiation Mask	2260

Chapter 5: Patent Orientation, Freedom to Operate and Adaptive Behavior: The Case of the Photolithographic Aligner Industry

Can firms keep up with the pace of technological change? This chapter explores the idea that firms differ in their adaptive behavior, namely fast response to technological change, based on their relative resource allocation to different patent orientations. From a detailed analysis of patents in the photolithographic aligner industry, the chapter examines the extent to which firm patenting behavior is oriented towards (1) internal technologies (2) customer and supplier technologies (3) competitor technologies and (4) technologies that are assigned to peripheral firms outside of the core industry. It is shown that firms whose patent orientation focuses on internal technological development and competitor technologies are adaptive relative to the pace of technological change, whereas focus on customer of supplier technologies offers no adaptive benefits. These results imply that the patent systems may not just offer economic gains, by protecting internal technological development and establishing barriers to entry, but can also offer organizational gains. In particular, the results suggest that organizations focused on 'freedom to operate' from competitor patents are more adaptive whereas investment in absorptive capacity does not increase a firm's adaptive behavior.

5.1 Introduction

Can firms keep up with the pace of technological change? For the last 40 years a central debate in organization theory has examined the extent to which organizations can respond to their environments, and if their ability to respond offers them the ability adapt. While these debates in their most fundamental form are a dialectic between free-will and determinism (Bourgeois and Brodwin 1984), the debate is empirically driven by assumptions regarding the speed that organizations can recognize and respond to change relative to the speed of change in their environment (Hannan and Freeman 1977; Hannan and Freeman 1984; Cockburn, Henderson et al. 2000).

A significant amount of existing scholarship has demonstrated an array of instances where the environmental change had outpaced incumbent firms. The organizational inertia of incumbents, namely their inability to respond to environmental change, is often found as a key reason why incumbent firms were not able to overcome entrants with fewer resources and lesser experience. For example, scholars in the management of technology have examined how radical shifts in technology, or technological discontinuities, displaced existing firms who often had the technology first (Abernathy and Utterback 1978; Landes 1983; Tushman and Anderson 1986; Gersick 1991; Christensen 1996). Some scholars have argued that strategic considerations (Gilbert and Newbury 1982, Reinganum 1983) or architectural innovations (Henderson and Clark 1990) can play a significant role in causing incumbent firms to fail. Other scholars have argued that instead failure derives through the resource allocation process which causes firms to overemphasize behaviors that are not consistent with adaptive (Bower 1970, Burgelman 1983, Christensen 1996, Noda and Bower 1996).

Certain scholars have argued that these models of rapid disruption and change are not the primary experience of many firms. Instead, some scholars believe that firms can compete by changing continuously rather than experiencing rare episodic change (Brown and Eisenhardt 1997). Continuous change theories have focused primarily on internal firm processes such as fast, innovative, and decisive decision-making (Bourgeois and

Eisenhardt 1988), internal communication and design freedom (Brown and Eisenhardt 1997), variation through the internal ecology of strategy making (Burgelman 1991), or implementation deriving from the interorganizational selection environment (Burgelman 1994). According to these theories firms are able to achieve success through the use of limited structure, testing for future markets through experimentation and external alliances with customers, and the successful selection of key opportunities. However, while continuous change theories suggest that the firm has the opportunity to outpace its environment; these theories do not empirically examine processes that relate the speed of change in the firm relative to the pace of environmental change.

This paper proposes the idea that adaptive behavior in changing environments is driven by the extent to which a firm 's strategic process engages firm environments. Whereas previous literature has examined accelerating adaptive behavior through forms of internal firm processes (Eisenhardt and Tabrizi 1995), or internal firm selection environments (Burgelman, 1991), I explore the idea that adaptive behavior is driven by the level of generic strategies that engage with the external environment. I find that adaptive behavior is driven by routines that orient to competitor patent positions, or what I call freedom to operate, as well as routines that relate to internal firm processes and organization effectiveness. Alternatively, where firms orient towards supplier or customer patent positions, what I argue indicates investment in absorptive capacity, this focus on external learning alone appears to offer few adaptive benefits. I offer additional evidence that high freedom to operate is associated with longer-term competitive advantage. The setting for this study is the case of the photolithographic aligner industry over nearly two decades, from the early 1970s to the late 1980s.

The chapter is organized in numbered sections. Section 5.2 provides the theoretical background and hypotheses while Section 5.3 defines the empirical strategy. Section 5.4 provides a brief overview of the photolithography industry, issues of sample construction and summary statistics. Section 5.5 presents historical data on competition in the photolithographic aligner industry. Section 5.6 describes the study variables, whereas Section 5.7 provides the empirical results. Section 8 offers the implications on performance, Section 5.9 discusses implications of the study, and Section 5.10 concludes.

5.2 Theories of Adaptive Behavior

Can firms adapt to the pace of technological change? Organizational scholars have developed a number of theories to address this question. Theories of technological discontinuities lend themselves nicely to ecological theories of selection and not adaptation. Selection theories at the firm level argue that organizational strategy and structure are set very early in the life history of an organization and that variability comes from the demise of older organizational forms. Selection theories argue that once firms become established incumbents, these 'existing firms, especially the largest and most powerful, rarely change strategy and structure quickly enough to keep up with the demands of uncertain, changing environments" (Hannan and Freeman 1984).

Other theories argue instead that adaptation can be a powerful force and contend that that organizational variability occurs because organizations are able to respond to environmental differences. Contingency theories are one variant of adaptation theories that emphasize that there is no one best way organize and that firm structures emerge to fit with technologies and environments (Thompson 1967; Lawrence and Lorsch 1967).

Alternatively, resource dependency theories argue that adaptation occurs through resource acquisition to minimize sources of environmental uncertainty and dependencies (Pfeffer and Salancik 1978). Institutional theories hold that structure adapt rationally to normative endorsed structures of organizing whereas, Marxism contend that owner adapt to control the labor process. Other theories argue that firms adapt primarily through nearly random endogenous process that are only loosely directed by internal and external demands (March and Olsen 1976). Finally, evolutionary economic theories suggest a process very similar to adaptation, considering 'short run' stability in routines, but with modification of routines, or operating characteristics over the longer run (Nelson and Winter 1982). Evolutionary economic theories are not explicit on what drives changes in routines, except to suggest that routines and decision rules themselves are 'rule guided'.

Scholars use adaptation theories in two general ways in understating the management of technology. Some scholars have identified adaptation as both a technological and organizational phenomena. In a study of technology implementation it was argued that technology and organizational adapt on separate cycles but align over time through mutual adaptation (Leonard Barton 1988). However, many scholars in the strategy literature primarily focus on organizational adaptation, considering technology as routines that change if there is an adaptive process.

There are two somewhat different views on how technology routines change. As Herb Simon (1970) defined, an adaptive process is one which uses feedback to correct for unexpected or incorrectly perceived events. Influenced by Bower's (1970) early work on the resource allocation process, a number of studies have held implicit that the strategy process and organizational constraints are what is critical to adaptive behavior. Relative to Simon's views, the idea is that the feedback process is what characterizes adaptive systems and allows them to achieve stability within their environment. This process is what drives the case in the study of Intel's strategy making process (Burgleman 2000), strategic decision processes in high velocity environments (Bourgeios and Eisenhardt1988), fast adaptation in product innovation (Eisehardt and Tabrizi 1995), and in productivity gains (Benner and Tushman 2003). In these cases scholars identified adaptation as structural processes changes in the ways that organizations compete (Eisehardt and Tabrizi 1995; Burgleman 2000), or as changes due to technological innovation (Bourgeios and Eisenhardt1988; Benner and Tushman 2003). In examining the resource allocation process the arguments that firms are inertial, and do not adapt, explains firm failure due to an overemphasis on customer orientation (Christensen and Bower 1996), financial opportunities (Noda and Bower 1996) and threat rigidities (Gilbert 2002).

Adaptation can also be viewed as a situated learning process (Levitt and March 1988, Tyre and von Hippel 1997), or as recently experienced learning (Barnett and Hansen 1996) with an increased focus on the actual content or knowledge developed during the feedback. In the strong form of this view, technology management is focused on opportunities towards continuously identifying and assimilating new knowledge that is either in the environment or not yet discovered (Nelson 1959; Allen 1977; Cohen and Levinthal 1989; Rosenberg 1990) and in a way that is decidedly complex (Barnett and Hansen 1996; Cockburn and Henderson 1998). Some scholars examine how firms can use R&D to increase productivity (Arrow 1962; Mansfield, Schwartz et al. 1981; Griliches 1987; Cohen and Levinthal 1989; Cohen and Levinthal 1990; Henderson and

Cockburn 1996), while others focus their scholarship on reducing challenges to the communication and sharing of knowledge (Allen 1977; Van de Ven and Polley 1992). Other scholarship addresses the knowledge bottleneck by focusing on how firms can achieve success by identifying and integrating new knowledge from different communities and locations (von Hippel 1988; Tyre and von Hippel 1997), or overcoming search challenges across broad technology landscapes (Levinthal 1997; Fleming 2001). Finally, some scholarship focuses on identifying typologies of knowledge search behaviors that potentially enhances a firms opportunities such as the trade-off between exploitation and exploratoration in search behavior (March 1991), cognitive or experiential search (Gavetti and Levinthal 2000), search across technological and organizational boundaries (Rosenkopf and Nekar 2001) and the search for younger or older knowledge (Katila and Ahuja 2000).

This chapter attempts to disentangle the effects of different resource allocations to internal research and development. In essence this paper is trying to solve one major question which is why do some firms appear to keep pace with technological change, and navigate the technology environment with ease, whereas others who perhaps even invented the new technologies can't act fast enough to stay competitive. This paper examines this question armed with two other curiosities: (1) that some firms fail to effectively execute their own technologies even though they allocate tremendous resources to new technological knowledge and (2) that some firms take patents much more seriously than others even when patent monopolies don't seem to exist. Both of these curiosities seem to persist.

It is common to think that the uncertainty of technology and the challenge of organizational inertia can be overcome with increased investment in new knowledge. This point is implicit in the population ecology literature (Hannan and Freeman 1984; Barnett 1990), and is directly addressed in more recent literature which finds that as an organization ages its increased innovative capabilities trade off with inertial factors as it loses pace with the environment (Sorensen and Stuart 2000). However, the challenges faced by environmental change suggest that firms insufficiently able to strategically brace against change through investments in new knowledge. Swiss watch manufacturers invented the quartz watch technology the Japanese used to disrupt the Swiss watch making industry (Landes 1983). Similarly, several disk drive manufactures had prototyped next generation drives well before new entrants displaced them with these very architectures (Christensen and Rosenbloom 1995), and US tire manufactures had effectively manufactured and sold radial tires overseas when Michelin displaced them with the same technology in the US (Sull 1999). Clearly other strategies beyond those requiring continuous investments in new knowledge may be necessary balance the overwhelming forces of organizational inertia.

