RETURNS TO ADOPTION AND THE EMERGENCE OF DOMINANT DESIGNS

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ABSTRACT

Three essays examine how increasing returns and standardization affect the emergence of dominant designs in the wake of innovation. The first essay (Chapter 2) links the innovation and economics literature with regard to how significant innovation in open production systems is accomplished. Though the innovation literature has regarded the firm as the locus of innovation, systems where a number of firms manufacture components only are common. Generating significant performance improvements in such systems requires that firms either use the market to develop a \textit{de facto} standard or coordinate development. I argue \textit{de jure} standards are explicit governance forms for coordination. I also examine the role of limited scope consortia in the development and passage of \textit{de jure} standards when institutional failure is anticipated.

In the second essay (Chapter 3), I contrast real options and transaction cost perspectives on when firms in the ITC industry make acquisitions. I argue that if firms are using a real options approach to acquisition, the timing should coincide with the resolution of uncertainty regarding technological outcomes. Conversely, transaction cost economics would suggest earlier acquisition while uncertainty is high. These are tested through data gathered on acquisitions of hardware producing firms in the ITC industry for 1995-2000.
The effects of equity investment, nonequity alliance and joint membership in industry alliances and limited scope consortia are included. I conclude that the transaction cost framework better explains the pattern of acquisitions but that framing the definition of an option differently may reconcile the theories.

The third essay (Chapter 4) develops a simulation to examine if and when innovation adoption occurs. I include market uncertainty, scope of returns to adoption, firm size and relative knowledge overlap with innovators as factors in the simulation. I find that firm size and overlap are strong predictors of adoption timing and that as returns to adoption increase, adoption may be deferred. At the industry level, the likelihood of new technology replacing old is strongly related to the scope of returns and when the first adoption occurs. Also, smaller innovators are more likely to win if theirs is the first technology adopted.
To Jonne, Emily and Kate: I couldn’t have done this without you

To my mother and father
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CHAPTER 1

INTRODUCTION

The strategy of firms, writes Joseph Schumpeter, must be set against the background of the constant change that results from innovation, the prime mover of a capitalist economy. Innovation unleashes a “creative destruction” that “strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives.” (Schumpeter, 1975). This perspective has informed much of the literature investigating innovation and its effect on industry structure. In it, innovation springs from the firm, is entered into the market and is subsequently adopted or fails. If enough adoption occurs, the new product or process becomes the “guidepost” or dominant design for future development (Dosi, 1988). When the invention differs from prior art sufficiently, the process of competition and adoption can drive incumbents from the industry as their skills and knowledge are not relevant in the new regime.

Scholars have used historical evidence of innovation and industry to make a compelling case in support of this approach. The initial incremental versus radical typology of innovation has been extended to address the characteristics of complex products, of relationships between components and even the effect of developments in technologically similar industries. This perspective is deterministic in that firms are endowed with certain
characteristics that allow them to survive in a given industry but if innovation means conditions change overmuch, they are susceptible to failure.

In all, there is a distinct sense of stimulus and response in this, which may be too simple a framework. The evolution of industries and, in some cases, their convergence is generating environments more complex than the model addresses. In particular, the growth of increasing returns to adoption markets and the rise of standardization have not been well investigated. The three essays of this dissertation argue that the economic theory of increasing returns needs to be included in the innovation discussion, primarily because these factors lead firms to employ strategies for survival and success that are adaptive and not reactive.

1.1 Innovation and the industry paradigm

Scholars have increasingly come to regard innovation in an industry as occurring in the context of a paradigm, which defines a problem space for industry members. Dosi (1988) argues that the paradigm is evolutionary in that it is selective and finalized in specific directions. Put differently, the collective experience of industry firms over time defines what problems are to be solved and how. The technology implicit in the paradigm is generally referred to as the dominant design. These designs evolve through competition among competing approaches with producers and users eventually settling on a preferred solution and have been defined as the dominant technological path in an industry’s design hierarchy (Anderson and Tushman, 1990; Suarez and Utterback, 1995). They are
recognized when industries transition to mass production (Abernathy and Clark, 1985) or when the product architecture claims at least half of the implementations of the technology (Anderson and Tushman, 1990). In other words, competition is no longer between-product classes but within-class. Anderson and Tushman (1990) have referred to this period as an “era of incremental change.”

Since the competition between classes is ended, innovation in this period refines and deepens the now established technological trajectory through changes that permit firms to differentiate through design variation or reduce production cost. As firms in the industry seek to compete in this way, the search for solutions is limited to areas proximate to what they already know and do. This occurs because there is an accepted design and because it is more efficient and productive (Levinthal and March, 1993). This learning and exploration is a cumulative and strongly path dependent process: the ability to learn is predicated by what is already known (Dosi, 1988; Cohen and Levinthal, 1990).

Because this incremental change tends to reinforce the power of firms in the industry (as it speaks to skills and assets already in use), it is not Schumpeter’s agent of creative destruction. That role belongs to innovation that offers a new paradigm. This is sometimes referred to as “radical” innovation, which has been described as that which originates outside the dominant trajectory and depends on new knowledge for successful implementation (Tushman and Anderson, 1986; Dosi, 1988). Obviously, the need for such knowledge places incumbent firms at a disadvantage. To the extent that incumbent knowledge stocks are oriented along the trajectory, departures from that trajectory mean
that firms must acquire new learning in order to compete. Competition here is between new product classes and between new technologies and their antecedents (Tushman and Anderson, 1986; Suarez and Utterback, 1995). Following an evolutionary model (Christensen, Suarez et al., 1998), producers and users select among the contending architectures. Eventually, a variant of the innovation wins and a new paradigm is established or no new technology survives and the old trajectory persists. Anderson and Tushman (1990) have described this as the innovation cycle.

Henderson and Clark (1990) have amplified the incremental-radical innovation dichotomy by addressing the effect of the innovation. They argue that while radical innovation can have adverse effects on incumbents, so too can seemingly trivial changes if they involve the architecture of systems or how components fit together. This insight reinforces the notion that the technological paradigm is not just the knowledge of how things work but the larger scale understanding and specification of a system. In other words, knowledge is still the key but it is not constrained to the root technology. Significant changes in the parts or in their relationships can have profound effects on firms.

Henderson (1993) extended the discussion by noting the necessary distinction between the economic implications of innovation and their organizational effects. Innovation may be radical from an economic perspective if it is capable of completely replacing an existing technology. Innovation may also be radical from an organizational view if the skills necessary to develop or imitate the new technology are absent or difficult to obtain.
However, these are not identical problems: economically significant innovation may not be particularly difficult for certain firms to employ or introduce and, conversely, innovations that may not replace existing still cause firms problems if they call upon new and costly to acquire knowledge. These effects will confound each other and unless controlled for, may yield spurious results when various predictors are tested.

1.2 The emergence of dominant designs

The process by which dominant designs emerge is often ambiguous. Suarez and Utterback (1995) have argued that producers experiment with variants on a technological theme through decisions to adopt particular approaches. Market feedback provides the information on satisfactory implementations. Dominant designs emerge as a result of patterns of invention and adoption and the interesting issues are the factors that drive or impede such adoption. Anderson and Tushman (1990) and Tushman and Murmann (1998) argue that the dominant design is more an outcome of non-technological issues. Specifically, dominant designs are generated by the “sociopolitical/institutional processes of compromise and accommodation between communities of interest moderated by economic and technical constraints” (Tushman and Murmann, 1998). In either case, though, the dominant design is the cumulative outcome of individual firm decisions as to what to produce.

The first essay in this dissertation (Chapter 2) investigates a particular manifestation of the processes Anderson and Tushman note. The economics literature has a rich
discussion of how increasing returns to adoption can moderate innovation outcomes. Here, learning by doing, technical committee coordination and network externalities can lead to winner-take-all competition (Cowan, 1991; Mookherjee and Ray, 1991). Increasing return economies are path dependent, self-reinforcing and, as Arthur (1989) describes them, “tippy.” That is, early and seemingly minor events can have a substantial effect on the final state of the industry. Innovation scholars have noted these possibilities but not treated them in depth.

Moreover, innovation itself has been regarded as a fundamentally firm centered process. Firms are the locus of innovation and the adoption process in the wake of innovation is firm centered and sequential. However, as Powell, Koput and Smith-Doerr (1996) have found, when the information required to generate new products is distributed among firms, collaboration and cooperation is often required to accomplish innovation. The combination of increasing returns markets and distributed knowledge give rise to particular problems of invention and coordination.

Chapter 2 examines standards setting organizations as a particular institutional response to increasing returns markets and the coordination of innovation. Firms seek to reduce risk through negotiation and compromise outside the market under a standard setting regime. This process can be slow and highly politicized, though, and as the pace of technological development increases, can also be an unsatisfactory venue for coordination. Evidence of how firms adapt to such conditions is presented.
In the third essay (Chapter 4), I integrate the firm centered and broader perspectives through a simulation based analysis of the factors that lead to adoption of innovations and the higher level emergence of dominant designs. The empirical research on innovation and adoption has usually focused on firm or industry level characteristics. Given that significant innovations can minimize or eliminate the value of knowledge in the incumbent technology paradigm, it is not surprising that the knowledge of the firm is a frequent focus of inquiry. Knowledge can be internally developed or externally acquired, as is discussed below, but in either event it seems to be requisite in the adoption and imitation process.

Empirically, the turnover of key employees to competitors commonality of relevant knowledge have been linked to ease and speed of imitation (Zander and Kogut, 1995). Schewe (1996) found that in order for firms to imitate leading innovators, they must have adequate capabilities, particularly technological competence. Stuart and Podolny (1996) studied the Japanese semiconductor industry in a network analysis of technological positions. They found that high knowledge similarity would permit firms, in principle, to serve as substitute innovators. That is, firms that were similar in their knowledge bases would have similar innovative capabilities. Dewar and Dutton (1986) argued for a link between depth of internal knowledge resources and the ability to adopt radical innovations. Studying adoption of footwear manufacturing technology, they observed that the number of personnel in engineering positions was strongly and positively related to the radical innovation adoption while this was less important for the adoption of lesser innovations.
Firm size has also frequently been used as an indicator of innovative and adoptive potential. While this stems in part from both of Schumpeter’s arguments regarding the effect of firm size on innovation (i.e., small firms are better innovators because they can move more rapidly versus large firms are better innovators because they have the resources to invest), it has been extended to the adoption process as well. Schewe (1996) argues that size is important since imitators often enter in periods of rapidly increasing sales. Large firms have the capacity to manage this and therefore should enter relatively early. On the other hand, Wernerfelt and Karmeli (1987) have proposed that because of their size, large firms have the ability to defer entry until outcomes are clearer. If the dominant design is a function of cumulative size of the producing adopters, this ability to tip the outcome could be very valuable. Absent other motivations to join (such as a profound difference in what the firm knows about the innovators), we should expect large firms to join later than other adopters.

The empirical literature has been as conflicted. Damanpour (1996) marshals a substantial set of studies in a meta-analysis to demonstrate this point. Here, some scholars find that the presence of slack resources, financial and market strength and deeper technical resources should facilitate innovation and adoption. Conversely, others show that large firms are more formalized than smaller organizations and thus suffer from inertia that prevents adoption.
Factors exogenous to the firm and industry should also play a role in adoption dynamics. For instance, the degree to which markets demonstrate increasing returns to adoption should matter, particularly as firm size and knowledge affect the decision to enter early or late. Either can generate bandwagoning effects, though for different reasons. However, the primary issue is that bandwagoning will be more important under some conditions than others.

While these variables have been broadly studied, they have not been integrated in a single approach. The simulation in Chapter 4 incorporates these under a broad array of conditions. The analysis focuses first on what affects the adoption decision at the firm level and is then extended to a similar analysis at the industry level. In terms of emerging dominant designs, I test for the factors that influence whether new technologies replace existing and the conditions under which smaller innovators might expect to be associated with a winning outcome.

1.3 Firm adaptation to innovation

If significant or radical innovation obviates the knowledge firms had as industry incumbents, how then do they survive? Often, they do not. Henderson and Clark’s (1990) study of architectural innovation argued that established firms, even if they invested in the new technology, were unsuccessful in the new regime. Even more to the point are the results reported by Christensen, et al (1998) on the disk drive industry. There, none of the seventeen firms that had constituted the industry in 1976 were still extant. On the other
hand, Anderson and Tushman (1990) found that early adopters of radical innovation were roughly evenly split between newcomers and incumbents, even though their prior work had shown that newcomers were more likely to introduce the innovation. This suggests that incumbents are relatively quick to adapt to the innovation and offer their own version. These results illustrate the dichotomy Henderson (1993) noted in contrasting economic and organizational effects of innovation.

The fundamental problem incumbents face with a prospective new paradigm is the need to acquire relevant knowledge quickly. Two broad types of difficulties attend this acquisition: the degree to which the new knowledge differs from the incumbent’s stock and the extent to which organizational dynamics impede acquisition (Christensen and Rosenbloom, 1995). With respect to the first issue, Cohen and Levinthal (1990) have argued that learning is a path dependent process. What can be learned now is a function of what has been learned in the past. Since, as Dosi (1988) observed, the development of a technological trajectory implies irreversible investments along certain learning pathways with the concomitant failure to invest in others, new technologies may depend on a set of learning that is far from prior investments. Under these circumstances, learning is a time consuming and costly process, which may mean that firms will not be able to acquire it readily (Cohen and Levinthal, 1990).