Similarly, both the practitioner and academic world are very mixed about whether patents should be taken seriously as economic tools. Although theories have abounded around how patents might actually work, very little evidence has shown them to be important outside of the pharmaceutical and chemical industries (where the effects of patents are notably intertwined with regulatory monopolies). In many industries, particularly some where there is very little litigation, there can be tremendous differences with whether firms take patents seriously or not.

This chapter will examine resource allocations to internal research and development examining both the strategic implications of allocations to internal and external technology development, as well as the strategic implications of allocations to technologies that are open and those that are constrained by competitor patents. The chapter presents three hypotheses regarding these strategic resource allocations to internal research and development.

5.2.1 Patent Orientation to Internal Technology Extension

Firms that develop technologies that extend already patented technologies owned by the firm may face the risk that the process of developing internal capabilities can drive the onset of structural inertia (Hannan and Freeman 1984) and a liability of aging (Barron, West et al. 1994; Sorensen and Stuart 2000). Aging may increase inertia due to rigid communication patterns patterned around internal technology resources, or selection on strategies that the reinforce these processes (Burgelman 1991).

However, scholars have long described innovation at the organizational level as reliant on the quality and coordination of routines and search strategies (Nelson and Winter 1982; Hannan and Freeman 1984; Cyert and March 1992). A substantial and varied literature examines how firms increase innovation through allocations to internally focused strategies. Strategies processes that focus on internal investments include those that derive from investments in basic research (Rosenberg 1990), structures for idea generation and creativity (Amabile 1988), improved communication (Allen 1977), career management (Allen and Katz 1992), increased cross-functionality in teams (Clark and Wheelwright 1992), ambidextrous organizations (Tushman, Benner et al 2003) and enhancing project management capabilities (Morone 1993; Nobeoka and Cusumano

1997). The ability to manage the internal selection environment by promoting adaptive behavior through the increased variation of organizational routines, and effective selection and retention (Burgelman 1991), suggests that investment in internal technological development can lead to highly adaptive organizations

H1: Internal orientation increases adaptive behavior

5.2.2 Patent Orientation to Supply Chain

There is a growing belief that internal development is not enough for a firm to be competitive. Research on the ability of firms to use outside knowledge has been substantial. Research has focused on overcoming the challenges of communication barriers across organizations (Allen 1977), recognizing external knowledge through internal research and development (Abernathy and Utterback 1978; Rosenberg 1982), and capturing spillovers (Cohen and Levinthal 1989; Henderson and Cockburn 1996). The ability for a firm to benefit from outside knowledge is the "absorptive capacity" of a firm (Cohen and Levinthal 1989; Cohen and Levinthal 1990; Henderson and Cockburn 1996) and is defined as the firm's ability to recognize new external information, assimilate it, and apply it to commercial ends.

Firms that supply technologies to improve customer capabilities are welcome to customers and it is in the best interests of customers to allow suppliers to offer products that conform to new developments in customer technology. Because of these potential efficiencies, suppliers and customers share knowledge to varying degrees about customer requirements and technology roadmaps. In the cases where new customer technology is patented, suppliers generally assume a de facto license to the patents so that they can make their products perform to the specification of the customers. Customers are also eager to take advantages of new supplier technology developments, and because the purchase from suppliers, customers will typically have tangible or de facto access to patented supplier technology. These transfers of usable, accessible knowledge is enhanced by increases in a firm's absorptive capacity, but the allocation of resources to internal development to increase absorptive capacity as a means to drive organizational adaptability may have advantages and disadvantages.

On the one hand, the development of absorptive capacity can permit a firm to rapidly recognize and exploit useful scientific and technological knowledge (Cohen and Levinthal 1990). However, investment in absorptive capacity may also pose a significant challenge not identified by the originators of the concept. Investment in absorptive capacity by established firms may act to reinforce existing relationships and learning structures, primarily because absorptive capacity is mediated by existing strategic processes. As such, the direction of absorptive capacity investment may result in knowledge that builds on the repeated use of an inferior procedures over a superior alternatives leading to a classic competency trap (Cooper and Schendel 1976; Levitt and March 1988). For example, a firm allocating resources to increase absorptive capacity to enable learning from a customer may increase inertial structures. When firm stakeholders act to reinforce existing structures it is very difficult for firms to adapt to changing environmental conditions (Bower 1970, Noda and Bower 1996). As has been demonstrated in the disk drive industry, (Christensen and Bower 1994) customers can seriously reinforce the existing resource allocation processes and reduce adaptive behavior.

H2: Supply chain orientation decreases adaptive behavior

5.2.3 Patent Orientation to Competitors

Firms typically have some degree of technology access to patents owned by them, their customers, and their suppliers. Because firms can use the technologies covered by these patents, it would not be unreasonable to anticipate that a firm that allocates resources to replicating or developing new technologies related to these accessible patents could benefit from knowledge related investments in these technologies. However, firms are unlikely to have access to valuable patents held by competing firms. Because of this patent access problem, firms are directly constrained in their technology development process as it relates to competitor technology. Therefore, regardless of firm investments in absorptive capacity, firms will not be legally able to directly use technologies embodied in competitor patents.

While firms are typically not granted access to patented competitor technologies, firms may still allocate resources to develop technologies that relate to patented competitor technologies. While a number of sophisticated patent strategies exist, firms typically invest to (1) create substitutes to competitor technologies that the firm can use, or to (2) create other patents block the competitors future use of the own technology. In essence, competitor patent orientation does not directly affect firms through learning mechanisms, but rather by focuses the resource allocation process in the firm to alleviate environmental resource constraints. In the case of patents, this allocation process is known as developing 'freedom to operate' which is defined here as the ability to identify, assimilate, and respond to environmental constraints that could be imposed by rule of law. Whereas others have recognized the importance individual design freedom on creativity and product development performance (Bourgeois and Eisenhardt 1988), freedom to operate (Grindley and Teece 1997; Branstetter and Sakakibara 2002) is an firm level factor associated with such promises as autonomy, liberty, and organizational sovereignty.

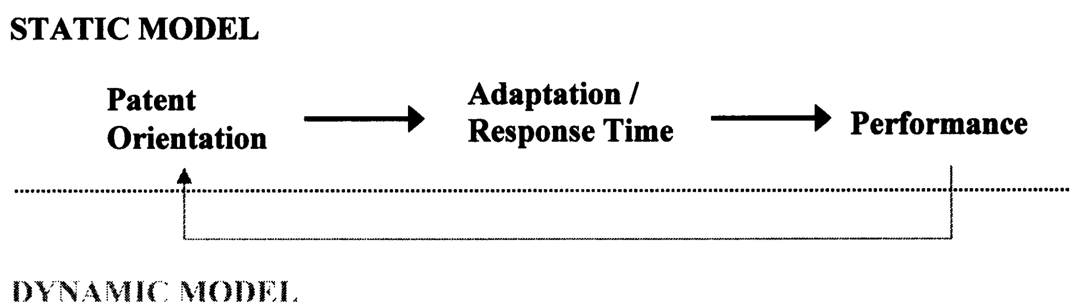
In the case of competitor patents, freedom to operate is much more limited than in the case of self-owned, supplier, and customer patents. In the context of the strategy literature Prahalad and Hamel (1990) argue that core competencies include both (1) the ability to use and integrate the technology, as well as (2) the ability to potentially use, or control, technology. Because the competitor development of patents is exogenous to the firm, but disrupts rather than reinforces existing structures, allocation of resources to freedom to operate should result in adaptive processes that help to match the firm to its technology environment.

H3: Patent orientation to competitors increases adaptive behavior

5.2.4 A Framework for Patent Orientation and Adaptation

This paper presents a very simple static model (Figure 5-1) whereby differences in patent orientation drive differences in the adaptive behavior of firms which, consistent with the product development literature (Brown and Eisenhardt 1990) , leads to increased technology performance. This papers also suggests a simple dynamic model that may be more representative whereby certain patent orientations may drive high degrees of performance which then in turn reinforce these same patent orientations in a manner consistent with the ecology of learning and Red Queen evolution (Barnett and Hansen 1996). In Red Queen evolution, which embodies the idea that competitors are basically running to stand still, adaptation by one competitor promotes a response in other competitors driving a cycle of increasing adaptation. This paper will make an empirical link between patent orientation and adaptation, but only offer some historical evidence on the full static and dynamic models.

Figure 5-1: Continuous Change Models:



Within the model of patent orientation, the consideration of freedom to operate drives an important distinction between differences in research and development allocations that orient externally towards vertical supply chain arrangements and horizontal competitor challenges because of the legal environment of the firm (Figure 5-2). The basic argument of the paper drives from idea that when a firm is focusing on high freedom to operate technologies, where technology access is not a major issue, resource allocations to research and development are directed towards knowledge generation and knowledge transfer efficiencies. However, when freedom to operate is low, and the firm is constrained from the using the technologies, resource allocation to research and development is efficiently directed towards technology access as patent constraints prevent these typologies of technologies from being legally used. There are two key predictions. First, both internal technology extension and competitor orientation will drive firms to engage in more adaptive behavior. However, similar to other studies of customer orientation (Christensen and Bower, 1996, Gilbert 2003), supply chain patent orientation will drive firms to be less adaptive as this orientation will reinforce inertial processes. The case of internally developed but externally committed patents is not examined in this paper.

Figure 5-2: Four Types of Inter-Industry Patent Orientations

		Freedom to Operate: High	Freedom to Operate: Low
Technology Orientation	**External**	Supply Chain Orientation (i.e. Supplier, Customer)	Competitor Orientation
	Internal	Internal Technology Extension	Internally Developed but Sold, JV'd, Ex-Licensed

5.3 Patenting in the Photolithography Aligner Industry

The data for this study comes from the case of photolithographic aligner industry. An optical photolithographic aligner is a sophisticated piece of capital equipment used in the manufacture of solid-state semiconductor devices (Henderson 1988, Henderson and Clark 1990, Henderson 1993, Henderson 1994, Henderson 1996). These pieces of equipment transfer very small, intricate patterns to the surface of the silicon wafer in a transfer process known as lithography. This transfer process requires extreme precision making the performance of the photolithographic aligner the critical element in the manufacture and competitive capabilities of semiconductor manufacturers to whom the aligner is sold. During the period of the study the aligners represented 30% of the cost of a new semiconductor facility.

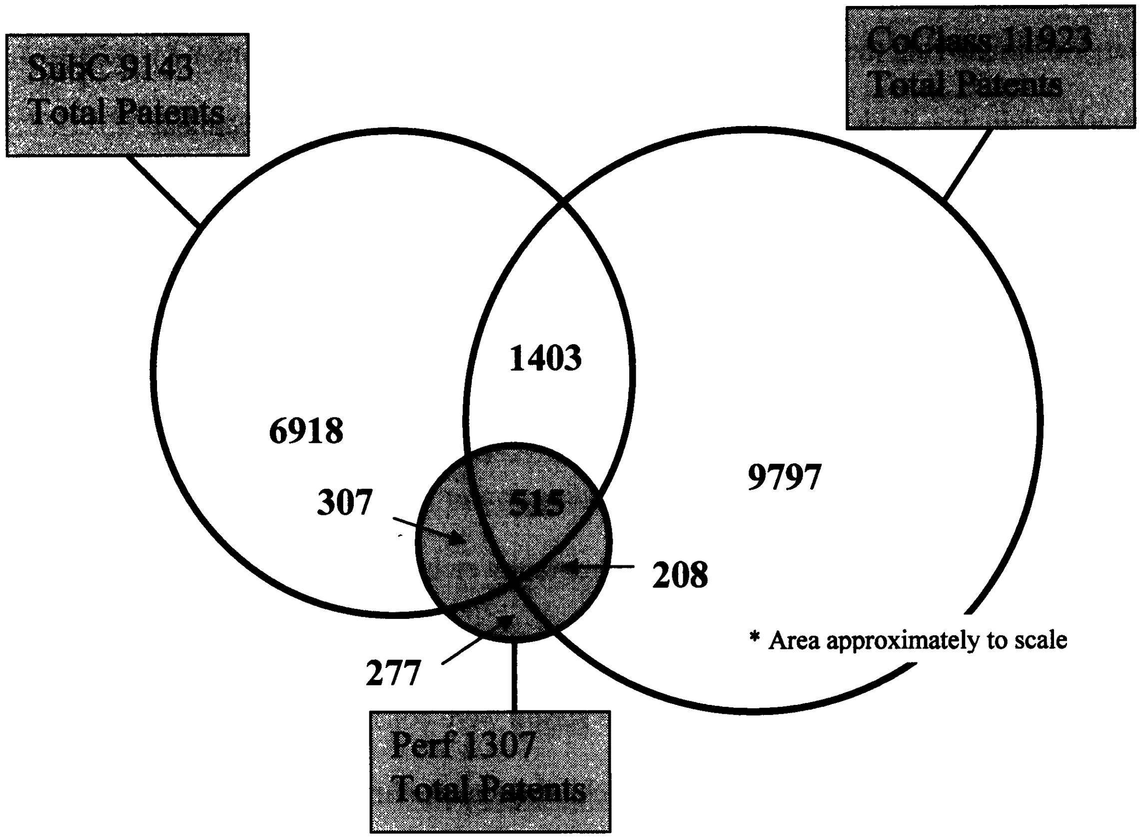
In many ways the photolithographic aligner industry is an opportune industry to study the role of adaptive behavior in complex technologies. At a first cut, the industry has been heavily studied and primary data including interviews, per project R&D costs and per product and industry sales from 1961 (approximate inception) until 1986 have already been collected for the 18 key firms (Henderson 1988). These studies show that the industry went through five different major architectural innovations between 1962 and 1986 where in each case an incumbent was displaced from the market in short time by entrants who quickly captured large market shares. By the mid-1980s the industry market shares had stabilized with a two single primary producers, one with substantially more sales than the other. In addition, as many patent researchers know, the period from 1960 to 1990 is ideal for collecting quality panel patent data as it precedes the patent explosion of the 1990s while providing a large portion of patents in electronically available format. Sampling over this period also allows us to collect at least ten years of forward citation data for each patent I include. Finally, as the technology is primarily in the mechanical arts, patent grants to application lags are generally a very short 2.25 years, mimicking technology cycles that are approximately 2.5 years.

5.3.1 Photolithographic Patent Sample

A substantial effort was made to develop a patent data set that reasonably approximated the patent environment surrounding photolithographic technologies. To develop the initial photolithography patent data set I began by developing a performance based data set referred to as "Perf" referred to in the earlier chapter. I examined patents that explicitly described technology aimed at increasing the performance of photolithography equipment or aimed at the process for the manufacture of semiconductors. I included patents for substitute technologies such as x-ray lithography, ion-beam lithography and others. Patents were read[22] and included if any substantial feature (abstract, background, summary of invention, examples and/or claims) explicitly targeted improving the performance of lithography (particularly alignment mechanisms, masks, pellicles, devices, optical systems, lenses, radiation sources, chemical compositions, and vibration isolation tables and devices). Patents were not included if they primarily focused on non-lithographic inventions which employed lithographic technologies that were 'known in the art' or 'standard' as was frequently mentioned in the read patents, and patents were not included if they only dealt with the design of specific semiconductor features, wafer bonding, wafer types, particular semiconductors or their methods of fabrication, or post-lithography etching technologies. A discussed in chapter four, this unique data set enabled the construction of two additional samples on the same technology during the same time period were constructed for comparison and were used in our analysis to control for technological proximity. One sample "CoClass" based on an identification of key companies and major patent classes (similar to Sorenson and Stuart 2000). A second sample was derived from identification of key patent subclasses "SubC" consistent with a previously identified method (Rosenkopf and Nekar 2001). Appendix 1 provides additional details.

[22] All of the patents were coded and read by the author although several steps were taken to ensure the integrity of the sample. Initially 54 photolithographic patents were identified using key word searches on the internet and USPTO, as well as primary and secondary source material (interview notes, papers and industry lawsuits). This list of 54 patents was set aside during the course of our collection, and when the dataset was at completion and it was found that all 54 patents were included over the course of the research design. Secondly, the author identified clear criteria for inclusion (above) and thus relied on the actual content of the patent for inclusion ensuring reasonable reliability. No attempt was made to determine the quality of the patent or invention, only that the patent, as written, targets photolithography. Finally, the process relied heavily on reading patents that were cited by those in the sample until convergence was reached (all patents cited 2x or more by the sample were read). Of those patents cited >5x, 90% were included in the sample. Approximately 40% of all citations made by the sample between 1962-1990 are within the sample.

Figure 5-3: Photolithography Patent Samples 1968-1986



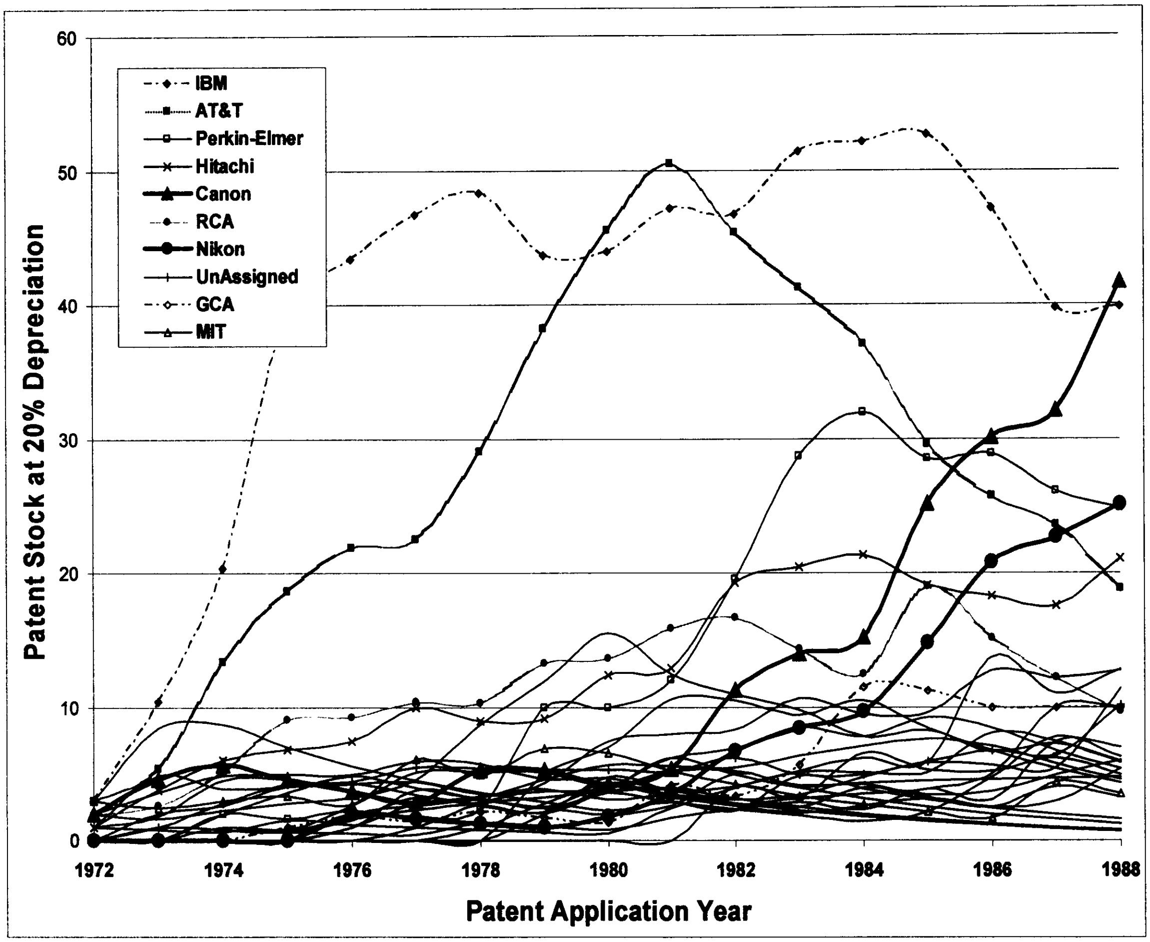
As Figure 5-3 depicts, the opportunities available to researchers studying patent data are highly dependent on how patent samples are constructed although to date this is the only research design that has explicitly examined this issue. The Perf sample I use is the closest reasonable approximation of patents granted in the period, good and bad, that could directly impact technologies in the photolithographic aligner industry from the late sixties into the early part of the millennia. An expert sample of important patents in the industry would be a subset of the Perf sample, while a somewhat optimized sample based on key subclasses and company names captures the most patents with the minimum amount of unrelated patents (although the likelihood of including irrelevant patents using this method is still extraordinarily high).