Organizational problems also emerge. For a variety of reasons, firms may be unable to implement learning even if they acknowledge its importance. Competencies that have proved successful in the past may become habitual responses and inhibit the
incorporation and utilization of new and perhaps contrary information (Leonard-Barton, 1992; Levinthal and March, 1993). Christensen and Rosenbloom (1995) show that organizational structure itself can impede the deployment of relevant information.

Given these problems, firms are increasingly turning to acquisition as a means to access critical knowledge and skills. A good example is the information and telecommunications industry, particularly in networking products. Since 1995, over two hundred acquisitions have been finalized in networking, reflecting a remarkable surge in innovative activity. However, innovations are by definition new and therefore risky. Acquisitions can represent a significant investment for a firm and in the context of a design battle for dominant design this can mean that a losing technology is a wasted investment. This is particularly true in networking products where technologies are often standardized. An interesting characteristic of these acquisitions is that some form of investment has preceded many. The uncertainty over technological outcomes can be examined in two theoretical frameworks.

One interpretation of the investments leading up to an acquisition is that they are real options or incremental investments made in physical assets or knowledge generating processes. Real options permit a firm to “hold” a position on technology and exercise it if the uncertainty about the technology is resolved favorably. Therefore, if these are real option investments, we should expect acquisition to occur at specific times. Another perspective comes from transaction cost economics, which would argue that the investments are made to resolve uncertainty about the opportunistic behavior by the
target rather than the overall technological outcome. If so, acquisition should occur when behavioral uncertainty is resolved, in order to integrate the knowledge into the organization. We should expect that this would happen sooner than the real options framework would predict. This is the subject of the second essay (Chapter 3) and uses data from the networking products industry for the period 1995-2000.

To summarize, the innovation literature has developed widely used and tested theories for understanding how innovation affects industry. However, the convergence of technologies in some industries and the nature of their markets yield structural conditions that have not been well addressed. By integrating perspectives from the economic literature on increasing returns and standardization, I analyze emerging responses to the innovation and dominant design problems. This is extended into a general discussion of how increasing returns and the previously identified factors affecting adoption fit into a larger framework. Finally, I use the acquisition activity firms undertake in pursuit of innovative technology under standardization to contrast real options and transaction cost theories.
CHAPTER 2

INTRODUCTION

Industries and their products are not as separate as they once were. For instance, television, computers and telephony were distinct industries with sets of firms that participated in one but not other markets. Now, the dual influences of deregulation and technological advance are eliminating boundaries and differences between sectors (David and Shurmer, 1996). This process has been described as convergence (Lei, 2000) and has several significant implications for firms. First, products become more complex in terms of the components or modules that comprise the final consumable. These modular (Langlois and Robertson, 1992) or systemic (Teece, 1996; Tushman and Murmann, 1998) products require coordination of interfaces to assure interoperability and connectivity. The second, and perhaps more important, implication is that convergence typically means there are few if any firms that are sufficiently vertically integrated to provide end to end production of systemic products. This is a natural result of the merger of disparate technologies and the fact that new competencies are required (Lei, 2000). Products that result from convergence are complex systems, increasingly open in their manufacture and supply.
Components of complex systems exist in rich and complex relationship to one another – what has been termed a “mini-ecology” (Arthur, 1996). How well the overall system performs depends on the underlying performance of the components and their interfaces. Interdependence also implies that improvement or innovation in a single component in a system of components may not generate system wide improvements (Singh, 1997). When the systems are open, an additional complication is added. Firms must find some way to coordinate the interoperability and interface of the components in a system that no single firm controls. Put differently, firms must devise a standard for how the components work together. One approach is to use direct competition in the market, but the desire to avoid market-based determination has fueled standards development through more formal, negotiated processes.

Standards are a way of coordinating the development and supply of products so as to meet performance and interoperability criteria. These can be internally generated (e.g., a firm may let bids to manufacture according to a specification, generating the ability to use components from various suppliers) or developed externally. In the past several decades, research on standards has focused primarily on how they emerge from market competition. From the perspective of the literature, standards are most discussed under conditions of increasing returns to adoption and are often characterized by winner-take-all outcomes (Arthur, 1989; Arthur, 1996). Because of the adoption characteristics, another outcome is possible: these markets can fail. Absent a clear technology leader, potential users can defer adoption in hope of a clearer signal about outcomes. In these cases, no technology wins. Thus, formal standards, termed *de jure*, emerge as the result
of coordination and compromise among interested parties, usually in the context of an independent standard developing organization (SDO). *De jure* standards allow firms to adapt to and develop appropriate solutions, reducing the risk of failure.

Even so, the pace of technological development and convergence within and between elements of high technology industries like telecommunications places conflicting requirements on firms. While coordination and compromise avoid the potentially disastrous losses that market based competition in increasing returns industries can bring, the process can also be slower and heavily politicized. Time to market is also important as advances in other technologies increase user demand for new products and competitive alternatives emerge. However, SDOs generally rely on a high level of consensus to pass a standard and politicking and delay are common (Farrell and Saloner, 1988; Genschel, 1997). This is exacerbated when very disparate technologies are competing for the standard and can lead to potential “institutional failure” (David and Shurmer, 1996).

How, then, do firms reconcile the dilemma of coordination and speed? Farrell and Saloner (1988) suggest that SDO activities can be made more efficient if they can be “subverted by preemptive action outside the committee”. While this insight was based on the result of game analysis, examples in the form of specific industry organizations exist, merging market and institutional roles to resolve the dilemma (David and Shurmer, 1996; Genschel, 1997). The research in such organizations has only recently begin to narrow with attention paid to the role of independent consortia (Hawkins, 1999).
The notion of consortia as actors is important but general. It does not capture the qualitatively different ways organizations can manage the prospect of institutional failure. In this essay, I will show how limited scope consortia (LSC) have assumed the role of subversion and how they differ from other quasi-formal standards bodies. LSCs are temporary sets of firms organized around the development and standardization of a single product architecture and the management of user expectations and demand. These alliances are not generating formal standards as such but work in parallel with the standards organization and act to align interests of member firms and speed up the standardization process. They differ from other industry groups due to the strict focus of their objectives and relatively short lifespans. The process will be examined through the experiences of firms and alliances in the Ethernet industry based on contemporary reports of industry observers and interviews with industry executives.

The contribution of this research lies in several areas. First, the exploration of one industry’s experience acts upon the suggestion of Katz and Shapiro (1994) with respect to understanding how industry coalitions form and how standards organizations behave in these circumstances. This addresses the dynamics of standards adoption. Second, it strengthens the link between the innovation and economics literature by expanding the discussion of how firms generate new products through cooperation. Historically, the unit of analysis in these streams has been the firm but in the ITC industry and others, innovation transcends the individual firm. Innovation becomes a collective activity
conducted in a formal structure and the linkage between innovation and standards is
developed. Finally, it clarifies the emerging discussion on the role of informal and quasi-
formal groups in standard setting.

This paper is organized as follows: in section two, I review the innovation and standards
literatures to provide the basis for the role of LSCs. Section three summarizes the basics
of local area networking technology and the history of the Ethernet, the largest
technology in LANs. Section four develops a rationale for the emergence and role of
LSCs in the context of the Ethernet experience. Section four concludes.

2.1 LITERATURE REVIEW

2.1.1 The locus of innovation

An innovation is a technological solution to a problem, the resolution of a bottleneck
(Dosi, 1988). They can be “pushed” by firms in the sense that the innovation is brought
from the concept and invention stage to the commercial market with an eye toward
generating demand or “pulled” by as yet unanswered market demands (Carayanis and
Roy, 2000). In general, the innovation process as described is fundamentally firm
centered: innovations arise at the firm level and compete for acceptance in the market. If
the demand for a particular approach is sufficiently high and other firms adopt the same
approach, the innovation becomes a dominant design or the paradigmatic approach to
solving the problem (Abernathy and Clark, 1985; Dosi, 1988; Anderson and Tushman,
The dominant design notion emerges from the nature of technological change, which is characterized by a path dependent and cumulative course of (Dosi, 1988; Teece, 1996). That is, solutions tend to emerge from prior experience, heuristics and techniques in problem inquiry. Successful methods are retained while those that are less fruitful are discarded. Individual firms do not necessarily hold these alone. Since products are introduced to a market by a firm, other firms have the opportunity to observe and learn, to imitate or improve upon the initial offering. In this way, an industry level paradigm emerges and most, if not all firms, adopt it (Dosi, 1988).

The paradigm can be overthrown, however. An innovation that solves problems in a novel way often has little in common with the preceding technology. To the extent that the new product or process significantly improves performance (Tushman and Anderson (1986) characterize significance as order of magnitude improvement in cost or performance), it becomes a candidate for a new industry paradigm. The process of innovation, widespread experimentation and ultimate survival or extinction of a technology has been called an “era of ferment” (Tushman and Anderson, 1986). At some point in the product history a particular design variant that accounts for 50% or more of the technology implementations emerges: this is an industry dominant design. This dominant design represents the new paradigm and subsequent development (the era of incremental change) follows this design until a new discontinuous change is introduced.

Tushman and Murmann (1997) develop at length a discussion of the characteristics of dominant designs. In particular, they draw attention to the fact that there has been a great
deal of confusion over what, precisely, constitutes such a design and the appropriate level of analysis. Many products are complex, consisting of multiple subsystems or modules and interfaces or linking mechanisms and are nondecomposable (Henderson and Clark, 1990; Langlois and Robertson, 1992; Singh, 1997). While the literature has generally focused on the final product as the unit of analysis, it is at the subsystem level that change occurs. That is, core subsystems experience their own dominant design battles, which are reflected in higher level, final products. These design battles are often sequential: after a particular core subsystem is defined by a new dominant design, innovation occurs at some other critical or newly critical juncture (Langlois and Robertson, 1992). Over a period of time improvements at the higher product level appear continuous because “the discreteness of technological evolution is hidden in technological transitions at the component level” (Tushman and Murmann, 1998). They conclude that dominant designs are seen at the product level when all core subsystems are in periods of incremental change.

Tushman and Murmann do note that innovations at the component level can require system wide modifications. The development of jet engines for aircraft is an example since the innovation in engines required coordinated changes in airframe design and landing gear (Tushman and Murmann, 1998). Another example is the development of large computer systems (Iansiti, 2000). However, in these cases, the system itself is provided and organized by single firms. This is consistent with Teece’s (1996) conclusion that vertically integrated firms are better suited to innovation in these systemic technologies since they can coordinate investment decisions and information flows.
However, the demands of the technologies can outstrip the ability of firms to be successful integrators as the skills and knowledge required advance too quickly for a single firm to master them all. In such cases, innovation can arise from a network of firms (Powell, Koput et al., 1996).

Vertically integrated production systems are considered “closed” in that competition is between complete final products or components bundled and sold as a system. Competition based on components alone (where users can mix and match) is considered open (Farrell, Monroe et al., 1994). If systemic innovation is feasible under closed systems, it is much more difficult to achieve in open systems. To see why, consider the situation facing component-manufacturing firms in such an industry.

Assume that a strictly open production product system exists. Manufacturers provide components that are purchased and assembled by end users or value added retailers under competitive market conditions. The performance of any system is a function of the parts; specifically, the optimal performance is constrained by the performance of the worst or slowest component. For the purpose of discussion, let this system be composed of parts A, B and C. The system performance criterion is speed and we shall say that A is the slowest performing component as a class. Here I assume that all components have identical within class performance so that any combination of components is identical to another. Also suppose that consumers find higher performance desirable and that component price is a direct linear function of system performance. That is, consumers are willing to pay for additional performance but only for the system as a whole. For
example, if a change in a component produces a 10% increase in system speed, consumers will be willing to pay 10% more than for unimproved components.

Suppose that one of the suppliers of B or C discovers a way to improve the performance of its product but at the cost of some development and promotional expenditures. Should it undertake the development? Assume the innovation improves component performance but does not reduce component cost. Then, under the competitive market assumption, the firm should not engage in new development. This is an outcome of the system performance issue. If A is the bottleneck, then any improvement in B or C will not improve overall system performance. As far as any user is concerned, the improved component provides no additional benefit and any rival component would do as well. Since the new product is in a competitive market, the maximum price obtainable would be that of the rivalrous components—or the price it was getting for its non-improved product. Under these conditions, the firm could not recover its costs of development so it would not introduce. Firms producing B and C will not innovate unilaterally.

If a maker of A is the innovator, then introduction is feasible. However, noting the direct price:performance relationship, there is an upper boundary on price. If the improvement does not remove the performance bottleneck, i.e., A is still the slowest component, then the price reflects the improvement of A alone. If A is sufficiently improved to make another component the slowest (let it be B), then the performance of the system improves but not as much as A is improved. Thus, no consumer would be willing to pay for A’s
performance in total. The upper limit is the performance constraint imposed by B. If the returns under this pricing system are adequate, then A is introduced and the focus of innovation shifts to manufacturers of the B component.

A direct result is that under these conditions, system improvement proceeds in a piecemeal fashion, just as the literature would have it (Langlois and Robertson, 1992; Tushman and Marmann, 1998). No matter how significant an improvement at the component level might be, overall system performance is a function of the worst performing component.

Consider now the case where component providers desire to improve the performance of the overall system. This could occur as a result of competitive pressures, such as the emergence of an alternative, incompatible technology that offers superior performance. If the performance level of the alternative is high enough and valuable enough, both old technology users and potential new users could be persuaded to adopt (Shy, 1996). In order to remain competitive, the performance of the existing system must be significantly improved. While improvement can be effected in an evolutionary way as in the example above, if time becomes a constraint technology providers cannot afford to pursue sequential development. Innovation must occur across the system.