Figure 5-3 is important for two reasons. First, despite the voluminous amount of research done using patent data, much of the research may not be comparable, or may be otherwise limited by how the patent data is generated and sampled. Secondly, Figure 5-3 clearly demonstrates that a least in the case of photolithography, that examiners classify patents in a way that appears significantly unlike how industry and citation patterns suggest they be classified. Given this paper is primarily concerned with how firms respond to the patent environment, researchers using patent data should appreciate that the patent environment is particularly difficult to decipher.

5.3.2 Photolithographic Industry Patents

Until the emergence of photolithographic aligner suppliers Canon and Nikon as technology leaders in the late 1980s, the majority of photolithographic patents were developed by firms that were customers from the mid-1960s onward. As Figure 5-4 shows, IBM and AT&T, and to a lesser extent RCA, Hitachi and US Philips dominated photolithographic aligner technologies, as measured by their "Perf" sample knowledge stocks (see Henderson and Cockburn 1996, cumulative firm patent stock depreciated by 20% per year), well into the early 1980's.

Figure 5-4: Photolithography Patent Stocks 1972-88 For Top Patenting Firms



* Additional firms were also plotted but are not labeled for simplicity. These firms, listed in order of depreciating total patent stock , are: Thomson, Fujitsu, US Philips, Optimetrix, GE, Texas Instruments, Westinghouse, NTT, Hughes Aircraft, Computervision, HP, Matsushita Electric, Fuji Photo, Kasper Instruments, Toshiba, Siemens, Motorola, Eaton, US Army, and DuPont .

While it may be contentious to measure knowledge stocks using patent count data, the relative position of the various firms seems consistent with primary accounts of the state of the industry over the period (Henderson 1988). IBM was particularly recognized as having bleeding edge technologies, but focused on high end flexible and customizable technologies rather than addressing mass market capacity needs which were provided by aligner suppliers. The dramatic decline of AT&T's knowledge stock mirrors the onset of the AT&T antitrust suit, while active firms such as RCA, Hitachi, and Philips, and to a lesser extent, Motorola, HP, Intel, Toshiba also have moderate stocks into the 1990s. It is also interesting to note that while customers own the bulk of patents, the flurry of Nikon and Canon patent response in the early 1980's is coincident with what appears to be a massive arms race. Although R&D data are not publicly available, Nikon was able to increase its portfolio with substantially less R&D investment over the period than either Canon or GCA suggesting that Nikon's patent strategy of targeting Canon (data later in the chapter) may have been particularly effective. As patent citations go, Nikon and Canon are outliers heavily citing each other patents. As mentioned earlier, given these heavy allocations of firm resources to the competitor patent orientations, combined with the near parallel development of their knowledge stocks is consistent with the view that investment in freedom to operate may have an effect similar to the Red Queen (Barnett and Hansen, 1996).

Organizations engaged in photolithographic patenting are divided in seven categories of market orientation (see Table 5-1) defined as "similarities due to the organization-wide generation of market intelligence pertaining to the current and future customer needs, dissemination of the intelligence across departments, and organization-wide responsiveness to it" (Kohli and Jaworski 1990). In a manner consistent with trade press accounts, historical interviews (Henderson 1988), and a moderate knowledge of the industry, the top 45 patenting organizations in the sample can be categorized into six distinct market categories: (1) photolithographic aligner suppliers, (2) customers, (3) niche suppliers, (4) chemical suppliers, (5) government labs, and (6) academic institutions. These categories would have been obvious to firms competing in the industry over the period of our study and are static.

Table 5-1: Firm Classification by Market Orientation

<table>
<tr>
<td>SUPPLIERS
(Received 585 citations)
ASM LITHOGRAPHY B.V.
CANON KABUSHIKI KAISHA
COMPUTERVISION CORPORATION
EATON CORPORATION
ELECTROMASK, INC.
GCA CORPORATION
KARL SUSS KG
KASPER INSTRUMENTS INC.
KULICKE AND SOFFA INDUSTRIES
NIKON CORPORATION
PERKIN-ELMER CORPORATION</td>
<td rowspan="3">CUSTOMERS
(Received 2804 citations)
AT&T CORP.
FUJITSU LIMITED
GENERAL ELECTRIC COMPANY
GENERAL SIGNAL CORPORATION
HEWLETT-PACKARD COMPANY
HITACHI, LTD
HONEYWELL INC.
HUGHES AIRCRAFT COMPANY
INTEL CORPORATION
INTERNATIONAL BUSINESS MACHINES CORPORATION
MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.
MICRONIX CORPORATION
MITSUBISHI DENKI KABUSHIKI KAISHA
MOTOROLA, INC.
NIPPON TELEGRAPH & TELEPHONE CORP.
RCA CORPORATION
SIEMENS AKTIENGESELLSCHAFT
TEXAS INSTRUMENTS, INCORPORATED
TOSHIBA CORPORATION
U.S. PHILIPS CORPORATION
TRE SEMICONDUCTOR EQUIPMENT CORPORATION
WESTINGHOUSE ELECTRIC CORP.</td>
<td>CHEMICAL SUPPLIERS
(Received 294 citations)
CIBA-GEIGY CORPORATION
E. I. DU PONT DE NEMOURS AND COMPANY
EASTMAN KODAK COMPANY
FUJI PHOTO FILM CO., LTD
MITSUBISHI CHEMICAL INDUSTRIES LTD.</td>
</tr>
<tr>
<td>NICHE SUPPLIERS
(Received 111 citations)
HAMPSHIRE INSTRUMENTS, INC.
THOMSON-CSF
VARIAN ASSOCIATES, INC.</td>
<td>GOVERNMENT LABS
(Received 74 citations)
USA ARMY
DEPARTMENT OF ENERGY
USA NAVY</td>
</tr>
<tr>
<td>ACADEMIC
(Received 95 Citations)
MASSACHUSETTS INSTITUTE OF TECHNOLOGY</td>
<td>Unassigned / Outside Industry / Low Incident Patentees
(Received 1999 Citations)</td>
</tr>
</table>

Given the availability of prior historical research on supplier firms, their frequent instances of total firm failure, and the emergence of the major patent stocks within different supply houses, we will examine photolithographic suppliers in detail before testing empirically testing our hypotheses on the full industry sample.

5.4 Adaptive Behavior of Photolithographic Suppliers

The introduction of this chapter asks if companies can keep up with the pace of technological change. For most of the major photolithographic aligner suppliers between 1972 and 1986 the answer is a resounding NO! The case of the photolithographic industry over this period is one where the dominant firms are displaced every four or five years (just under two product generations) by an entrant that they do not perceive as a threat (Henderson and Clark 1990). One by one, industry leaders Cobilt, Kasper, Perkin Elmer, and GCA are knocked out of the market by a new entrant with a new architecture. However, two interesting outlier firms stand out in this market. First, Canon, while never and industry, leader managers to achieve regular market share over multiple photolithographic aligner architectures, something that no other firm is able to do (Henderson 1994b). Second, Nikon, which took a tremendous time to enter the market (they had developed prototypes some fifteen years before attempting a commercial entry) shifts the rules of the market. Along with Canon, Nikon breaks these cycles from an environment where a leading firm is dying every few years, to a market where Nikon and Canon dominate sales for the next fifteen years at stable market shares.

This portion of the chapter will provide evidence of three assertions: (1) that supplier firms that allocated research and development resources to internal technology extension and competitor freedom to operate had much short technology cycle times than firms that focus on customers or extra-industry technologies; (2) that supplier litigation between the period 1972 and 1986 was rare, and that patents appeared to be quite minor and benign and did not appear to act like traditional monopoly tools; and (3) that many top supplier firms were not well linked from a technology perspective to the industries largest customer, while those that were typically had slow technology cycle times. While this illustrative data highly support the three hypotheses, these hypotheses will be formally tested, with the appropriate controls in the empirical model.

5.4.1 Citations Patterns between Photolithographic Suppliers

The levels of patent response behavior by the leading supplier firms for the period are provided in Table 5-2A, although it should be noted that this data, while richly illustrative, this is only a small portion (~13%) of the data that will be used in the empirical investigation.

Table 5-2A: Patent Citations Between Competing Suppliers (Cumulative 1972-86)

Citing Companies	Cited Companies COBILT	KASPER	CANON	PE	GCA	NIKON	Citations Made to Competing Suppliers	**Total Citations**	Proportion of Citations Made to Suppliers
COBILT			2				2	**52**	3.8%
KASPER		9					9	**44**	20.5%
CANON		4	30	8	2	7	51	**189**	27.0%
PE		4	9	42			55	**264**	20.8%
GCA	1				2	1	4	**91**	4.4%
NIKON	2	1	21	1	1	18	44	**112**	39.3%
Total	3	18	62	51	5	26	165	**752***	21.9%

* This table only represents a fraction (~13%, or 752/5962 citations) of the citation data set that comprises the empirical analysis. Nonetheless, patterns evident here are consistent with our detailed knowledge of supplier competitiveness during this time period.

The patenting response behavior shown in Figure 5-2A is consistent with some of what is already known about the leading photolithographic aligner suppliers. First, Canon, while never the leading supplier, was the only firm that was successful in managing multiple product architectures (Henderson 1996) and confirming this result the tables shows that Canon is the only leading firm that focuses on four different major architectural suppliers. Second, it seems clear that most firms had active patenting programs and, from the self-citations, there is evidence that firms were building on their internal expertise and developing their portfolios. Also consistent with prior evidence of disruptive architectural change (Henderson and Clark 1990; Henderson 1993), there is remarkably little evidence that the incumbent firms Kasper, Cobilt, PE, and GCA respectively responded to rival technological challenges as citations to entrants are very rare. Finally, the absence of citations from entrants to incumbents is also interesting. This behavior suggests that for the most part entrants were able to completely ignore incumbent patent portfolios and, given the low degree of patent litigation history of the industry, this seems to have been a reasonable decision.

Two anomalous occurrences are also noted in this figure. There is a reasonably high level of cross-citation between PE and Canon. This is likely explained by focused attention due to an infringement claim PE brought to Canon that, while resolved out of court, delayed Canon's market entry by two years (Henderson and Clark 1990). The second anomaly is more interesting. From the patent data, Nikon appears to be responding to Canon patent positions, although one might have thought that during this period that Nikon would be chasing GCA, the clear industry and technology leader within supplier firms in the early 1980s. This latter point might offer an important lesson given the particular challenges GCA faced with its rivals. Although there is no positive evidence in this data, GCA's organizational incompetence, described in previous research (Henderson 1993), may have also prevented GCA from developing mechanisms to recognize and respond to a substantial patent race that was going on while it was the incumbent. The opposite causality could also be true. Because GCA did not allocate sufficient resources in freedom to operate, it did not engage with leading competitors and may have been effectively blocked out the market by the emerging Japanese suppliers.