The obvious problem here is coordination. Improvements in all components are needed but unilateral development can confound interoperability. There is not necessarily a need to be backward compatible (though this could be advantageous) but it is essential that the
components of the new system be compatible among themselves. Under the simplest scenario, only one firm in each component group develops a new product. Since all are key to the system and no one provider dominates, market selection of a standard interface would be difficult. Coalitions of one or two firms have no payoff since all three are required so only an all-firm coalition has any payoff. The logical step is for firms that can collectively provide all of the requisite components to ally to develop a system that meets the new performance criteria. While they can choose to do so in a market environment as the JVC alliance did with VHS and the Toshiba alliance did with DVD (Cusumano, Mylonadis et al., 1992; Holyoke and Armstrong, 1995), a negotiated outcome may safer, quicker and more efficient. This is the rationale for formal standard setting organizations (Farrell and Saloner, 1988).

2.1.2 Standards and the standardization process

Standards are dominant designs with conditions of compatibility and are generally classified as de facto (market derived) or de jure (negotiated). The benefits to standardization include building direct network externalities, supporting the growth of complementary goods, developing a thicker second hand market and, as far as consumers are concerned, a higher level of price competition (Farrell and Saloner, 1985). The idea of network externalities is an important one in standardization for it considers the “connectedness” between users of a technology.
Network externalities mean that each buyer of a technology receives greater benefits as the user network increases in size. Examples of this include telephone service, fax machines and computer software written under a particular operating system. Similarly, support services for a product (such as the availability of mechanics for certain types of automobiles) can constitute an externality. Experience and learning are also examples: this knowledge is more portable and available to prospective new users the more widely the technology is adopted (Katz and Shapiro, 1986; Katz and Shapiro, 1992).

Related but not identical is the notion of a network market where externalities can dominate the emergence of winning products. Network markets are also known as increasing returns markets (Arthur, 1989) and differ significantly from more conventional decreasing or constant returns markets. In particular, they are “tippy”: network markets are not shared but rather end up with several potential equilibria, which are generally corner solutions. In other words, incompatible contenders in such markets will not find a stable interior solution where both coexist in the market. One will fail. Also, historical events are not averaged away but matter in the ultimate outcome. As Arthur notes, increasing returns markets magnify chance events and are unpredictable (Arthur, 1989). This tippiness implies that network markets are disposed toward the emergence of de facto or single winning technology standards unless de jure standards are established first (Katz and Shapiro, 1994).

If we assume that users of a technology are forward looking, their purchase decision will be affected by how they perceive the market will turn out. There are two contrasting
effects to be considered. At the outset, buyers may be reluctant to adopt a new technology in a network market since the value of their choice depends on the choices others make later. Rational expectations models sometimes generate the result that no buyer moves to the new technology no matter how attractive it may be. This may happen because buyers will purchase a new technology only if private benefits exceed the cost of purchase. Benefits are derived from the standalone value of the product and its network value (Kristiansen, 1998) If there are no other users in the network, it is irrational to make the first purchase if the standalone value does not exceed purchase price. Another cause is the fear potential users have of adopting the wrong technology and being subsequently stranded. This problem is termed “excess inertia” (Katz and Shapiro, 1994).

Excess momentum can also occur. Prospective adopters may flock to a new technology without regard for the costs imposed on users of an existing technology. This occurs for several reasons: first, the new technology may offer advantages over the old even though a network has not been fully established (Farrell and Saloner, 1986). More precisely, the new technology will be adopted if the utility of the innovation, even with the reduced effect of a small network, exceeds the utility of the old technology with optimal network size (Shy, 1996). Second, if the technologies are regarded as substitutes rather than complements, such small network adoption can occur (Shy, 1996).

The tension between inertia and momentum and the prospect of a winner-take-all outcome tends to make pre-standard competition in network markets fierce with tactics such as penetration pricing and product pre-announcements used to sway or hold up user
selection (Farrell and Saloner, 1992; Besen and Farrell, 1994; Katz and Shapiro, 1994). These latter tactics are characteristic of sponsored technologies where property rights are retained by the firm that invented or controls the technology. These firms are typically willing to make investments in the dissemination of the innovation. Unsponsored technologies are usually the state of markets where critical patents have lapsed and products are sold by a number of firms on a competitive basis (Arthur, 1989). Successful sponsorship, especially in system products, means that externalities are internalized and firms secure some of the benefits otherwise distributed to users. Much of the earlier work done in the economics of standardization has focused on the case of competition between sponsored and unsponsored technologies. Sponsored innovation tends to get adopted over rival, unsponsored products because of the difference in ownership rights. That is, firms supplying products in a competitive market have no incentive to incur the costs of battling the tactics of a sponsored technology due to free ridership problems. Absent \textit{de jure} product standards, firms have an incentive to invest in sponsorship of a new technology to weaken established rivals and develop a new \textit{de facto} standard (Katz and Shapiro, 1986; Axelrod, Mitchell et al., 1995).

One of the key choices a firm with a new technology can make is that of compatibility with existing technologies or with competing new technologies. Compatibility can create demand side economies of scale through interchangability of competitive products and ease of communication. It can also reduce buyer costs (Farrell and Saloner, 1986). For
consider the intra-technology coordination between firms with respect to compatibility choice. Effective coordination usually requires more involved processes than spot market contracting (Katz and Shapiro, 1994).

Intra-technology compatibility through recourse to market competition is possible but this does not assure that any technology wins, due to widespread excess inertia. On the other hand, if one technology is successful, supporters of the other technology can be devastated. An increasingly common alternative to market based outcomes are de jure standards, which result from compromise among interested parties about technology features and attributes. Standard developing organizations such as IEEE, ANSI or ISO (International Standards Organization) debate and issue standards that detail how products should perform and, in cases of interconnectivity and interoperation, how these should be accomplished. In the next section, I describe the function and structure of SDOs, the causes of institutional failure and how firms have managed innovation and standardization under those conditions. This is done in the context of the Ethernet industry.

2.2 SDO’S, INSTITUTIONAL FAILURE AND THE RISE OF FACILITATING CONSORTIA

2.2.1 Roots of SDO failure

In this section, I propose that limited scope consortia arose initially as a response to potential institutional failure but that subsequent uses of the approach are based on early
success as a template. LSCs emerge from specific SDO environments and are designed to address specific technology implementation problems and as such, they differ from more permanent consortia that exist outside the SDO environment. There are a number of ITC industry groups designed to have a longer life and address a broad range of technical issues, mostly from a developmental perspective. Put differently, these long-term groups are interested in generating a class of technological architectures while LSCs are interested in implementing a particular approach.

Firms resort to institutional coordination to minimize market failure problems (Farrell and Saloner, 1988; Hawkins, 1999). Institutions can take the form of de facto standard setting alliances in markets where no formal standardization is present (Cusumano, Mylonadis et al., 1992; Gomes-Casseres, 1997), as alliances outside the SDO created to address general concerns and emerging technologies (Genschel, 1997; Hawkins, 1999) or as focused, limited scope groups initiated to solve particular problems within the context of a standard development organization. The latter case is evident in the generation of anticipatory standards.

Standards development organizations have been operating for about a century and have moved from an early concern over a wide range of standardization issues on a national level to industry oriented organizations, often in an international context. Today there are approximately fifty SDOs operating in telecommunications alone (Genschel, 1997). SDOs are usually organized around principles designed to facilitate open exchange, which includes an emphasis on due process, ordered and transparent debate and
participation, consensus among stakeholders with regard to decisions and voluntarism (David and Shurmer, 1996). Organizationally, the SDOs are structured around committees and work groups composed of engineers who develop and submit the proposed standards. As David and Shurmer (1996) note, the underlying ethos in this approach is a “strong belief that engineers could find a unique solution which...represented the best of the technical options (and) would be agreed upon by all parties.” This is not to suggest that standards organizations are apolitical since voting members are often also employees of competing firms. Farrell, Menroe and Saloner (1994) argue that this is one reason standards organizations are considered slow to resolve problems.

The intellectual property issues in standards setting has the potential to be disruptive but many SDOs have developed a way to circumvent it. Cooperation is improved in multiplayer games if side payments are permitted as they enable firms to reduce the risk in the form of variance in return on investment. The usual way this is accomplished is through an explicit agreement that firms successful in having a key technology central to a standard will license that technology at low rates. Since all firms that desire it have access to a technology, licensing increases the number of firms with a direct interest in promoting the new standard and also promotes sharing of information between firms (Katz and Shapiro, 1994; MacInnes, 1994).

Standardization in advance of general market introduction is used to prevent problems with excess inertia but the nature of SDO structure and process can generate problems.
First, the consensus rule means that incorporation of new or radical technologies can be time consuming due to uncertainty over functionality. Second, the deregulation of the ITC industry and the concomitant growth in the number and diversity of SDO participants means that consensus under any circumstances is more difficult to achieve (David and Shurmer, 1996). Some participants care much more about outcomes than do others and it is the latter, according to Genschel (1997), that have the power. Because they are needed to generate sufficient majority, they can hold out for more favorable terms or play bargainers against each other. This can generate obstructionism and opportunism. Finally, participants with strong preferences reflecting specific firm assets or resources can mean that voters are less willing to compromise. New standards that eliminate particular approaches can put firms at a competitive disadvantage relative to those whose resources are supported by the standard (Genschel, 1997). As a general rule, when the perceived mutual gain from a universal standard is low, the speed of standardization decreases (David and Shurmer, 1996).

Put differently, participants in standards setting may anticipate institutional failure when they believe that the SDO process will fail to deliver a standard in the time frame needed or that compromise and consensus will deliver the “wrong” standard. The process has been described as unstructured and as such, makes it “nearly impossible to set tight schedules and to adhere to them” (McCarron, 1998). When time is important, Farrell and Saloner (1988) also show that a hybrid model is the best performer: “while committees are better than the pure bandwagon system, they are even better if they can be subverted by preemptive action outside the committee”. Although they present no examples of such
subversive action, they note a potential solution in explicit inter-firm cooperation to facilitate the development and adoption of a product system standard either through a separate standards organization or, conceivably, as a standalone effort (Farrell and Saloner, 1988). A general sense that SDOs were subject to failure has led to the growth of many private groups organized to craft proprietary standards. Often, these are delivered to SDOs as *de facto* standards that are subsequently “rubber stamped” (David and Shurmer, 1996; Hawkins, 1999). There is a wide range of such organizations, some of which have been in existence for decades.

Current research tends to call all of these private groups “consortia” and the term includes R&D focused groups, industry associations and, under some circumstances, other SDOs (David and Shurmer, 1996; Genschele, 1997; Hawkins, 1999). While potential institutional failure may be a factor in the emergence of such consortia, it is not a specific cause. For instance, industry trade organizations may include a role or perspective on standards in their ambit but this is not the sole reason for being. Similarly, groups like the ATM Forum and Optical Internetworking Forum are organized under the 1993 National Cooperative Research and Production Act where the emphasis is on pre-competitive research and development. The key characteristic here is that these groups are not organized as a specific response to failure in an SDO but operate in parallel with them. Often, as is the case with ECMA (the European Computer Manufacturers Association), they provide recommendations to a number of SDOs. Moreover, these are permanent organizations in the sense that their function is open ended or at least long term. For example, ECMA has been in operation for about forty years and the ATM Forum is ten
years old. While there are many more such groups than there are cases of LSCs, failure to differentiate between the types is to overlook a relatively new but growing method for handling problems of institutional failure. The events surrounding the development of 100Mbs Ethernet provide a good illustration of how LSCs emerge and operate.

2.2.2 Ethernet and limited scope consortia

PC based networking was introduced in the early 1980s by a number of firms with, usually, proprietary schemes. An exception was Ethernet, which was advanced as an open architecture that vendors could access for a small one-time fee (for more information on networking, see Appendix A). By the early 1990s, Ethernet accounted for approximately 80% of node installations (Fisher, 1994). While Moore’s Law has been widely adopted as a metric of the pace of change in the microprocessor industry and high technology areas generally, demands placed on networks are growing even more rapidly. As one industry expert observed in an interview, network demand was a function both of numbers of computers placed on the system and the type of data each node was using. The late 1980s introduction of the 80386 microprocessor and the related introduction of Microsoft Windows increased the number of high-powered nodal computers. These events also led to the generation of more data rich applications including CAD/CAM, email, rich text documentation and video streaming and conferencing. Internet usage had been doubling every year and, in the midst of the Fast Ethernet development, the introduction of graphical browsers drove usage of the Internet up by over 1000% for several years (Coffman and Odlyzko, 2000).
Because of the problem of speed, several technologies that had the potential to compete with Ethernet were being developed. In 1993 ATM (asynchronous transfer mode) emerged as a possible alternative to local networking because it promised transmission speeds of up to 630Mbs for backbones and 25Mbs to the desktop. Interestingly, one of the primary backers was IBM, which had previously promoted the Token Ring technology. ATM was not compatible with existing LAN technologies but the promise of dramatically higher speeds was prompting some industry observers to forecast this as the new networking backbone, replacing Ethernet. Further, FDDI (fiber distributed data interface) had not only been incorporated in backbones but was being pushed as a possible desktop solution in itself (Didio, 1992).