The data in Table 5-2A is extended with Table 5-2B which offers the mean response time of the citations.

Table 5-2B: Mean Patent Citation Time in Years between Competing Suppliers

Citing Companies	Cited Companies COBILT	KASPER	CANON	PE	GCA	NIKON	Mean Citation Time Competing Suppliers	Mean Citation Time **Total Citations**	Mean Time Difference
COBILT			8.5				8.5	**7.2**	1.3
KASPER		5.7					5.7	**6.9**	-1.2
CANON		6.5	4.4	4.4	6.0	4.7	4.7	**6.0**	-1.3
PE		5.0	4.3	5.2			5.1	**6.3**	-1.2
GCA	6.0				4.5	5.0	5.0	**6.0**	-1.0
NIKON	10.5	3.0	3.6	4.0	5.0	3.2	3.8	**5.6**	-1.9
Total	9.0	5.6	4.2	5.1	5.2	3.7	4.7	**6.3**	-1.6

Again, the data is intended to be illustrative and represents a portion of the empirical sample. As demonstrated in the tables, a high degree of self-citation is consistent with fast, or what is described as adaptive behavior. One might suggest that some of these fast responses emerge as an artifact of the patent system whereby a large invention spills out several patents within a short time frame. However, given the heterogeneity of the mean ages across firms, this can not be explained entirely by a structural view. Consistent with H1, adaptive behavior appears to be driven by internal technology extension.

This small selection of firms also illustrates the potential role that freedom to operate has to play. Firms are, for good reason, reluctant to build on technologies that rival firms have previously developed and patented. Because of rival patent positions, citations to rival firms are likely to signal that the citing firm has responded to a constraint posed by the rival rather than a signal that the firm has used rival technology. As such, citations to rivals is likely a signal of a firms investment in freedom to operate, such as through the development of substitute technology or defensive patents, and these citations are also significantly faster than the firm mean citation age a firm. Consistent with H3, adaptive behavior appears to be driven by competitor orientation.

5.4.2 Litigation between Photolithographic Suppliers

The photolithographic supplier industry had relatively low incidence of litigation over the period 1972-1986. This is consistent with the view that patent response is an adaptation to a minor constraint. This view is fairly well supported because despite sizable incumbent patent portfolios, incumbents have died peacefully rather than in a flurry of litigation (See Table 5-3). In fact, as mentioned earlier, incumbent portfolios are peacefully ignored by entrants even though the displacing technologies have often been perceived as copies, or minor innovations, relative to the incumbent's product.

Table 5-3: Patenting Behavior and Litigation Between Existing and New Suppliers During Critical Periods of Technological Change

Period	Incumbent "I"	Entrant "E"	"I" Perception of "E" Product	Citations "I" to "E"	Citations "E" to "I"	Litigation
1972-76	Kasper (5 patents)	Canon (7 patents)	Copy*	0	0	No
1972-81	Cobilt (12 patents)	PE (27 patents)	Different*	0	0	Yes**
1974-82	Canon (12 patents)	PE (27 patents)	Don't Know	4	4	No***
1977-88	PE (61 patents)	GCA (18 patents)	Don't Know	0	0	No
1977-88	GCA (18 patents)	Nikon (44 patents)	Copy*	1	1	No
1982-88	Canon (62 patents)	Nikon (39 patents)	Neither "I" So N/A	19	37	No

* From Henderson and Clark 1990
** PE sued Cobilt but the suit was not the reason for Cobilt's failure. According to two executives, Cobilt had won the first judgment, but had ceased R&D and begun the process of dissolving their existing business before the PE appeal was decided. In a sad turn of events, Cobilt lost track of the suit as their lead attorney died and no one "kept their eye on the ball", at an ultimate cost of $40M.
***PE challenged Canon's design on the ground that it infringed some of its key patents. The dispute was settled out of court but effectively delayed Canon's entry by two years into the photolithographic aligner market (Henderson, 1996).

The only exception to the rule of minimal litigation has been recent, and has followed Nikon and Canon's successful dominance of the industry for twenty years. Given the unique patenting behavior of Canon and Nikon which emerges in the early 1980s, it is interesting that ASM Lithography (ASML), the first entrant to successfully challenge Nikon's dominant position, is met in 2002 with the industry's first bloody patent suit which is escalating and still ongoing. According to ASML chief executive Doug Dunn "ASML prefers to fight and win in the marketplace, not in the courtroom. However, Nikon has chosen to litigate rather than compete…Their unjust claim to our intellectual property will be vigorously contested."[23] ASML has held to its promise with a $95 million dollar lawsuit accusing Nikon of patent infringement and anti-trust violations in the US. ASML have recently expanded the battle to include anti-competitiveness charges in Japan and Korea, as well as another suit targeting both Nikon and Canon in Europe.

5.4.3 Citation Patterns between Photolithographic Suppliers and IBM

Until the emergence of photolithographic aligner suppliers Canon and Nikon as technology leaders in the late 1980s, the majority of photolithographic patents were developed by firms that were customers from the mid-1960s onward. As was shown earlier in Figure 2, IBM and AT&T, and to a lesser extent RCA, Hitachi and US Philips dominated photolithographic aligner technologies, as measured by their knowledge stocks[24], well into the early 1980's.

While it may be contentious to measure knowledge stocks using patent count data (the only such use of traditional patent counts in this study), the relative position of the various firms seems consistent with primary accounts of the state of the industry over the period (Henderson 1988). IBM was particularly recognized as having bleeding edge technologies, but focused on high end flexible and customizable technologies rather than mass market capacity provided by aligner suppliers. The dramatic decline of AT&T's knowledge stock mirrors the onset of the AT&T antitrust suit, while active firms such as RCA, Hitachi, and Philips, and to a lesser extent, Motorola, HP, Intel, Toshiba and others also have moderate stock into the 1990s.[25]

[23] Internetnews.com, August 20, 2002.
[24] See Henderson and Cockburn 1996, cumulative firm patent stock depreciated by 20% per year.

The role of customer firms, particularly IBM, as both a leading generator of photolithographic technologies and as leading users of supplier technologies, suggests the opportunity for a high of knowledge flows between levels in the supply chain. In this industry this was very much the case, perhaps to the detriment of the supplier firms. GCA, Kasper and PE, all failed firms, worked very closely with leading edge customers (Henderson 1996). Another supplier, Canon, prided itself on customizing its equipment to meet customer needs (Henderson 1988). Indeed, with the emergence of Canon and Nikon as serious competitors to GCA, firms such as IBM, Rockwell, and Westinghouse increased their technical collaborations with GCA in an attempt to keep the American supplier alive, despite the onslaught of what was overwhelmingly higher performing Japanese technology.

In the earlier stages of the industry key personnel for several small supplier firms moved from one supplier to start another (Henderson 1988), however this seems to have been less tractable and probably less of an issue after the mid-1970's, particularly with rivals Canon, Nikon, and GCA. Instead, numerous industry and trade press accounts suggest that significant technical knowledge frequently moved between supplier firms and customer firms which worked closely toward the mutualistic goal of increasing photolithographic aligner performance. For this reason, citations between levels in the supply chain offer a fairly strong signal of the recognition and exploitation of external knowledge, or firm investment in absorptive capacity. In this case, illustrative evidence leading to support or rejection of H2, that absorptive capacity drives adaptive behavior, is difficult to track. An illustration of IBM's record in this area is mixed.

Table 5-4: Mean IBM Patent Citation Counts and Ages (1972-1988)

Firm	IBM Citations to Firm	Mean Citation Age (Years)	Firm Citations to IBM	Mean Citation Age (Years)
Canon*	3	2.3	16	6.9
PE*	2	2.5	25	6.1
Toshiba	11	2.8	8	6.8
Kasper*	6	3.3	6	5.5
Intel	13	3.3	3	4.3
US Philips	25	4.4	10	5.3
IBM	320	4.5	320	4.5
Hitachi	20	4.6	44	6.8
Siemens	10	4.7	2	6.5
All Citations	**975**	**5.4**	**773**	**5.3**
Motorola	20	5.9	13	4.5
TI	20	6.0	15	4.8
RCA	47	6.1	28	5.9
AT&T	58	6.2	68	4.6
Westinghouse	23	8.3	5	4.6
Nikon*	0	n/a	11	6.8
GCA*	0	n/a	2	2.5

* Denotes supplier. All other firms are photolithographic aligner customers.

As Table 5-4 demonstrates, IBM appears to infrequently react to supplier patent positions, but when it does so it does so in a manner that is highly adaptive.[26]On the other hand, suppliers tend to frequently cite IBM but in a way that is typically maladaptive, or slower than the pace of environmental change. Because absorptive capacity is dependent on existing knowledge stock (Cohen and Levinthal 1990), it may be that this effect is because of IBM's unique position with respect to photolithographic technologies, but because there is low fidelity in our illustrative example, this will be tested this in the empirical section.

The data from the tables might suggest that adaptive behavior is just a "Japanese" effect. Many citations made to and from Japanese suppliers in the illustrative examples are very young relative to American firms. American trade press often berated Japanese

26

supplier firms as appropriating American intellectual property, and an extension from that might be that the Japanese are patenting more trivial technologies and this is why the citation times are so short. The patent history suggests that all these arguments are probably wrong. Firstly, by the mid-1980s most of the supplier patents were Japanese not American, and in 1985 Canon surpassed even IBM's patent stock with Nikon close behind. Secondly, the Japanese technologies were not trivial as the market proved (Henderson and Clark 1990). Thirdly, some firms cited a lot of very old Japanese technology regularly suggesting that early Japanese technology was important. For example, Eaton Corporation, which cited Nikon the most after Canon had an average citation age of 8.3 years. On the whole, patents citations made by American firms were slightly younger (~1month) than those made by Japanese firms.

5.5 Empirical Examination of Adaptive Behavior

The conclusions from regarding different patent orientations, although illustrative, are limited to using only portions of the patent data and while considerations of other factors such as technology controls and year effects are not introduced. The simple model is examined empirically using all the sample data to examine if the results are consistent with the earlier hypotheses and conclusions.

5.5.1 Empirical Strategy

The empirical strategy proposed in the chapter is to formally test whether a particular firm's behavior is adaptive, or fast, relative to the pace of environmental change. The analysis is based primarily on patent citation data and is estimated using aggregated data at the level of the firm year.

The analysis is based on the simple model of adaptive behavior:

$$y_{it} = \alpha + \beta_1 Internal\ Technology\ Extension + \beta_2\ Supply\ Chain\ Orientation$$
$$+ \beta_3 Competitor\ Orientation + vControls + \varepsilon_t$$

Adaptive Behavior, y_{it}, is a measure of whether the response to the external environment is faster than the average pace of environmental change. For each year, the mean age of back patent citations in that year is determined. If a citation is younger (ie. faster) than the mean age of a back patent citation in that year, we count that as an Adaptive Behavior. If a citation is older, or a slower response, than the mean age of back patent citations in a given year we describe that behavior as maladaptive, or inertia. Adaptive Behavior is modeled as a relative resource allocation to in three generic strategies of internal research and development:

1. Internal Technology Extension is the degree to which a firm's Patent Orientation is towards building on earlier firm technology. Internal Technology Extension is the proportion of self-citations that a firm makes in a given year.
2. Supply Chain Orientation is the degree to which a firm's Patent Orientation is towards firms that are one level up or down the supply chain. Supply Chain Orientation measures differences in routines that incorporate knowledge from the external environment. Because firms between levels in a supply chain gain from coordination, firms will typically be able to access customer or supplier knowledge and technologies as there can be a mutual benefit from knowledge sharing. Therefore, even though these technologies are patented, the expectation is that firms will have freedom to operate and be able to access knowledge from these firms. Supply Chain Orientation is the proportion of citations made to either suppliers or customers in a given year.

3. Competitor Orientation is the degree to which a firm's Patent Orientation is towards firms that are direct competitors of the citing firm. Competitor firms do not typically allow other firms to develop technologies that infringe their patented technologies and therefore citations to competing firms are measures to overcome constraints, or legal rules, imposed by the environment. Competitor Orientation is the proportion of citations made to competitors in a given year.
4. The controls include measures for market orientation, technological proximity, patent quality, and previous knowledge, as well as firm and year effects.

The model is estimated using ordinary least squares regression, having negligible skewness, but moderate kurtosis. The model has been estimated at the individual citation level using logistic regression, and using an alternative construction of the proportion measure that exhibits increased independence (both not presented) and in both cases the results are consistent with those presented at the firm year. For all models VIF tolerances were tested and multi-collinearity was not detected in any of the models.

5.5.2 Variables

Table 5-5 lists and describes all variables used to examine adaptive behavior within the photolithographic aligner industry.

Table 5-5: Descriptive Variables

Variable	Type	Description	Measures (See note below)
Adaptive Behavior	Dependent	Measure of behavior that is faster than the rate of environmental change in a given year	Proportion of backward citing patents that are younger that industry mean age of backward citing patents in a given year
Market Orientation			
Supplier	Control	If company develops and sells PL aligners	Equals 1 if patent assigned to a supplier
Customer	Control	If company is a customer for PL aligners	Equals 1 if patent assigned to a customer
Niche Supplier	Control	If company is using radical new technologies in aligners	Equals 1if patent assigned to a niche supplier
Chemicals Supplier	Control	If company is a specialized chemical supplier	Equals 1 if patent assigned to a chemicals supplier
Government Lab	Control	Government organization	Equals 1 if patent assigned to a government lab
Academic	Control	Academic organization	Equals 1 if patent assigned to a university
Technological Proximity			
Same Major Patent Class	Control	CP is to the same major patent class	Equals 1 if CP belongs to the same major patent class
Within Sub-Class Sample	Control	CP in sample based on patent sub-class	Equals 1 if CP is in "SubC" dataset
Within Perf Sample	Control	CP in sample based on reading patents	Equals 1 if in "Perf" patent dataset
Patent Quality and Stock			
Originality	Control	Breadth of technology the patent draws on	Measure of diversity of backward patent citations
Generality	Control	Measure of patent impact	Measure of diversity of forward patent citations
Knowledge Stock	Control	Measure of Technological Capabilities	Cumulative annual firm patent stock depreciated at 20% per Year
Patent Orientation			
Internal Technology Extension (ITE)	Independent	Measure of orientation to developing from internal technology capabilities	Proportion of self-citations relative to all citations
Supply Chain Orientation (SCO)	Independent	Measure of orientation to developing from technologies	Proportion of citations to firm supply chain relative to all citations
Competitor Orientation (CO)	Independent	Measure of competitive response to local constraints	Proportion of citations to direct competitors relative to all citations

The dependent variable, Adaptive Behavior, aims to capture responses to the environment that are faster than the rate of environmental change. While there are a number of previous studies examining adaptive processes (Eisenhardt 1989; Eisenhardt and Tabrizi 1995), these studies have typically focused on the raw speed of organizational processes across projects. In this chapter, consistent with the literature on adaptive and maladaptive processes (Barnett and Hansen 1996) the speed of the behavior is benchmarked relative the industry pace of environmental change in each year over the period of the sample.

To construct the measure of Adaptive Behavior it is necessary to first estimate the rate of environmental change. The rate of environmental change is estimated as the technology cycle time (Hicks, Breitzman et al. 2001) which is measured as the annual mean of all focal patent years subtract the application year of the back cited patent . This measure is constructed in a similar fashion to conventional organizational patent measures such as technology age (Sorensen and Stuart 2000) but is important to note that there are critical differences in how this measure is interpreted. Some scholars interpret a old back citations as an indication that the firm is using obsolescent knowledge to the firms detriment (Sorensen and Stuart 2000). Other scholars might argue that the focal patent represents a novel recombination (Fleming and Sorenson 2001), and because older knowledge is more reliable and understood, a recombination citing older patents may have a higher probability of success (Katila and Ahuja 2000). Unlike this previous literature, this paper considers citation age as an outcome and not an input. Consistent with practice in the product development literature (Eisenhardt 1989), the outcome measure is dependent on the speed of technology development rather than the stock of technology development. The rational behind this view is that while firms may have high degrees of innovative capabilities, those capabilities are not necessarily adaptive, or fast enough, to respond to changing environmental conditions. Given our framework, it is not helpful to simply measure the extent to which a firm innovates, but rather whether the firm's innovations are fast enough to react to the changing technological environment.

During our longitudinal study the mean rate of environmental change, or technology cycle time, linearly increases from four years to just over seven years, potentially reflecting the changing age of the stock of older potential citations which increases each year. Given the dynamic nature of these citations, adaptive behavior is benchmarked relative to mean industry behavior in the same year. Adaptive Behavior is scored as the firm aggregate proportion of patent citations made that are younger than the mean age of all patent citations made in that application year.[27]

Three independent variables are constructed to represent various firm strategies: Internal Technology Extension, Supply Chain Orientation, and Customer Orientation are generated from classifications based on a firm's patent orientation.

Internal Technology Extension (ITE) is a measure of whether the firm patented a new technology based on rsrouce allocations to technologies that extended previous organizational knowledge and routines. Similar to the patent citation measure of local search (Katila and Ahuja 2000; Rosenkopf and Nerkar 2001), Internal Technology Extension measures the proportion of patent citations in a firm year that are self-citations.

Supply Chain Orientation (SCO) measures the degree to which a firm allocates resources to patents that are external to the firm, but to which the firm has likely access or freedom to operate. This measure of patent orientation is used as suppliers and customers routinely shared knowledge, and because technology development is mutually beneficial

[27] The distribution of citation ages are fairly skewed to the left, thus median age in the sample is typically half a year younger than mean age for most years. The analysis seems fairly indifferent to this choice of variables so, for simplicity, mean measures of technology cycle time are used.

between levels of the supply chain. Supply Chain Orientation measures the proportion of patent citations in a firm year that are between a supplier and a customer.

Competitor Orientation (CO) measures the extent to which firm patents are targeted towards freedom to operate, or overcoming legal constraints created by other organizations. Because firms are unlikely to invest in developing new knowledge in technologies for which their rivals hold early patent rights (Gilbert and Newbery 1982), Competitor Orientation offers a good signal of the extent to which a firm allocates resources towards behavior that focuses on increasing its sovereignty, autonomy, and freedom. Competitor Orientation measures the proportion of patent citations in a firm year that are between two competitors.

Four broad categories of control variables are used. Control variables were constructed for (1) market effects, and where possible, firm effects, (2) technological proximity, (3) patent qualities, and (4) previous knowledge. Year effects are also considered but these are expected to be fairly small as adaptive behavior is relative to the mean citation age in a given year.

Control variables are constructed for each of the six market orientations (Supplier, Customer, Niche Supplier, Chemical Supplier, Government Lab, Academic) as certain environmental factors might be common to one orientation relative to the others. Factors that make the orientations different in their behavior might include capital opportunities, the appropriability regime, reward schemes, government regulations, labor force and training opportunities, as well as other structural factors. As such, a dummy variable is employed for each of the six market orientations except for suppliers, which are controlled against.

Three variables were constructed to control for technological proximity. Technology proximity is controlled for because technologies that are very similar are more likely to induce a fast reaction than those that are further apart. From a learning perspective, a technology that is very similar to one being developed, or less novel to an actor, should be easier to identify and assimilate (Carlile 2002). To control for technological proximity between a focal patent and its citation, two proportion measures are developed from USPTO classifications. One measure, Same Major Patent Class, is scored if the focal patent and prior art citation is identically categorized by one of the 400 major USPTO patent classifications, or not. The second measure, Within Sub-Class Sample, is scored if the citation is to one of the 37 of 100,000 unique USTPO patent sub-classifications that are identified as being the most important for photolithographic aligner technology (see Appendix 1, Chapter 4), or not. The third control, Within Perf Sample, is a similar binary variable to Within Sub-Class, and is scored if the citation is to a patent within full Perf sample, which extends back into the late 1950s, or not.

It is important to control for patent quality as patents vary widely in their value and importance. Two standard controls are used from the NBER patent dataset (Hall, Jaffe et al. 2001), focal patent Originality and focal patent Generality (Henderson, Jaffe et al. 1998). Originality is based on the Herfindahl concentration index of focal patent prior art citations made to classes out of all prior art citations made by the focal patent. A low originality score suggests that the focal patent derives from a narrow set of technologies whereas a higher score suggests that a broader set of technologies were used by the focal patent. Generality is a similar measure to Originality except it based on the Herfindahl concentration index of patent prior art citations made to the focal patent. A high generality score suggests that a patent has widespread impact as it impacts a broader variety of future technologies. To date there has been no work comparing Originality or Generality to patent citation age although some ongoing work has shown that because of delays in future patent citations there is some drift in these measures over (Hall, Jaffe et al. 2001). While mean measures of generality begin to significantly decline for granted patents in the late 1980s, over the period of our sample the measure is fairly stable. Measures of mean Originality have trended upward approximately 15% from the early patents of our sample to those in the late element, but even if year effects were not controlled for, this would likely be a minor bias.