Firms in the Ethernet industry responded in late 1992 with several proposed methods for solving the speed problem. Early on, three approaches were being considered with the earliest coming from a partnership between Hewlett Packard and AT&T. The other major contenders were the startup Grand Junction, led by former 3Com executives including Robert Metcalfe, the creator of Ethernet (Didio, 1992; Panettieri, 1992) and a coalition forming around the work of LAN Media. That group included 3Com, SynOptics and Intel, all major players in the existing Ethernet market (Didio, 1993). When the proposals were floated at the IEEE committee charged with Ethernet standards (committee 802.3), participants were cognizant that they couldn’t “afford to let their standards efforts get mired in the hair splitting debates that have characterized previous 802.3 committee efforts”. One participant specifically noted that the window of opportunity for development of a 100Mbs system was estimated to be a year and that
argument among the members would be self-defeating (LANTimes, 1992). Failure to enter the market on time would be risking loss of opportunity to FDDI advances (Didio, 1992).

That tentative rapprochement soon broke down as the rival camps split over whether the new standard should include the existing Ethernet media access control protocol (CSMA/CD) or a new approach called priority scheduling, which was the HP/AT&T preference. A vote on whether to include CSMA/CD as the basis for development failed to pass as only about a third of the voters assented (Didio, 1993). The conflict over CSMA/CD was a major issue for the MAC protocol defines how the network operates and the two systems were incompatible. Recalling Farrell and Saloner’s (1988) observation about the politicization of the standards process, it is interesting to observe that initially, neither technology was to be handled in the 802.3 committee but were instead assigned to new groups. While this was understandable for AnyLAN given the technological foundation, most participants found the decision to move the Fast Ethernet group less palatable. A number of industry commentators noted that this outcome was strongly influenced by the fact that the 802.3 chair was an employee of HP (Didio, 1993; Gold, 1993).

Thus, demand was high and expected to grow, the window of opportunity perceived to be brief and there were strong and contrary positions being held by participants at the outset.
of the standardization of 100Mbs network development. These are the conditions that could lead to stalemate and delay in the development of a consensus on the product. I propose:

*Proposition 1: LSCs will be more likely to form when participants face the threat of institutional failure*

IEEE committees begin work on standards based on the research of Study Groups, which are formally sanctioned groups within a committee charged with refining information about a technology and preparing a PAR (project authorization request) (IEEE, 1998). Generally, the committee anticipates a single PAR from study group work but in this case, the 802.3 High Speed Study group was unable to agree on a single technology (Didio, 1993). The CSMA/CD versus priority scheduling debate was intense and acrimonious for several reasons. First, a compromise standard would have been difficult to implement given that the data conflict resolution methods could not be used simultaneously in a network (Fisher, 1994). Second, both groups had committed resources in pursuit of their favored technology. For instance, the CSMA/CD group argued that the substantial industry experience with the protocol would result in fiercer competition, based on the ability to leverage existing silicon designs for NICs and hubs (Didio and Caron, 1993). In other words, CSMA/CD advocates were strongly asymmetric in their experience with the relevant technologies and faced a learning period if the
AnyLAN approach was the sole standard. One executive observed that proposed standards that give one faction a time to market advantage tend to stimulate a counter response, which happened here.

Finally, even though there were 20 million Ethernet nodes in existence, the participants were split on the relevance of the installed base. AnyLAN proponents had not designed any bridging silicon that would let AnyLAN and Ethernet hubs communicate and this was a potential problem. Most participants agreed that user demand for 100Mbs networking was not uniform (Didio, 1992). While many on a network could manage with the 10Mbs version, some users would find the faster version extremely valuable. Given the different wiring requirements (four pair versus two pair) for AnyLAN and the fact that the MACs were not identical, support of the high end users would require a parallel network rather than selective replacement of network interface cards and hubs. On the other hand, Fast Ethernet would require only a switching hub and new NICs for the relevant terminals. This meant that Fast Ethernet installations could be viewed as a simple migration strategy for enterprises. Some viewed the AnyLAN proposal as opening doors for other technologies and a termination for Ethernet products by those users.

Once it was clear that the positions were irreconcilable, at least in the short term, the 802.3 committee authorized two PARs and established two working groups to generate them. As noted earlier, AnyLAN was developed in IEEE 802.12 and though the intent was to put the CSMA/CD camp in another committee as well, that working group was convened under 802.3 by December of 1993 (Roberts, 1993). In August 1993 the
members of the Fast Ethernet working group formed the Fast Ethernet Alliance (Caron, 1993) and in March of the following year, the 100VG-AnyLAN Forum was organized (Dryden, 1994). The objective of both of these groups was to foster interoperability, speed formal standardization and lobby for support in the user community in anticipation of product introduction. Consistent with this discussion, I propose that:

\textit{Proposition 2: LSCs will be more likely to form around single technology architectures}

Closely related to this proposition is the maturity of the technology solution itself. Although both Fast Ethernet and AnyLAN came out of the 802.3 study group, it is not always the case that such advancement represents a mature enough technology to standardize. That is, there are cases where the technology is in such a state of change that standardization is difficult to coordinate. One executive interviewed compared the Ethernet position to wireless LANs (another IEEE committee effort, but one that required six years for standardization). In the case of wireless LANs, emerging global positions on frequency choice and changes in technology made the standard a moving target and participants were unable to come to agreement. In Ethernet, the technology that emerged from the study group effort was well defined and could be implemented fairly quickly. I propose that:

\textit{Proposition 3: LSCs will be more likely to form around well-defined technology architectures}
To this point, the description of how LCSs form exhibits many of the characteristics Doz, Olk and Ring (2000) ascribed to emergent consortia. In that paper, interdependencies such as the need for agreement on standardization or common threat by environmental change were argued to drive the formation of R&D consortia. Specifically, there is no central node and “no one single entity creates the collaboration” while engineered organizations require a triggering entity or champion to organize the process (Doz, Olk et al., 2000). One of the propositions their research developed was the expectation that emergent networks would terminate sooner than would those created by an engineered process. This earlier mortality was attributed to the premise that emergent coalitions draw together firms with similar interests, generally from the same industry. When the need for standardization or the environmental threat is resolved, the need to collaborate diminishes and the consortia terminate.

This expectation is consistent with the history of LCSs in the Ethernet industry. The Fast Ethernet Alliance dissolved itself in September 1995, roughly two years after formation. The reason provided by the alliance was that the objectives had been accomplished but some members claimed that competition inside the group had grown too fierce (EETimes, 1995). The Gigabit Ethernet Alliance was formed in 1996. The IEEE 802.3 passed one version of the standard in June 1998 and the last version (Gigabit Ethernet over copper cabling) in 1999. Finally, the 10Gigabit Ethernet Alliance was formed in February 2000 and the GEA was terminated shortly after.
That the alliances terminate so quickly should not be surprising. Participating in SDOs is not free of cost as it involves dues, the time engineers and other representatives spend on SDO projects as well as other, related events (Rosenkopf, Metiu et al., 2001). There are additional costs to participate in LSC activities. The dues for steering committee members in the Gigabit and 10Gigabit Ethernet Alliances are $20,000 per year. Moreover, the participation level is higher: as one industry respondent put it, since the IEEE 802.3 committee meets just three times per year, the Alliances can get a great deal accomplished due to a more frequent meeting schedule. In other words, LSC activities impose additional governance cost on the innovation process. Since the purpose of alliance activities is the joint creation of value (Nootboom, Berger et al., 1997), the cessation of relevant activities generating value means that only governance costs are incurred and there is no longer a reason to make the expenditures. In contrast to the way non-SDO oriented consortia operate, I propose:

*Proposition 4: LSCs will dissolve when they are successful*

Finally, experience with LSCs may moderate the effect of anticipated institutional failure. Being typically of short duration, the LSC experience provides quick feedback on the efficacy of the approach to solving innovation and coordination problems. While much of the literature about learning and alliances has focused on what firms learn *from* partners there is relatively little about what firms learn *about* the alliance process. It has been demonstrated that, especially in research oriented alliances, firms learn to generate value
through repeated alliance experience (Anand and Khanna, 2000). If so, experience may allow firms to discern and employ alliance opportunities where they might not have before.

The data from the ITC industry are encouraging in this regard. The Fast Ethernet Alliance was, according to industry executives, a response to incipient institutional failure. The Gigabit Ethernet Alliance (GEA) may have been as well: both Ethernet and AnyLAN proponents made gigabit technology presentations to the 802.3 committee in January 1996 (Wirbel, 1996). However, AnyLAN has essentially disappeared and Hewlett-Packard became a member of the GEA. Most recently, the 10Gigabit Alliance formed simultaneously with the establishment of the sole working group in the 802.3 committee. Table 1 lists the founding members of all three alliances and it is noteworthy that there is a high degree of carryover from one generation to the next. Perhaps most telling is the involvement of Cisco and 3COM as founders of similarly focused groups outside Ethernet specific efforts. Both are founding members of the Virtual Private Network Consortium, the iNOW! Group dedicated to interoperability among IP based telephony vendors and the wireless LAN group WECA. These organizations are all involved with managing the basic interoperability problems among vendors under prospective or evolving standards. Given this recent history, I propose:

*Proposition 5: prior successful experience will lead firms to form new LSCs even if institutional failure is not anticipated*
CONCLUSION

The purpose of this essay was twofold: to strengthen the link between the innovation and economics literature on the locus of innovation and to explore the role of LSCs as an adjunct to formal standardization. The innovation literature has almost exclusively focused on the firm as the engine of innovation. However, developing and introducing complex products or those comprising hierarchies of components often requires resources outside the domain of a single firm. Powell, et al (1996) found that these resources are often knowledge or skill based and that innovation can come from a pooling of abilities. In this essay, the disparate knowledge and abilities of firms play a role in deciding what to do but the physical coordination of interoperation and compatibility define how to bring products to market.

Faced with the need to cooperate to bring a full system to the market, firms in open production industries cooperate or ally to solve the coordination problem and establish a common method for manufacture. While this is sometimes pursued through market competition between alternate approaches, firms increasingly turn to negotiated outcomes under the auspices of standard developing organizations. Simply put, when innovation is no longer in the purview of single firms, broader governance is created to manage the process.

The SDO process is often faster than market battles (Farrell and Saloner, 1988) but it is, as Genschel (1997) observed, subject to a set of problems that can stymie standards
passage. Deregulation and technological advance have not only increased the number of projects SDOs face but also the number of participants. To the extent that voters politicize the process, delay can be common. From the perspective of firms with strong interest in particular outcomes, this can lead to two problems. First, the standard may be too late to fend off the advances in substitute technologies. Second, if the positions inside the SDO are extremely polarized on technical issues, compromise will likely be perceived as disadvantageous for at least one party. This threat of institutional failure leads firms to implement limited scope consortia in pursuit of a quicker, stronger standard.

LSCs organize to resolve the problems of performance and interoperability among the components produced by the members. This is a necessary condition for the passage of a standard. LSCs also pursue market activities in support of the incipient standard. For instance, the FEA was conspicuous in describing Fast Ethernet as an evolutionary change in technology. While Tushman and Anderson (1986) would describe the Fast Ethernet order of magnitude improvement in performance as a significant innovation, the objective of the FEA, according to an industry executive, was to reassure customers and provide a migration path for upgrades by minimizing the scope of the change.

More recently, it appears that prospective institutional failure is not a necessary condition for the formation of LSCs. Given prior success with the model, firms may be allying through LSCs for the sake of efficiency in the sense that the model worked well before and will again. On the other hand, early moving firms (especially powerful ones) may be
using LSCs as a means to generating speedy standards proposals for endorsement by the relevant SDO, thus leveraging a formal process for \textit{de facto} standardization. While some of the executives interviewed for this essay regard this as the case, it is also true that SDOs are not apolitical. Whether the coalitions are inside or outside, it is still consensus at some level that drives the process.

There are some interesting areas for further research in LSCs and their relationship to standards generally. Primarily, there is some evidence that LSCs are fitting into a larger approach to how firms manage standardization. While LSCs typically work with well-defined technologies, this begs the question of how that definition came about. Often, preliminary work is done in R&D consortia. The Fast Ethernet Alliance, for example, borrowed heavily from work done in FDDI research and applied it as a crucial component in its own solution. While this may have been fortuitous timing, recent efforts have been more deliberate. Cisco and 3COM were founders of the Optical Internetworking Forum, a group organized to investigate and resolve some fundamental issues with high-speed optical data transport and integration of local and wider area networking. This group also issues publicly available specifications (PAS) for SDOs to use in their work, one of which is being used by the IEEE 802.3ae 10 Gigabit Ethernet committee. Cisco and 3COM are also founders of the 10GEA, the consortium developing the standard in conjunction with 802.3. It will be interesting to inquire if the old model of R&D consortium in the ITC industry, which undertook research, wrote PAS and coordinated interoperability and practical development, is being replaced by a decoupled system where firms collaborate to manage stages.
If the *de jure* standards process emerged from a desire to avoid the problems of market determination and failure, it is a useful but occasionally imperfect solution. Potential institutional failure can lead firms to generate intermediate and adaptive forms of governance. Moreover, these alliances may transition from response to preemptive solution. Recent history seems to indicate an uncoupling and externalization of the standards process. If so, it would be odd but true that the standardization in this industry is coming to resemble its own complex, open products.
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<td>Grand Junction</td>
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<td>LAN Media</td>
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<tr>
<td>National Semiconductor</td>
<td>Cisco Systems(^2)</td>
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<td>Standard Microsystems</td>
<td>UB Networks</td>
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<td>Sun Microsystems</td>
<td>Packet Engines(^1)</td>
<td>World Wide Packets</td>
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<td>Extreme Networks</td>
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Note 2: Cisco acquired Granite Systems in 1995 and entered the FEA.

Note 3: Packet Engines was acquired by Alcatel in 1998. Bernard Daines, the founder of Packet Engines left the company shortly after the acquisition and formed World Wide Packets.

Table 2.1: Founding firms of the Ethernet Alliances
CHAPTER 3

INTRODUCTION

Over the past seven years, the network products industry has experienced significant growth and consolidation. According to recent networking industry online summaries from Tech Fest and Converge Network Digest, approximately 200 acquisitions have been consummated since 1993. Of these, more than half of the acquisitions have been made since the beginning of 1999. By 2000, the mid 90’s Big Three of Cisco Systems, 3Com and Bay has been replaced by a new Big Six: Alcatel, Cisco Systems, Ericsson, Lucent Technologies, Nortel Networks and Siemens AG.

One often cited reason for the surge in acquisitions is the rate of innovation and the difficulty incumbents have in keeping up with development (Hatlestad, 1997; Rogoski, 1997; Donnelly, 1999). This industry is marked by significant, sometimes radical, innovation efforts, which have both increased network transmission speeds by several orders of magnitude over prior art and generated new technologies in the process. To achieve this level of performance, new technologies for use in local and wide area networks (LAN and WAN, respectively) are borrowed and modified from other industries, such as telecommunications. Each stage of innovation sees the florescence of startup firms, many staffed by former employees of industry incumbents and it is these
firms that provide the impetus for change through leading technologies. A critical feature of the LAN/WAN industry is the reliance on standards or commonly agreed protocols and methods of interconnection and interoperability. Since the candidate technologies generally have diverse approaches to the problems, this implies that not all proposed solutions will survive or even find their way into the market. As one Cisco executive put it, “we don’t believe we are smart enough to know all the important technologies over the next few years. You pick some, and then watch the industry” (Rogoski, 1997).

Such technical change increases uncertainty and risk in forecasting which solutions will emerge as winners. The proliferation of possible solutions implies that internal development of suitable new products requires some investment gamble on what outcomes will emerge before markets and costs are accurately estimable (Bettis and Hitt, 1995). This level of change also has the capacity to make the capabilities of industry leaders obsolete by virtue of its novelty: to the extent that firms are not experienced with a new technology, they are handicapped in the imitation and implementation of new products (Tushman and Anderson, 1986). To the extent that firms cannot or prefer not to undertake multiple research streams simultaneously, this becomes a high-risk approach.

These difficulties provide one explanation for the growth in acquisitions: firms are outsourcing R&D by buying it in the form of technologically leading companies (called by some A&D: acquisition and development). The approach has been characterized as “buy the product, buy the engineers, and get a faster time to market”, letting the venture
capital backed startup firms develop new products “on their nickel”. Incumbents subsequently choose and purchase from among those that have developed winning or at least promising products (Donnelly, 1999).

This combination of uncertainty and technological innovation seems to be a good testing ground for contrasting the use of real options and transaction cost economics approaches to managing the problem. When the real options literature has addressed the use of options between firms, it has focused on the deployment of joint ventures, equity or alliances as first stage investments that are, when uncertainty is resolved, struck through acquisition or abandoned. From a transaction cost economics perspective, this is exactly opposite what should occur: given transaction specific investments, acquisitions should occur when uncertainty is high. This leads to mutually incompatible hypotheses about likelihood and timing of acquisitions as uncertainty over outcomes changes.

In this essay, I inquire into whether the pattern of investment and acquisition in the network products industry fits either framework. I show that if intermediate investment in the form of minority equity or alliance is considered the option investment, mutually exclusive hypotheses about acquisition timing and likelihood under the transaction cost and real options frameworks can be developed and that the results fail to support the real options framework. That is, acquiring firms do not appear to be using these investments for the purpose of real options but do appear to be acquiring in a fashion consistent with a
TCE interpretation. However, if the notion of what constitutes an option investment is expanded to regard the acquisition as that investment, then the pattern of acquisitions is consistent with both the real options and transaction cost perspectives.

This research contributes to the literature in several ways. First, it adds to the innovation literature by exploring an alternative survival mechanism in the face of significant change. This research also contributes to the real options and transaction cost literatures by illustrating how a conflict at one level of analysis can be resolved at another.

3.1 THEORETICAL BACKGROUND AND HYPOTHESES

3.1.1 Literature Review

Innovation is undertaken to reduce costs, improve performance or both. It has been argued that technological changes are generally continuous in that they reflect a path dependent and cumulative development. Solutions to problems emerge from prior work at both the firm and industry levels. Dosi (1988) has described this as a technological paradigm or pattern of inquiry. A particular implication of path dependency is that a firm’s innovative efforts are strongly conditioned by experience, which constrains the ability to freely, and easily develop or imitate innovations.

Such continuous change is described as incremental or regular and occurs when product designs are stable. Incremental change tends to reinforce the market power of incumbents because it utilizes existing competencies in development and can be deployed through an established set of sales and marketing resources (Abernathy and Clark, 1985; Anderson
and Tushman, 1990; Teece, 1996). Discontinuous change, on the other hand, can be very disruptive. These innovations often develop outside the established paradigm or technological trajectory and result in large shifts in the cost or performance characteristics of competitive products. To the extent that the innovation embodies a new technology or new approach, incumbent firms are handicapped in responding as innovation within a paradigm entails an opportunity cost in that alternative paths are not explored. In the face of a novel approach, incumbents may have little or no relevant development history to draw upon (Dosi, 1988).

The introduction of a discontinuous innovation often spurs imitations and alternatives as firms seek to not only respond to but improve on the new product. This “era of ferment” usually revolves around competition between product alternatives and is resolved when one version of the technology emerges as a dominant design (Tushman and Anderson, 1986). The emergence of this design implies that other contending designs have failed or are at best consigned to a minority position in the market. This distinction is starker in increasing returns or standardized markets where only one version of a technology prevails and others are not supplied at all.

When a new generation of technology is introduced, firms that decide to adopt must also decide when to do so (Lawless and Anderson, 1996). Timing of introduction can be critical: empirical evidence suggests that the original discontinuous design rarely emerges as the winner (Tushman and Murmann, 1998) so firms committing to a design approach early face a higher risk of failure than do somewhat later entering firms (Christensen,
Suarez et al., 1998). Audretsch found that early entrants failed more frequently in highly innovative industries than later entrants but that if they could survive for several years, subsequent survival rates improved significantly (Audretsch, 1995). On the other hand, waiting is also risky. Under certain conditions, entering a market late but on budget is far inferior in terms of profit compared to entering on time but significantly over developmental budget (Ali, Krapfel et al., 1995). Similarly, an investigation of the personal computer industry found that late entrants experienced lower performance in terms of market share (Lawless and Anderson, 1996). The risk is not limited to eroded profits and share: firms that have succeeded in the design conflict appear to gain some early mover survival advantages relative to late entering incumbents (Mitchell, 1991; Christensen, Suarez et al., 1998). Christensen, Suarez and Utterback (1998) in particular found that survival was a U-shaped function with firms entering just before a dominant design emerged being less prone to failure than either earlier or later entrants.

The decision of when to enter is not independent of other factors. In choosing timing, a firm also chooses which technology to adopt and how it is going to be developed. These are functions of the history and capabilities of the firm and uncertainty over outcomes. Put another way, the choice is over internal and external development and the primary issue is not just whether the technology can be produced internally but whether it can be done quickly enough (Chaudhuri and Tabrizi, 1999). For minor or incremental innovations, the choice is generally not difficult since, by definition, these are technological changes that are close to the current trajectory. Firms in production of prior technologies already know a great deal about how to proceed.
Under conditions of radical or significant innovation, choosing to develop internally is more difficult. The technologies that comprise the innovation are likely to be very different from the skills previously assembled in the firm. Since the ability to experiment in novel fields is strongly related to experience, a dearth of experience makes learning difficult (Iansiti, 2000). This is complicated by the possibility that multiple approaches to the innovation exist. For example, in the currently developing optical switching field, candidate technologies include micro-electro-mechanical systems (MEMS) which are arrays of mirrors “grown” with mechanical capabilities and waveguide switches incorporating liquid crystal applications. A third emerging technology combines waveguides with inkjet technology (Bishop, Giles et al., 2000). All are very different from the current electro-mechanical switching devices that characterize the current state of the art in the industry.

Spillovers in terms of what solutions other firms are developing may spread quickly in an industry but the ability to imitate does not necessarily develop as easily. Imitation and emulation are creative efforts and become more costly as the importance of tacit knowledge relevant to the innovation increases. Having made long term and irreversible commitments to competence in certain domains, what a firm can develop in the short run is constrained by those commitments. (Dosi, 1988; Teece, Pisano et al., 1997). This path dependency means that firms need to re-invest in order to acquire the relevant skills and knowledge to compete in the new technology. This is hampered by a number of factors.
First, prior success in developing competencies may block firms from adjusting to the new environment. Leonard-Barton (1992) noted that these competencies exist on several levels including skills and knowledge, management systems and institutional values. Projects closely aligned with existing knowledge are better enabled by the managerial systems and values (hence, more likely to succeed) but for development that differs greatly from existing knowledge, the former competencies may become rigidities or barriers to performance. Leonard-Barton found that some firms faced with this conflict abandoned the projects or re-conceptualized them to be more familiar and less threatening (Leonard-Barton, 1992).

Even given the awareness that the current skill set may be insufficient and that new knowledge must be acquired, developing sufficient internal resources may be difficult. To the extent that the requisite knowledge is tacit, it becomes costly and difficult to develop (Cohen and Levinthal, 1990). The resources may not be easily tradable or accessible in the market (Teece, Pisano et al., 1997; Nagarajan and Mitchell, 1998). If time to market is a factor, re-training or educating current firm technologists may not be feasible.

Finally, firms entering innovation battles early face uncertainty not only in the costs of proceeding with development and manufacture of the product but also a more fundamental uncertainty over which technology or solution will prevail (Dixit and Pindyck, 1994) which Dosi describes as strong uncertainty (Dosi, 1988). If the technologies in question are well known and all industry players have access to them.
uncertainty is relatively low. At the other end of the innovation continuum, the use of new and sometimes still developing technologies as the basis of an innovative advance (as often occurs in computer, electronics and defense technologies) increases uncertainty substantially (Shenhar, Dvir et al., 1995).

Since investments in R&D are regarded as irreversible (Dasgupta, 1988; Teece, Pisano et al., 1997), firms are sometimes reluctant to invest under high uncertainty, leading to development delay (Ali, Krapfel et al., 1995). Risk averse managers would prefer to avoid such uncertainty because the possibility of having no R&D outcome is increased (Morris, Teisberg et al., 1991). This is exacerbated in increasing returns markets, as initial investments in design and development tend to be high and outcomes often beyond the control of the firm. In these cases, inferior technologies may win and the returns to the superior (but unsuccessful) technology are not only the loss of investment but at least a delay in participating in the market with the winning technology (Arthur, 1996).

The “window of opportunity” for entry summarizes the dilemma incumbent firms face in developing an answer to a discontinuous innovation. Choosing a technology only when it is a clear winner is certainly less risky from a technological perspective but may subject the firm to unacceptably high risk of failure or marginalization due to the head start competitors have. On the other hand, the novelty of the innovation means existing knowledge stocks are not sufficient so new knowledge must be developed. Moving to enter the market in a timely fashion means that firm must choose and invest in a new technological path under conditions of high uncertainty.
This may explain why firms frequently turn to external sourcing, particularly acquisition, in an attempt to access new technology (Hitt, Hoskisson et al., 1990; Chaudhuri and Tabrizi, 1999). In the following section, I contrast real options and transaction cost theories of the conditions under which we should expect acquisitions to occur.

3.1.2 Real options

Choosing whether to wait or commit to development should depend on how the firm values the project. The tool most frequently used to evaluate investment opportunities is the net present value (NPV) of the proposal. This requires calculation of revenues and expenses and selection of a discount factor over the relevant time frame. Dixit and Pindyck (1994) argue that the primary drawback to this method is that most investments are irreversible and that the timing of investment is assumed to be “now or never”. This has two effects: first, the decision to make an irreversible investment kills the option to wait until outcomes are clearer. Second, the decision usually entails an opportunity cost in options not explored. The ability to delay an investment can affect the subsequent valuation of the project or alternatives as uncertainty decreases.

Real options theory presents an alternative to the wait/fully commit dichotomy. Real options are an extension of the familiar financial option wherein an investor in a financial option spends a small amount at one time to purchase a right to buy or sell a financial instrument later when uncertainty about the value of the instrument has been resolved. By
making small investments in internal and external technology opportunities pending the resolution of uncertainty, firms can hold an option on future development and capture the same sort of benefits. These are considered “real” options in that they are investments in physical assets or knowledge generating processes (Bowman and Hurry, 1993; Dixit and Pindyck, 1994; McGrath, 1997).

As McGrath (1997) notes, “the distinguishing characteristic of an options approach lies in firms making investments that confer the ability to select an outcome only if it is favorable”. If the outcome is unfavorable, the real option, like a financial option, can be allowed to lapse with the downside risk equal to the relatively small initial investment. Also like financial options, the value of real options increases with the variance of expected returns on the underlying asset. In high volatility regimes, the best course is to hold the option but when volatility decreases, striking the option may prove more valuable (Bowman and Hurry, 1993; McGrath, 1997). As such, taking options early in a product life cycle under radical innovation can prove an effective hedge against selecting the wrong technology (McGrath, 1997).