Finally a firm's accumulated knowledge is controlled for through the measure Knowledge Stock. Earlier work (Cohen and Levinthal 1989; Cohen and Levinthal 1990) has identified that the concept of absorptive capacity depends on the level of a firms accumulated knowledge. Similarly, because patent data is used to estimate a firm's knowledge base, this variable may also be important as a measure of the level of autonomy that the firm has already developed. For example, firms that have developed a large stock of patents may become more aware of external constraints because of increased prior art searching and feedback from USTPO examiners. Knowledge Stock is a measure of the stock of patents using an annual perpetual inventory method and a 20% depreciation rate (Henderson and Cockburn 1996). Patent stock is measured for each firm-year and is the only measure which derives from traditional patent count data. As such, knowledge stock is biased by such effects as varying propensity to patent, but to a large extent these concerns are mitigated by firm and year effects.

The analysis presented in this chapter is developed by developing proportion and controls for each variable at the level of the firm-year. Analysis at the firm- year is important in that it examines if small environmental responses have significant firm effects. While additional analysis was done at the level of the individual patent citation (not presented) aggregating to the firm year significantly reduces our available sample size and power. Given this, marginal effects found to be significant at the level of firm year should be viewed as more important than effects at the citation level. Finally, aggregating the data to the firm year allows the construction of various interaction variables based on the independent variables. For example, the pursuit of freedom to operate may drive organizational learning either by improving existing firm technology or by learning from the environment. Similarly the level of internal development may be related to the level of external learning and vice versa. Three interaction variables were constructed based on our independent variables, these are: (1) ITE x SCO, (2) ITE x CO, and (3) SCO x CO although none were found to be significant. Because knowledge stock, or the level of patenting might also mediate the explanatory power of our independent variables, our independent variables were also interacted with Knowledge Stock in the aggregated models, but these are also omitted from the analysis below as they too were not found to be significant.

5.5.3 Empirical Results

The raw citation data (not shown) identifies that for the top 45 patenting firms, 61% of the 5,412 citations are by firms I classify as customers, whereas nearly 26% are made by firms classified as suppliers. Although the top 45 firms account for approximately 85% of the patents in the Perf dataset, they only receive 53% of the citations, with additional citations going to patents which are unassigned or to firms who are not highly active in the industry. Summary statistics for all variables measured at the level of the firm year (Table 5-6A) are fairly similar to those found in the analysis of the raw citations, although the mean value of knowledge stock is substantially decreased. This effect is caused by the fact that firms with high knowledge stock also tend to have more citations, and thus high knowledge stock is over-weighted in the summary statistics for the earlier analysis.

Table 5-6A: Summary Statistics (N=342 Firm Years)

Variable	Mean	Std. Deviation	Minimum	Maximum
Adaptive Behavior	0.568	0.264	0	1
Supplier	0.225	0.418	0	1
Customer	0.579	0.494	0	1
Niche Supplier	0.058	0.235	0	1
Chemicals Supplier	0.076	0.265	0	1
Government Lab	0.041	0.198	0	1
Academic	0.020	0.142	0	1
Same Major Classification	0.518	0.286	0	1
Within Sub-Class Sample	0.522	0.295	0	1
Within Perf Sample	0.432	0.288	0	1
Originality	0.426	0.208	0	0.86
Generality	0.501	0.209	0	0.90
Knowledge Stock	9.055	11.092	0	52.69
Internal Tech. Extension (ITE)	0.116	0.165	0	1
Supply Chain Orientation (SCO)	0.082	0.161	0	1
Competitor Orientation (CO)	0.275	0.265	0	1

Table 5-6B presents bivariate correlations for all variables measured at the level of the firm year. For the most part correlations are as expected. There is a high correlation between Within Perf and Within Sub-Class which is expected as the 37 key Sub-Classes were primarily identified from the Perf sample (see Chapter 4). Originality is highly negatively correlated with Same Major Class. This is expected as Originality is constructed from the breadth of sub-classifications of the focal patent. Patents with low Originality are likely to have a higher degree of citations that are Same Major Class. Generality and Originality measures are partially correlated which is interesting given that they are not generally correlated. This suggests that patents that draw on more diverse technologies also have broader applications. Knowledge stock is highly correlated with customers, who generally have substantial portfolios, whereas it is very low for niche suppliers who are not major patentees. Correlations between our independent variables and our market orientation dummy's are fairly high driven by a disproportionate level of citations by all firms to customer firms. However, this concern is in part mitigated by dummies for market orientation when estimating the level of Adaptive Behavior.

Table 5-6B: Correlation Matrix (N=342 Firm Years)

Patent Response	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 Adaptive Behavior	1.00															
2 Supplier	-0.09	1.00														
3 Customer	0.10	-0.64	1.00													
4 Niche Supplier	0.05	-0.13	-0.29	1.00												
5 Chemical Supplier	0.00	-0.16	-0.34	-0.07	1.00											
6 Government Lab	-0.13	-0.11	-0.24	-0.05	-0.06	1.00										
7 Academic	0.01	-0.07	-0.16	-0.03	-0.04	-0.03	1.00									
8 Same Major Class	0.02	-0.04	-0.01	0.07	0.08	-0.09	0.02	1.00								
9 Within Sub-Class	0.15	-0.15	0.10	0.06	0.07	-0.11	0.05	0.08	1.00							
10 Within Perf	0.18	0.00	0.08	0.00	-0.07	-0.08	-0.03	-0.03	0.62	1.00						
11 Original	-0.06	0.07	0.00	-0.12	-0.05	0.07	0.00	-0.56	-0.15	-0.02	1.00					
12 General	-0.11	0.10	0.01	-0.23	-0.03	0.06	0.03	-0.24	0.02	0.03	0.27	1.00				
13 Knowledge Stock	0.11	0.00	0.17	-0.07	-0.15	-0.11	-0.05	0.07	0.04	0.04	-0.03	-0.04	1.00			
14 Internal Tech (ITE)	0.11	-0.09	0.10	-0.10	0.05	-0.07	0.08	0.09	0.15	0.07	0.03	-0.02	0.35	1.00		
15 Supply Chain (SCO)	-0.01	0.63	-0.33	-0.13	-0.15	-0.11	-0.07	-0.05	-0.05	0.11	0.10	0.14	-0.04	-0.09	1.00	
16 Competitor (CO)	0.15	-0.34	0.64	-0.26	-0.22	-0.20	-0.14	0.02	0.09	0.19	-0.02	0.00	0.06	-0.16	-0.27	1.00

Table 5-7 presents the OLS estimates for the models of Adaptive Behavior at the level of the firm year. The distribution of the proportions data is approximately normal, with negligible skew and some kurtosis, so OLS is reasonably appropriate. Model 1 estimates a baseline model of control variables only, while Model 2 estimates a baseline model on all control variables. Model 3 includes three independent variables of which two, Internal Technology Extension and Competitor Orientation, are significant. Model 4 is the best fit with Customer Orientation, and Model 6 is the best fit model without Customer Orientation. Finally Model 6, is the same as Model 4 but with fixed effects. As noted, Model 6 is over-specified, but even when the analysis is done on several thousand individual citations, there are not significant fixed effects once our independent variables are taken into consideration. Neither year effects, nor our three interaction variables described earlier, both not shown, were significant.

Table 5-7: Adaptive Behavior and Logistic Regression Models (N=342 Firm Years)

Adaptive Behavior	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Customers	0.081	0.053	0.028			
	(0.035)*	-0.036	-0.047			
Niche Suppliers	0.108	0.072	0.153	0.129	0.133	
	(0.066)+	-0.069	(0.077)*	(0.064)*	(0.062)*	
Chemical Suppliers	0.062	0.064	0.106			
	-0.059	-0.061	-0.068			
Government Lab	-0.1	-0.089	-0.023			
	-0.076	-0.078	-0.084			
Academic	0.05	0.078	0.122			
	-0.103	-0.11	-0.115			
Same Major Class		-0.039	-0.062			
		-0.06	-0.06			
Within Sub-Class Sample		0.011	0.01			
		-0.064	-0.064			
Within Perf Sample		0.151	0.108	0.101	0.098	0.111
		(0.064)*	-0.066	(0.051)*	(0.049)*	(0.054)*
Originality		-0.043	-0.066			
		-0.084	-0.084			
Generality		-0.115	-0.114			
		-0.072	-0.072			
Knowledge Stock		0.002	0.002			
		(0.001)+	-0.001			
Internal Tech (ITE)			0.203	0.256	0.261	0.303
			(0.099)*	(0.088)**	(0.086)**	(0.099)**
Supply Chain (SCO)			0.206	-0.024		-0.007
			-0.13	-0.096		-0.122
Competitor (CO)			0.203	0.202	0.208	0.181
			(0.077)**	(0.061)**	(0.056)**	(0.080)*
CONSTANT	0.513	0.538	0.491	0.434	0.431	0.436
	(0.030)**	(0.081)**	(0.084)**	(0.033)**	(0.030)**	(0.037)**
Observations (Citations)	342	333	333	342	342	342
Adjusted R-squared	0.018	0.044	0.062	0.064	0.067	-0.095
Fixed effects (Note: Model over-specified)						45

Standard errors in parentheses + significant at 10%; * significant at 5%; ** significant at 1%

The models of Adaptive Behavior generate several interesting and consistent results. First, an examination of the first models shows that that with the exception of two negative but insignificant coefficients for Government Lab, every market orientation is more likely to engage in Adaptive Behavior than photolithographic aligner supplier firms (an effect that was much more pronounced at the individual citation level). This simple fact is consistent with the substantial churn with suppliers and much less so even with smaller niche players. The citation data also supports that the category Niche Suppliers, which typically included smaller companies that primarily invested in radical substitute technologies such as x-ray, ion beam, and e-beam, exhibited much more adaptive behavior than the industry as a whole. Some models also support this view for the Academic category which was limited to just citations made by MIT focal patents. As expected, there is also support that technological proximity increased Adaptive Behavior. The variable controlling for Within Sub-Class Sample was dropped from later models as it is highly correlated with Within Perf Sample and offered no additional information. Other measures of technological proximity, patent quality[28], and knowledge stock were insignificant at the firm-year.

The models consistently support H1, that increased allocations to Internal Technology Extension significantly increases the likelihood of Adaptive Behavior. This result is consistent with the expectation that increased allocation to internal technologies are more likely to offer adaptive than maladaptive, or inertial consequences.