Dixit and Pindyck (1994) have identified technical and cost as types of uncertainty firms face in considering investment decisions. Technical uncertainty addresses the time, effort, and materials required to achieve success as well as the probability of that outcome. This, they argue, can only be resolved through actually undertaking the project. Cost uncertainty is regarded as exogenous as it includes factors such as government action on labor or environmental standards. McGrath (1997) argues for a third form of uncertainty
that is external to but potentially subject to influence by the firm. For example, standards
are set outside the firm but firms can affect standards development. McGrath therefore
suggests that investments in influencing such outcomes can be prudent (McGrath, 1997).

Although real options do not have maturation dates, strike signals do develop. As long as
learning through the option reduces uncertainty, it makes sense to hold the option open.
However, if the opportunity arrives (i.e., uncertainty is resolved), then striking the option
is appropriate. A second signal is the threat of expiration or closure of the option through
the action of a competitor (such as preemptive closure of the asset through acquisition). Waiting
past the signal loses the option so striking upon expiration is practical (Bowman and
Hurry, 1993).

This line of reasoning has most generally been applied to internal development projects
(Dixit and Pindyck, 1994; McGrath, 1997) although other scholars have extended the
analysis to include external opportunities such as joint ventures (Kogut, 1991; Bowman
and Hurry, 1993), equity in both private placement and participation in venture capital
funds (Hurry, Miller et al., 1992; Hurry, 1993; Amram and Kulatilaka, 1999) and
bilateral alliances (Hurry, Miller et al., 1992; Alvarez and Barney, 2000). As Hurry
(1993) notes, “a firm’s ability to leverage its strengths across new industries and markets
arises from investments that secure preferential access to future expansion and
acquisition opportunities”.

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A key feature of real options is the right to strike the option or develop the investment further. How this is done is clear-cut for internal development projects since the right is implicit in the proprietary nature of the project. The application of a right to exercise for investments outside the firm is not as clear. Kogut (1991) argues that many joint venture contracts have provisions for buyout by one partner or the other that form an option. A somewhat more liberal view comes from Bowman and Hurry (1993) and Hurry (1993) who observe that options may be in the form of preferential access to further investment. In the context of the evolution of joint ventures, Bowman and Hurry note that passive equity investment can place a firm in a favored position with respect to acquiring the partner. Hurry (1993) has also observed that the relationship established through the option investment will likely be reflected in a preference by the target for overtures from the partner relative to potential outside bidders.

To summarize, inter-firm real options, like internal options, have highest value if purchased when uncertainty is high and struck when and if the uncertainty is resolved favorably. In the context of technology development, this means investing in firms with interesting and prospectively successful technology when outcomes are not clear. Striking the option, following Kogut (1991) and Hurry (1993) would be the acquisition of the investment target.
3.1.3 Transaction Cost Economics

The transaction cost economics (TCE) framework argues that firms choose boundaries or governance forms so as to economize on the costs of managing them. The general sense of TCE rests on the foundational assumptions of bounded rationality and the threat of opportunistic behavior. Williamson describes Simon’s assertion that human actors are intendediy rational but limited in their ability to be so as the crucial element for economic organization. Bounded rationality implies that all complex contracts are necessarily incomplete, that is, the actors are incapable of specifying all future contingencies that may arise (Williamson, 1998). Per Simon, it is also the case that humans exhibit “frailities of motive” which Williamson suggests implies the possibility of opportunistic behavior or “self-seeking with guile” (Williamson, 1998). Given these two characteristics of actors in contractual relations, the role of governance is to mitigate the hazards attendant to a transaction deemed possible by forward looking actors.

The severity of potential hazards in a contract is contingent on the particular attributes of the transaction including degree of asset specificity, uncertainty and frequency. Asset specificity refers to the degree to which assets are specialized to the transaction. Assets which are unspecialized represent no particular threat to the parties since alternative sources are available on the market and owners of the assets can find other buyers. However, as the extent of specialization to the needs of one party grows, both purchaser and supplier are constrained in alternative sourcing or selling. Both parties thus have an incentive to craft safeguards since productive value would be sacrificed if the contract
were prematurely (Williamson, 1998). On the other hand, asset specificity represents an
appropriable rent stream for both parties: each is motivated to protect his share of the
rents.

An additional concern is the degree of uncertainty pertinent to the transaction. Generally,
as uncertainty rises, the ability of limitedly rational actors to write complete contracts is
diminished. Ex post uncertainty addresses the degree to which the conditions relevant to
the contract at outset change and the costs parties to the contract incur in trying to adapt
to them. Ex ante uncertainty is concerned with how costs are incurred in negotiating and
developing the contract. The relevance of uncertainty depends on how transaction
specific the assets are. When assets are unspecialized, uncertainty can be managed on a
spot market basis. However, contracts involving specialized assets eliminate that
possibility and give rise to the need for interfirm cooperative adaptation under conditions
where environmental changes give one party or the other opportunity to defect or attempt
to claim additional portions of the rent stream (Williamson, 1979; Williamson, 1998).

Under the primary framework, firms ought to seek the most cost economic governance
form based upon these attributes. Thus when there are no assets specific to the
transaction, market contracts are preferred in a least cost sense. As asset specificity
increases (along with uncertainty), recourse to internal organization becomes more cost
effective though it is, as Williamson notes, the “organization form of last resort”
(Williamson, 1998).
This general approach has been widely tested and has been judged an empirical success story (Williamson, 1998) and the “predominant theoretical explanation of boundary choice” (Poppo and Zenger, 1998). The role of asset specificity has been consistently supportive of the theory. The results for uncertainty, particularly technological uncertainty have been mixed. Some studies have found that vertical integration levels are lower under high technological change (Balakrishnan and Wernerfelt, 1986; Robertson and Gatignon, 1998) or that the results of including technological uncertainty are broadly insignificant (Walker and Weber, 1984; Poppo and Zenger, 1998). This suggests that the role of uncertainty deserves closer inspection.

A reason for the variation in outcomes may be that uncertainty has been operationalized in disparate ways. Balakrishnan and Wernerfelt (1986) selected changes in process technology, while Walker and Weber (1984) focused on the expected number of changes in component specifications and probability projections of future changes. Poppo and Zenger (1998) and Robertson and Gatignon (1998) also used questionnaire responses to queries regarding expectations of change frequency. What these approaches do not evoke is any sense of the scope of change involved nor do they capture other nuances of technological uncertainty. For instance, technological uncertainty has been divided into private and market forms (Dixit and Pindyck, 1994; Amram and Kulatilaka, 1999). Private uncertainty refers whether a particular project (internal or external) will succeed as a working product. Market uncertainty captures the different element of whether the product will win in a dominant design or standards battle. The VHS and Betamax conflict provide a good example. In this case, a number of firms attempted to develop video
products and not all succeeded. This reflects private uncertainty. Of the two major versions that succeeded at the private level, one lost in the standards battle: the outcome of market uncertainty (Cusumano, Mylonadis et al., 1992).

A deeper criticism lies in explicating precisely what is meant by integrated production versus outsourcing. These studies and others have found that under technological uncertainty, firms turn out rather than in. Given the role of technological trajectories discussed above, this may not be initially surprising as the more significant the innovation, the less likely firms will have the relevant resources inside. Two observations come immediately to mind: first, if a market for the innovation exists (such as is the case with process technology in Balakrishnan and Wernerfelt (1986), information services in the Poppo and Zenger (1998) study and component production in Walker and Weber (1984)) then the “thin market” problem Williamson describes as precursor to problems of opportunism is mitigated. More importantly, internal development is not the only route to integration. Intermediate or hybrid forms of governance may serve as temporary organizational forms (Williamson, 1991) as firms search for appropriate skills and solutions prior to acquisition and integration.

In particular, Williamson sees the innovative process as an essentially decomposable one. Invention is the first component and is often the purview of smaller, entrepreneurial firms. The subsequent stages of development and efficient supply may require greater resources than a small firm has to achieve a minimum efficient size. Conversely, larger firms have the pertinent resources for efficient production but are not often the inventors
of such new products. The transfer via market solution is subject to a number of moral hazard problems, particularly in the sense of impacted information and the threat of opportunistic behavior. To the extent that a large firm is unable to execute early invention processes, a practice of imitation or acquisition on the part of these firms may be “rationality of the highest order” (Williamson, 1975).

The problem is drawn more starkly if timeliness is an issue. Masten et al (1991) found that if it matters when something has to be done, the task tends to be internalized: this was termed “temporal specificity” (Masten, Meehan et al., 1991). As entry timing into a new market can be crucial (Williamson, 1991; Christensen, Suarez et al., 1998), the notion of entry as a form of temporal specificity becomes relevant.

To put these arguments in context, integration as governance choice is indicated when asset specificity and uncertainty are high. If entry timing is important, then it constitutes a form of temporal asset specificity. Certainly, an alternative to acquisition is to wait until the technological uncertainty is resolved through passage of a standard and negotiate a market transfer of the technology. This faces several problems. First, markets for the production of innovative products may be thin, a problem exacerbated by the standards process which removes some firms as potential providers. Second, to the extent that the innovation providers are privately held and new, incumbents have little knowledge about how a given provider will behave. Third, to the extent that incumbent firms have not internalized the knowledge that permits them to work in the new field, the need for downstream developments and improvements exposes the incumbent to moral hazard
problems. This is compounded by transaction specific investments the firm has made in training, advertising and adaptation of own products to interface with the new products. These tend to be the conditions under which transaction cost economics scholars have argued integration is warranted.

If integration is preferred but incumbents lack the relevant skills, they must develop them or acquire them. Recalling that the sort of knowledge in play is generally regarded as tacit and therefore difficult to develop, especially in short order, the presence of timeliness requirements argues strongly for acquisition. As lack of relevant knowledge suggests uncertainty about the potential value and outcomes of a technology strand, higher uncertainty suggests relatively earlier acquisition in order to develop the requisite knowledge and skills to be positioned for entry.

3.1.4 Hypotheses

The real options and transaction cost economics arguments present potentially contradictory predictions about whether and when we should expect acquisitions to occur under uncertainty. For the argument, I take the acquisition of a firm to be the strike of a real option investment or the integration decision by a firm.

The first hypothesis deals with the relationship between contemporaneous uncertainty and the likelihood of acquisition. The real options framework argues that when proposed investments are subject to sufficient uncertainty, they should be deferred until resolution
develops and further investments can made with greater assurance. When technological uncertainty is high, we should expect firms to defer the strike and when uncertainty is low to close the option through acquisition. The TCE perspective argues that higher uncertainty, especially when learning is important, should accelerate acquisition. I hypothesize:

\[ H1a: \text{as uncertainty increases, acquisitions are less likely to occur (real options)} \]

\[ H1b: \text{as uncertainty increases, acquisitions are more likely to occur (TCE)} \]

Beyond the question of whether acquisitions occur under specific uncertainty conditions, we can also inquire when they occur. Innovations differ in how radical they are considered. The more an innovation deviates from standard practice in an industry, the newer the knowledge and more radical the approach (Tushman and Anderson, 1986; Dosi, 1988). As innovations become more radical relative to an industry, the more uncertainty incumbents will face in choosing a developmental path. Based on the argument above, the real options framework argues that waiting rather than committing best resolves this sort of uncertainty. Conversely, the transaction cost argument implies that if acquisition is the mode of internalization, under this sort of uncertainty firms will move to acquire earlier so as to learn sufficiently. Thus, we should expect that:

\[ H2a: \text{as initial uncertainty about the technology increases, acquisitions will occur later (real options)} \]

\[ H2b: \text{as initial uncertainty about the technology increases, acquisitions will occur earlier (real options)} \]
No matter the level of uncertainty attendant at the outset of a new technology, critical aspects with respect to market and private issues are eventually resolved. While much of the innovation literature has focused on the emergence of a dominant design, this can only be recognized ex post (Tushman and Murmann, 1998). In many high technology industries, this is not the situation. Instead, independent standards bodies implement de jure standards. This is a quasi-public process in that representatives from interested firms can participate but membership requirements include some expertise in the area and the general public is not included in the development nor can outsiders vote on the proposed standard. Most standards bodies seek a high degree of consensus if not unanimity (David and Shurmer, 1996) which suggests that industry firms have some developing idea about which technologies are going to succeed and which will not. In short, market uncertainty is being resolved. If so, real options theory suggests:

\[H3: \text{acquisitions with option investments are more likely to occur just before or at the standard date}\]

### 3.2 DATA AND METHODS

#### 3.2.1 Data sources

Data for this study are based on acquisitions in the networking products industry for the period 1994-2000. This represents a particularly fertile and turbulent time as the industry transitioned from partitioned local and wide area network products suppliers to an integrated, convergent environment that combines communications and computer
technologies. This was driven by several factors. Up until about 1993, the open Ethernet standard and IBM’s Token Ring approach dominated LAN (local area network) technology. Data was passed over these systems at 10Mbs and 17Mbs respectively. However, the increasing capacity of microprocessors in terms of speed and volume was placing a strain on such systems, as was a change in content. Demand for data intensive applications such as distributed learning and network video exceeded the capacity of systems to deliver.

In the early 1990’s, Asynchronous Transfer Mode (ATM) was under development as a solution to the speed and bandwidth problem. This technology was expected to replace Ethernet and like systems and promised significantly higher speed (up to 640Mbs). Additionally, this technology was designed to be used in wide area networking applications, providing a seamless transition from local net to distant net or user. Shortly after ATM began to show promise, some industry firms focused on upgrading Ethernet. By 1995, an IEEE standard for 100Mbs Ethernet was published and several years later, 1000Mbs (Gigabit) Ethernet was standardized. Much of the need for this has developed with the rise of the Internet and the demand that places on user systems. Graphics intensive applications require significant bandwidth, driving advances. Currently work is underway on a 10Gbs version that depends heavily on optical networking advances. While prior advances had generally depended on some variation of electromechanical switching processes, optical networking is developing some completely novel solutions for high speed, pure optics switching.
Another stimulus came from Congress’s passage of the 1996 Telecommunications Act. Following this legislation, firms other than existing local exchange carriers were freed to enter the market. The most relevant issue here is the rise of both integrated computer-telephony applications (such as computerized call centers) and voice over Internet Protocol telephony which permits computer to handset or computer calling. One of the greatest implications here is the projected increase in essentially costless long distance telephony outside the normal long lines system. Finally, this act also led to the competition between “last mile” service for network services to consumers as both telephone, cable and wireless companies seek to provide in home broadband services.

The technologies employed have varied in their novelty or degree of newness. For example, Fast (100Mbs) Ethernet was not significantly different from the earlier 10Mbs version (and vendors took great pains to assure users of this) but the technology employed in optical networking is not only quite different but as yet unproved outside the laboratory. The rate of innovation has also increased: over half of the patents in multiplex communications since 1978 have been granted in the past five years and almost the same level for optical communications patents over the same time frame. Thus, the convergence of technologies and applications has created substantial uncertainty for many incumbents over which, if any, solution to back.

This paper uses acquisitions in the ten major technology fields that have emerged in this industry since 1994 as dependent variables. In one sense, the best data set for an investigation of this sort would be all firm investment behavior including minority equity,
other alliances, and even decisions not to invest with acquisitions as the dependent variable. Failure to include all investments and the "did-not-invest" set could mask a systematic difference between these firms and those that specifically pursue investment as an option, which would affect the interpretation of the statistical results. However, there are a number of problems with this approach. First, defining the relevant set of potential decision makers _a priori_ is arbitrary. Second, investment in real options may be a matter of perception. That is, there may be reasons other than an option to acquire as a basis for an equity position in a firm. If the investment is an option, failure to acquire would constitute abandoning the option. However, the investor may not have ever intended acquisition, as may be the case with firms that underwrite a portion of venture capital funding or parent firms that hold a position in spin-offs and then liquidate to realize gains. A third difficulty arises from the confidentiality surrounding such investments as they constitute strategic behavior and publicity may provide competitors with insight as to the beliefs of investing firms. In general, firms are not forthcoming with information about equity positions in firms that still may be targeted. A general examination of the trade press reveals that minority equity outside venture capital funding is often not publicized unless and until an acquisition is made.

The focus on technology groups as the unit of analysis reduces the potential distortion. No generation of technology had a large incumbent or newly entering major player that did not take some sort of alliance based position in another firm. For instance, prior to Alcatel entering the ATM and Ethernet industries as a new competitor, it took positions in several smaller start-up firms such as Packet Engines. Therefore, in this study, I take
the acquisition as given and focus on how investments are used. The list of acquisitions was derived from online industry sources such as TechFest and Converge Network Digest as well as cross-reference to incumbents’ own acquisition lists. Acquisitions were classified into the various technology families based on the technology noted in press releases and other public statements. Since this paper focuses on technologies in standard setting environments, some acquisitions such as software, consulting and other non-hardware fields are not included. The final count of acquisitions included is 145.

3.2.2 Dependent variables

Hypothesis 1 investigates the likelihood of acquisition given certain uncertainty measures. The dependent variable here is the number of acquisitions in a period (acquired). Hypothesis 2 focuses on acquisition timing relative to the emergence of a strike signal so the chief dependent variable is the centered month (centmth), a measure of distance in months from the publication of a standard in a particular regime. Prior studies have used other strike signals such as initial public offering (Hurry, 1993) but I am concerned here with the resolution of technological uncertainty. The passage of a standard resolves the market uncertainty question of technological success or failure. The value of centmth for acquisitions announced prior to the standard are negative, those after are positive. Standards dates were established through records of the relevant group such as IEEE, IPSec or ITU. Hypothesis 3 uses the absolute value of centmth and is used to identify the proximity of an acquisition to the standard date. This is denoted abscent.
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3.2.3 Independent variables

*Equity* is a dichotomous variable indicating minority equity investment by the acquirer in a target firm prior to the acquisition offer. This data was assembled through correspondence with the CFOs or CEOs of the acquiring firms. Two firms declined to participate so additional investigation was conducted to determine equity positions. Given the information from participating companies, I conducted Lexis/Nexis searches on all acquisitions and found a complete correspondence between noted equity positions and at least two public references to the investment. Based on this result, I examined the acquisitions of the two non-participating firms. The presence or absence of equity in publicly held targets was determined from examination of the target’s last proxy statement prior to the acquisition offer, all subsequent Form 13 (investment) filings and from news reports. Press releases and independent news reports were used to determine equity in privately held firms. All but ten acquisitions were conclusively classified and those ten were designated as having no prior equity investment. A colleague evaluated the classification on the two non-participating firms with access to the same information. All but one acquisition were identically classified, yielding an inter-rater kappa of \( \kappa = 0.895 \) (\( z = 5.76, p > z = .0000 \)).

Joint membership in a relevant industry technical alliance prior to the acquisition offer is indicated by a dichotomous variable *techall*. The data were derived from alliance press releases on membership, correspondence with the alliances and, in some cases, examination of Department of Justice reports some of the fora filed in compliance with
the National Cooperative Research and Production Act of 1993. *Bilatall* is a dichotomous variable indicating an OEM, marketing or development relationship between acquirer and target prior to the acquisition offer. This was derived from an examination of *Lexis/Nexis* documents that contained the names of both firms. Search for such evidence was conducted until the evidence was found or the document list was exhausted. This search covered newspapers, trade journals and business publications. Since various forms off alliance sometimes overlapped, I also include a dichotomous variable that captures if one or more forms of alliance existed prior to acquisition. This is termed *option*.

Measures of uncertainty were developed around patent information for both technologies and firms. Data were derived from searches of IBM’s Delphion Intellectual Property Network, which lists all patents granted in the US up to the present time. Profiles were developed for each of the technologies by conducting searches of all patents that contained the relevant technology names (e.g., ATM or asynchronous mode) in the title or patent abstract. Each patent is classified in a primary family. Given the patent list, I developed a random sample of each family to determine the primary family. The random sample was based on a uniform distribution and accounted for at least ten percent of the patents in a family with not less than 40 patents sampled. In some cases, the number of patents was small enough (20-60) to allow me to examine them all. Patent families that from largest to smallest accounted for 80% of the assignments were noted and listed as technology groups.
The earliest technologies under consideration are Ethernet and ATM networking which arose at nearly the same time. The vast majority of patents granted in these technologies are classified in the 370 family. Most of the other groups list significant patent families that are not 370, which should indicate a different set of knowledge. The technical knowledge difference between initial and subsequent technologies is captured in the variable techdiff, which indicates the percentage of patents in a given regime that are not in the 370 family. The greater the value for techdiff, the less in common with the initial technologies. Still, while patent families are intended to contain related knowledge but this does not mean that knowledge in one family does not draw upon that in other families. Patents as a whole are classified in a single family but the individual claims within the patent are also so classified. Thus, a patent in the 370 family may also have claims that draw upon and are classed as 375. To control for this overlap, I searched for patents that co-listed in family 370 and each of the remaining families. To the extent that overlap occurred, I adjusted techdiff down to reflect that the knowledge sets were related and thus not new. This variable is intended to be a measure of the uncertainty that attends the emergence of a new technology.

Several measures of the rate of change in patent granting were also developed. Counts of patents granted by year by technology group were constructed. The variable total patents captures the number granted in a given group in a specific year. Variance on a year to
year basis in the number of patents granted in a regime is captured in \textit{logvariance}, the
natural log of the variance. This variable is used rather than the direct measure when
analysis of an absolute residual plot indicated increasing variance. Another set of change
variables is the proportion of patents granted in a given year to the total granted to that
point. This measure for the year of acquisition is called \textit{currprop} and for the year
preceding the acquisition is called \textit{priorprop}. The share of patents an acquirer held in the
relevant technological family in the year of acquisition compared to all acquirers is
termed \textit{patent base}. This was constructed from a year by year analysis of all patents
assigned to the acquirer in the appropriate families of patents.

Control variables include \textit{private}, a dichotomous variable indicating whether the
acquisition target was privately or publicly held. \textit{Nasdaq} is the midyear close on the
index. This is used as a control for the ability to acquire, as many firms used equity to
fund the purchase.

\textbf{3.2.4 Models}

H1 uses a negative binomial model to test for how uncertainty affects the propensity to
acquire. As outcomes are events and discrete, nonnegative and not dichotomous, a
Poisson regression is indicated. However, the Poisson model assumes that the variance
and mean are equal but initial analysis indicated that this model was overdispersed and
the equality assumption did not hold. Therefore, a negative binomial regression model is
specified (Stata, 1999). This model is based on the Poisson but includes an extra variable
$u_i$ such that $\exp(u_i)$ has a gamma distribution with mean 1 and variance $\alpha$ (the overdispersion parameter) such that

$$Y_i \approx \text{Poisson} \left( \mu_i^* \right)$$  \hspace{1cm} (1)

where

$$\mu_i^* = \exp(\mathbf{x}_i \beta + \text{offset} + u_i)$$

$$e^{u_i} \approx \text{gamma} \left( 1/\alpha, 1/\alpha \right)$$

The dependent variable is *acquired* or the number of acquisitions in a particular technology group-year. That is, I count the number of acquisitions per year in each group. The independent variables are technology family specific and include *logvariance*, *currprop*, *priorprop*, *total patent* and *techdiff*. I include the variable *nasdaq* to control for ability and opportunity to acquire and also control for the technology group-year.

The models for this hypothesis contrast and then combine flows and stocks of knowledge. The change in knowledge flows in the technology family is linked to *currprop* and *priorprop*. I also include control variables *nasdaq* and *techdiff* and add the interaction term *technew* which captures the difference in technology relative to the 370 patent base and the volume of change as reflected in new patents for the year of acquisition. Total knowledge stocks are linked to *total patent*. These are tested separately and then combined along with controls for the year of acquisition.

H2 and H3 use robust standard error regression. Initial development of the model indicated no difficulties with excessive heteroskedasticity or omitted variables but other analytics were more problematic. Specifically, a leveraged versus residual analysis
showed a number of high leverage values, all associated with one of two technology groups. Second, a DFBETA test of the \textit{techdiff} predictor (test value $= 2/(141)^{1/2}$) showed that a number of observations had significant influence on the coefficient. A remedial measure for these sorts of results is robust regression (Neter, Kutner et al., 1996; Greene, 1997). Further, the role of the technology groups in the diagnostics indicates a possible issue with within-group dependence. The observations are independent across technology groups but may not be independent within groups. Some observers of the industry have characterized the acquisition process as a race, that is, some firms use acquisition as a response to similar actions by another firm in the same technology (Wirbel, 1999).

An analytic solution to this problem is to group the analysis on technology families. This differs from the general robust estimator in that it tends to reduce bias in standard errors over the entire sample by summing within the group first (Greene, 1997). Specifically, the variance estimator for robust regression is:

$$V_{\text{robust}} = (X'X)^{-1} \star \left[ \sum_{i=1}^{N} (e_i \star x_i)' \star (e_i \star x_i) \right] \star (X'X)^{-1}$$

The estimator for groupwise robust regression is

$$V_{\text{cluster}} = (X'X)^{-1} \star \sum_{j=1}^{nc} u_j \star u_j \star (X'X)^{-1}$$

(2)

where:

$$u_j = \sum_{j_{nc}} e_i \star x_i$$

(Greene, 1997)

The general model for these hypotheses is:

$$\mathbf{Y} = \mathbf{X} \beta + \epsilon$$
where $Y = \text{centmth}$ (H2 a and b), \textit{abscent} (H2c); $\beta$ = coefficients of predictor variables and $X = \text{a matrix of variables techdiff, logvariance, patent base, bilatall, equity, techall}$ and \textit{private}.

### 3.3 RESULTS

The descriptive statistics for the 141 acquisitions studied are listed in Table 1. None of the variables were particularly highly correlated as only \textit{currprop} and \textit{priorprop} ($\rho = .629$) had a value in excess of .5. This suggests little evidence of multicollinearity.

#### 3.3.1 Hypothesis 1

H1 proposes that when uncertainty is high, acquisitions are less likely (real options, H1a) or more likely (transaction cost economics, H1b) to occur. Results of the negative binomial regression are shown in Table 3.2. The \textit{logvariance} variable was dropped from the model for simplicity after analysis showed that the variable was neither significant in itself nor did its presence or absence change the outcome of the models significantly. Model a uses \textit{priorprop} and \textit{currprop} as measures of uncertainty related to changes in knowledge flow or number of new patents in a technology family. While none of the main effects are significant, the interaction between \textit{techdiff} (the degree to which the technology group differs from the 370 family) and new patents is significant at the .05 level. Model b tests the knowledge stocks but no variable is significant. Model c combines the two approaches and again, the interaction term is significant. Finally,
model d includes controls for the group-year in which acquisitions occurred. In this case, both stock and flow variables were positive and significant (\textit{currprop} at the .05 level and \textit{total patent} at the .01 level), as was \textit{nasdaq}. If technology groups have more than four years of acquisition history, the latter years are significant as well.