There is no support for H2, that Supply Chain Orientation decreases adaptive behavior although we find that the measure offers no significant result. Perhaps, the measure of Supply Chain Orientation is too limited a measure to capture key knowledge flows and the implications of absorptive capacity in the industry, namely learning that occurred due to a patent response between a customer and supplier. It is important to consider the implications of restricting the view of absorptive capacity. Nearly 50% of

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[28] Patent quality measures such as Originality and Generality are difficult to aggregate from the individual patent to the firm year. To the authors knowledge there is no method to weight patents in a manner that would appropriately account for all the information in a way that would not reduce our sample size. However, provided we had a rich distribution of patents for each firm year we might use the 'winner's' approach which truncates the available data (Henderson et al. 1998).

patent citations are not to the 45 firms I identify as important to the industry. A broader definition of knowledge flows through absorptive capacity might assume that all of these additional citations were actually measures of external learning that do not generally show up in the historical record. However, this assumption was to be followed, absorptive capacity would actually create a major drag on the level of adaptive behavior as these responses are significantly outpaced by other resource allocation. It is important to note that dominant firms in this industry, such as IBM, Canon, and Nikon, have substantially fewer of these external patent citations than the average firm (see Table 5-2A and Table 5-4 respectively), although their relative levels of our three independent variables are mixed. Alternatively, GCA, which fell even faster than its short lived meteoric rise, was primarily focused on technologies that seem to be very distant, both in market and technological position, from the industry (Table 5-2A).

Finally there is broad support for H3, that Competitor Orientation increases Adaptive Behavior in addition to the previously identified resource allocations in research and development. While the effect is still small relative Internal Technology Extension, it nears the effect of Adaptive Behavior as identified in our models.

5.6 Adaptive Behavior and Performance

Adaptive behavior is of little importance if it does not drive long term firm performance. One might expect that companies that reacting to nearer term environmental changes would be higher performing, unless of course it is suspected that nearer term technological development might distract a firm from bigger opportunities that required a longer term view. However, within the limited case of suppliers, firms like

Nikon and Canon both reacted faster and took the long view of technology. Indeed, a major challenge when attempting to consider the case of Nikon from an ecological perspective is identifying when the firm entered the industry. Nikon ran a very small research program for many years before launching their first product. However, at the time of its first product launch in 1978, Nikon had spent over five years developing a patent portfolio and by the late 1970s, Nikon had a similar portfolio of patents to other early suppliers and most major customers. Nikon's patent portfolio at this time was still negligible relative to that of AT&T and IBM, and they were still not seen as any significant threat until they began displacing GCA in the marketplace in the early 1980's.

It has already been established that leaders in photolithographic aligner supplier industry were generally caught by surprise by the subtle but critical force of architectural change (Henderson and Clark 1990; Henderson 1993; Henderson and Cockburn 1996). This point is further supported by this study because supplier incumbents were not linked in the patent data to new entrants. Similarly, that incumbents were typically not able to exercise their patent portfolios to deter entry. Indeed, the study of photolithographic patents does not show subtle behaviors . While the patenting behavior of for most firms, exhibits low growth and stays fairly flat into the 1980s, (an exception is Perkin Elmer which grew a substantial patent portfolio up until the early 1980s) the period that follows is very different. From 1980 to 1986, Canon and Nikon exhibit about 800% patent stock growth, whereas Perkin Elmer drops 10%, IBM drops by 20%, AT&T by 60%.

The growth of Nikon and Canon patent stock growth particularly as both firms are very focused on each others patents when the rest of the industry didn't. One hypothesis for their heavy interest in each others patents might be that the firms colluded in their technology development, although there are no suggestions of this in the trade press at the time. Given that paper is based on primarily on patent data, our biggest assumption is that patent response to rivals is indeed a real phenomenon that has real economic and organizational implications, even if these implications are individually very small. However, even if firms share these assumptions and want to acts to reduce even slight environmental constraint; the harsh realities of the patent system pose a significant barrier to firms wishing to identify, assimilate and respond to routine changes in the patent environment. To develop freedom to operate within the patent system a firm needs to invest in routines that: (1) overcome the expense of monitoring overwhelming, frequently inaccessible, and incomplete information; (2) coordinate expertise to decipher complex and specialized information; (3) manage the challenges posed by the uncertainty and legality of patent rights and; (4) overcome organizational and inter-organizational incentives that value patent counts over quality, and prior art ignorance over constraint response. However, regardless of the mechanisms by which these firms addressed these patent constraints, the important element is that these firms succeeded in part by what appears to be a distinct effort to allocate research and development resources that had a high degree of competitor orientation.

The role of adaptive behavior on performance is limited at this point to suggest that Nikon's and Canon's behaviors probably mattered. Not only did rapid disruption in the photolithography industry cease after this period, but both firms held the top two market share positions for nearly twenty years. Not surprisingly, given the focus of these firms on intellectual property, the new entrant ASML is being met by a world war in litigation (literally in Japan, American and the EU) which looks to pit patent rights against anti-trust regulations across several continents.

5.7 Discussion

This chapter is the first study which empirically examines the strategic process of resource allocation in research and development from the perspective that different patent orientations matter. This chapter is also the first study that addressed the strategic implications of "freedom to operate" within an organizational rather than economic context, and elevates the status of this concept beyond its more common reference to an exercise in patent analysis. In this paper, a distinction is developed between resource allocations to internal and external technological orientations and open and constrained systems. This distinction was tested across the broad industry surrounding photolithographic aligner technologies.

There are two key findings. The first finding is that firms that allocate research and development resources toward internal technological extension and freedom to operate through competitor patent orientation can increase their level of adaptive behavior. For firms whose performance is directly linked to lead-time or the speed of competitive response (Brown and Eisenhardt, 1995), the increase in adaptive behavior of these firms suggests direct performance implications.

The second finding is that the analysis demonstrates little support for the role that supply chain orientation and absorptive capacity (as defined) as strategy process that promotes adaptive behavior. Critical assumptions of the nature of technology will fundamentally drive whether this result for absorptive capacity is consistent with a scholar's world view; however this finding is consistent with inertial constraints posed by resource allocation decisions that are driven by major customers (Christensen and Bower 1996).

Because internal technological extension, supply chain orientation, and competitor orientation are based on patent citation measures, the hypotheses are affected by how well our measures are representative of the strategic allocation processes that are being measured. For patent citation data, citation patterns may be driven by (1) specific features of the technology that uniquely link focal patents with their cited patents and (2) salience of certain patents to different firms or patentees. In regards to the most interesting finding, that pursuing freedom to operate through competitor orientation can drives adaptive behavior, an attempt has been made to address the alternate hypothesis that our freedom to operate measure is driven by technology specific factors. Included in the analysis are controls that approximate technological similarity based on major patent class, patent sub-classifications, as well as a measure of proximity based on inclusion in our unique sample. Unfortunately there is little opportunity to distinguish other measures of technological similarity, for example the extent to which the technologies are incremental, radical, architectural, or modular (Henderson, 1990). Similarly, the extent to which the technologies are either product or process inventions is in this study undefined (Utterback 1994).

Citation measures of freedom to operate might also simply capture patterns that emerge because patent examiners or patentees recognize certain patents as more salient than others. This paper is not able to exclude this alternative hypothesis, but detailed examinations of several firms' photolithographic aligner supplier citations suggest that this is probably a minor concern. First, persistent 'favorite patents' between firms are not observe in the citation data and within a given firm most back citations are unique, with the occasional patent being cited twice. Thus, unlike academic papers, patent citations appear to be less influenced by legacy citations, or patents that 'everyone' in the firm has read. On the other hand we could imagine other processes by which certain patterns could emerge more dynamically. For example, trade press used by certain firms in the industry might alert some firms or examiners to the 'patent of the week' influencing citation behavior. However, to the extent that these influences correlate with the focus of firm attention on constraints caused by external patents, regardless of the mechanism, the more resolute the competitor orientation result.

This study has additional empirical challenges. While every effort has been made to identify the relevant patent environment faced by these firms in photolithographic technology, most of our measures are fairly coarse. There is also the concern that the measures are not reasonably independent, as is assumed given the large number of extra-industry citations, or that they are the artifacts of patenting processes resulting in biases that are not identified. Similarly, citation measures may not be appropriately identified as linkages through licenses and supplier relationships are not fully detailed in the case history. As with most studies using a sample of firms, key firms may be misidentified or under represented, particularly if important firms did not patent at all. However, because of these challenges, a significant effort has been made to compare our technology focused patent sample with other more standard methods previously described (Scherer 1965; Schmookler 1966; Griliches 1987; Henderson and Cockburn 1996; Sorensen and Stuart 2000; Fleming 2001; Rosenkopf and Nekar 2001) and a substantial effort has been made to understand if our measures effectively reflect the history of this industry (Henderson 1988; Henderson and Clark 1990; Henderson 1993; Henderson 1995; Henderson 1996).

Other challenges faced by this study include the lack of existing empirical guidance in measuring the pace of organizational change, as well as the lack of robust estimators for behavioral variables based on patent citation data. Finally this study is limited in that is an in depth study of just one case, the photolithographic aligner industry. Because of this the paper forgoes broader claims across industries, although this marks a substantial opportunity for future research.

5.8 Conclusions

The idea that firms direct their abilities to pace themselves relative to their environment is a novel and challenging research agenda. This chapter develops the idea that research and development activities that have high levels of competitor orientation, towards achieving freedom to operate, can explain adaptive behavior beyond existing concepts in the continuous change literature and the learning literature. Building on previous findings (Bourgeois and Eisenhardt 1988; Brown and Eisenhardt 1997) this chapter demonstrates that the concepts of "freedom" and "fast" are not just related, but that the pursuit of freedom is what drives some firms to change at a faster rate than their environment.

This research agenda may be important, not just in technology research and intellectual property studies, but in other areas such as environmental regulation, accounting standards, securities regulation, and other regulatory changes where firm's may have become increasingly complacent. The pursuit of freedom to operate through the resource allocation process may act through several mechanisms. It may be important because a firm needs simple access to best technology, resource, or standard to grow or become more efficient. It could also act in a way similar manner to the Red Queen (Barnett and Hansen 1996), as firms that don't recognize and respond to environmental constraints actually fail because they fail to manage constraints that increase the market power for remaining firms. Alternatively, freedom to operate may simply be an exercise that frees the firm from complacency and sloth through the development of new routines (Nelson and Winter 1982). If one day the firm is asked to run a steeplechase, they have already practiced running most of the course and aren't tripped up at every turn. Finally, although this was not explored in our study, freedom to operate may act by directing and mediating investment in absorptive capacity making investment in external knowledge more efficient. While the micro-mechanisms offer opportunities for future research, the result is prescriptive; by allocating resources to freedom to operate, and external constraint resolution, firms will be less sensitive to environmental change, they will act faster, and they will continuously exercise their capabilities for change.

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