Overall, these results suggest that as uncertainty increases, firms are more likely to make acquisitions. In models a and c, the interaction term captures a specific kind of uncertainty related to fast growth in unfamiliar technologies. However, once the year of acquisition is controlled for, it is interesting to observe that basic measures of knowledge stocks and flows are also important. Controlling for the group-year should absorb some of the variance that might come from particular industry trends. Note in particular that relative to the first year of acquisitions in a technology group, subsequent years tend toward negative coefficients and, for years five to seven, the difference in likelihood is significant. If uncertainty is highest at the outset of a new technology group, these results also support an acquire when uncertainty is high argument. The positive coefficient on all of the primary predictor terms is consistent with the prediction of H1b. I conclude for it and reject H1a.

3.3.2 Hypothesis 2

H2 proposes that the timing of acquisitions will be a function of initial uncertainty. The hypothesis contrasts the expectation that under a real options approach, acquisitions will
occur later the higher the initial uncertainty. Conversely, under the TCE argument, higher initial uncertainty should result in earlier acquisitions. The results of this analysis are presented in Table 3.3.

Initial uncertainty is measured as techdiff or the degree to which patents in a technology are classified in a family other than family 370. The coefficient on this variable in the full model a is negative and significant at p<.01. This strongly suggests that as uncertainty about the nature of a new technology increases, firms acquire earlier. Of the proposed option investments only bilateral alliance is significant (p<.10) and it is positively signed, indicating that these relationships characterize acquisitions that occur, all else equal, later than those that do not involve such an alliance. Firms that were privately held tended to be acquired earlier than publicly held firms (p<.05). In model b, the individual option investments were replaced with a single dichotomous term that captured if any of the three were present in a given acquisition. This option variable was not significant.

### 3.3.3 Hypothesis 3

H3 proposes that if the investments in acquisition targets are in the nature of options, they should be struck just before or at the standard date. Results are shown in Table 3.3. H3 was tested using the absolute value of centmonth as the dependent variable. The closer to the standard date an acquisition occurs, then, the lower the value of abscent. This actually permitted acquisitions made just after the standard date to also be included, as these
would have values equal to those acquisitions made just before the standard. However, the results do not indicate that the option investments either individually or collectively predicted acquisitions near the standard date. H3 is therefore rejected.

3.4 DISCUSSION

The objective of this paper is to contrast real options and transaction cost perspectives on how uncertainty affects acquisition likelihood and timing. The empirical results tend to support the position that firms acquire technology developers earlier when lack of familiarity with the emerging technology field is high and that acquisitions are more likely to occur when innovation is unfamiliar and increasing. In short, firms respond to uncertainty not by deferring acquisition but by proceeding with it. Insofar as acquisitions are assumed to be the strike of a real option investment, then, the results suggest that this is not the approach firms in this industry have adopted.

The role of proposed option investments is mixed. One explicit argument of real options theory is that firms have the right but not the obligation to strike the investment when conditions warrant. This essay has made use of the literature that argues inter-firm investments are real options but the right to strike is problematic. Other than the explicit contractual agreements Kogut mentions in the context of joint ventures (Kogut, 1991), there is no particular claim that firms holding an option have rights to strike. Rather, they may take advantage of information asymmetries and preferential position to move before
competitive firms do. I investigate three sorts of options, which should vary in how they might convey information asymmetry and preference, and explains to some extent the results of the analysis.

Equity investment in firms should result in the highest asymmetries in that the investor has the right to information others do not. In startups without a record of development or sales, this difference in information could be substantial. This essay argued that equity investment could form an option on the new technology but the results do not substantiate the claim. The presence of a minority equity position had no significant effect on when firms made acquisitions relative to a standard date. This result makes it difficult to argue that equity constitutes a real option investment but it does encourage a broader discussion of why firms take such positions.

The relationship between uncertainty and equity investment is a portion of that discussion. Aside from the role of equity as a real option, one could also argue that equity fits in the transaction cost framework as a way of reducing the threat of opportunistic behavior. That is, the investment not only addresses private technological uncertainty but also serves as a check on misrepresentation (or excess enthusiasm) by a startup firm. According to industry observers, startups are often led by former employees of firms in a related technology. To the extent that incumbent firms “know” these entrepreneurs through prior experience and reputation, then the less uncertainty over misrepresentation there ought to be. However, as the difference in knowledge employed in the startup increases, the likelihood of being familiar with the work of these entrepreneurs should
decrease. We should therefore expect that techdiff and equity are related and in fact a logistic regression indicates that increases in techdiff are significantly and positively related to the likelihood of equity investment preceding an acquisition. Further work in defining how acquiring firms use equity is warranted, particularly with respect to defining the overall scope of equity investments. This essay has confined the discussion to acquisitions but it would be interesting to extend the analysis to equity investments across the industry, whether or not an acquisition occurred.

Bilateral alliances are weaker in terms of information asymmetries. That they are associated with acquisitions that occur relatively late in a technology field should not be too surprising in that the existence of bilateral alliances supposes that firms have been in business long enough to develop them. As such, these firms do have a record in the market and there may be less unknown about them. The anecdotal evidence from the industry is that the technology developing firms - the targets of early acquisition - are typically startups with little history. The purchase of bilateral alliance partners generally occurs after a standard has emerged which indicates that the acquisition is not made to capture novel technology. A reading of the trade press on the acquisitions overall suggests that purchases may be made for two general reasons. First, firms acquire developing technology as has been explored here. Second, firms may acquire to consolidate market power. Often, these later acquisitions are characterized as providing a new customer base or filling a gap in the buyer’s product line. For example, Alcatel has
made a cluster of purchases in technologies after standards emerged as it entered the North American market from Europe. Further investigation of the difference in acquisition objectives and timing is warranted.

The technical alliances represent the weakest form of option as claim. Since these are multilateral, there are few informational asymmetries. Therefore, no alliance member firm gains a particular informational advantage relative to other members. The lack of significance for techall in any model bears this out. However, as noted in Chapter Two, these alliances may have varying roles. Some are extended in duration and oriented toward very basic development of new technologies. Others are more limited in scope and are focused on bringing particular implementations of technology to market in very short order. To the extent that an alliance is involved in developing specifications for a standard, the role of membership in a technical alliance may not be as an option but as an “amplifying preinvestment” (McGrath, 1997). That is, by participating in and influencing the standardization process, firms can protect and enhance the value of other option investments.

On the other hand, this study has not discriminated between the types of alliances. One potential confounding aspect is that some of these groups are sequential in organization and development. For example, the Optical Internetworking Forum has generated publicly available specifications for optical data transport at 10Gbs that are being used by other alliances such as the ATM Forum and the 10Gigabit Ethernet Alliance. To the extent that firms participate in multiple stages of sequential development, it would be
difficult to distinguish which represents an option investment. Alternatively, one could regard these as a "sequence of embedded options" [Grenadier, 1997 #143] in the sense that participation at each stage is a necessary investment in order to participate in the future. If so, it may not be reasonable to attempt to identify a particular alliance investment as the relevant option. Another possible confounding element arises from the fact that a number of acquirers and their targets were joint members of several alliances at the same time, again making it difficult to discern which would constitute an option. If multilateral technical alliances do have value as option investments, these issues must be differentiated.

An alternative way of evaluating the overall results is to reframe the notion of what constitutes an option investment. Following Kogut (1991), Bowman and Hurry (1993) and Hurry (1993), this essay has specifically construed the option as one of a set of investments between firms and acquisition as the strike. However, it is possible to regard the acquisition as the option investment (Smith and Triantis, 1994) or as a link in the chain of option investments [Grenadier, 1997 #143]. This approach is quite consistent with the results.

If options should be purchased when uncertainty is high, this research shows that in the network products industry, acquisition timing is related to uncertainty in the expected way. Acquisition also conveys a much stronger right to strike through further investment in production and marketing. This approach would also help explain why firms make
multiple buys in certain technologies. An example is the optical networking field where some firms have made large acquisitions covering several technological approaches.

Much of the real options literature argues that the option investment is “small” (Bowman and Hurry, 1993): is it possible to regard expenditures of several billions of dollars in this way? In some respects, the absolute magnitude of the option price is insignificant. What matters are the potential returns from that investment and if they are high enough, the price is warranted. However, as acquisition prices increase and firms are more willing hedge on new technologies by taking several options, such an approach may be inefficient. One emerging solution deserving further examination is the practice of industry incumbents in forming their own venture funds. In the past two years, Lucent, Intel, Cisco, Alcatel and others have initiated venture capital funds investing in startups in various segments of the industry in which the specific intent is to identify and acquire new technologies (Gunn, 1998; Grossi, 1999). As such, these may form compound options and be more efficient is several respects. First, managing such a fund expands the first pass set of potential targets as the funds often receive thousands of investment proposals. Second, for relatively little investment, corporate funds are able to acquire proprietary information on a relatively large number of startups. An assessment of the online sites for these funds indicates that they typically cover thirty to forty firms. If this bears out as an option investment, we should expect that future acquisitions will be strongly related to this private venture funding.
3.5 CONCLUSION

This study has examined acquisitions in the network products industry in the context of real options and transaction cost economics frameworks. Under a specific set of assumptions about the nature of real options, the results show that firms do not seem to employ an option approach by deferring strike investments until uncertainty is resolved. Rather, acquisition is more likely as contemporary uncertainty increases and occurs earlier in a technology group as initial uncertainty increases which is consistent with a transaction cost interpretation. An alternative specification of what constitutes an option investment is proposed.
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Table 3.1 Summary statistics and correlations
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<td>0.000 (0.000)</td>
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<td>-0.530 (0.577)</td>
<td>-0.632 (0.538)</td>
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<td>techxnew</td>
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<td>0.013 (0.007)</td>
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<tr>
<td>year 2</td>
<td>0.211 (0.338)</td>
<td>0.148 (0.439)</td>
<td>0.777 (0.579)</td>
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<td>year 3</td>
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<td>-2.594 (1.115)**</td>
<td>-5.033 (1.800)**</td>
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</tr>
<tr>
<td>year 4</td>
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<td>0.706</td>
<td>0.902</td>
<td>-0.173</td>
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<td>lnalpha</td>
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<td>-1.035 (0.396)</td>
<td>-1.246 (0.448)</td>
<td>-2.222 (0.807)</td>
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<td>LR $X^2$</td>
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<td>10.17</td>
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<tr>
<td>p&gt;$X^2$</td>
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<td>0.1065</td>
<td>0.1177</td>
<td>0.0114</td>
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<tr>
<td>Pseudo $R^2$</td>
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<td>0.050</td>
<td>0.127</td>
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</table>

* significant at p<.10
** significant at p < .05
*** significant at p<.01

Table 3.2 Results of regression for Hypothesis 1
<table>
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<td>(0.679)*</td>
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<td>(1.982)**</td>
<td>(2.094)**</td>
<td>(2.564)</td>
<td>(2.150)</td>
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<tr>
<td>constant</td>
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<td>(4.441)</td>
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<td>R²</td>
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<td>0.086</td>
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<td>F</td>
<td>51.98</td>
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* significant at p<.10
** significant at p <.05
*** significant at p<.01

Table 3.3 Results of regression for Hypothesis 2 and Hypothesis 3
CHAPTER 4

INTRODUCTION

Significant innovations change industry structure. Small, incremental improvements to product and process rely on extensions of existing technology and tend to consolidate the power of industry leaders while more significant innovations can make the knowledge and competencies of firms obsolete. Such discontinuities in technology may elevate new leaders in an industry and drive out firms that cannot adapt. Successful variants of these innovations become dominant designs in the sense that the majority of implementations of the new technology reflect the core of the original innovation. While the mechanics of which firms adopt and when, as well as what drives the decision to adopt, have been widely studied (Wernerfelt and Kambil, 1987; Mitchell, 1991; Teece, 1996; Christensen, Suarez et al., 1998), the emergence of a resultant dominant design has been less analyzed. This may be due, in part, to the observation that such technology winners emerge as the “outcome of the social or political dynamics of compromise and accommodation between actors of unequal influence” and, as such, they cannot be determined in advance (Anderson and Tushman, 1990; Tushman and Murmann, 1998).

Still, a dominant design is just the cumulation of a sequence of decisions across many firms. This is analogous to a political election: no single vote likely creates a victor but
the sum of votes does. Political analysts make a living by understanding the trends that motivate particular positions by voters and with those, predict outcomes. Similarly, I take the position that if certain factors drive adoption by an individual firm, then in the aggregate they may also explain the conditions under which a dominant design might emerge and which technology it may be. In order to show this, I develop an agent-based model that explores the linkages between firm level, industry and environmental factors such as knowledge overlap, firm size, uncertainty and scope of returns.

In general, I show that the significance of these factors varies over time and this effect can shape ultimate outcomes. It is the stage of the adoption game that gives weight to the various considerations. Early in the innovation adoption process, firms that have a compelling reason to adopt do so because it may influence the eventual outcome to their advantage. Other firms, due to uncertainty, indifference or inability, may wait until outcomes are clearer or not adopt at all. What constitutes a compelling reason will vary with which firms lead as innovators and the levels of industry and environmental factors. On a broad scale, strong regularities in adoption timing and the characteristics of technology winners emerge from the analysis.

The innovation and diffusion literatures are rich in theoretical and empirical work describing how innovation emerges, the role of knowledge and learning, firm size and complexity in the innovation and adoption decision and, in the case of increasing returns economies, the importance of critical market mass or bandwagoning. This paper contributes to the research by integrating these factors in an explanation of why firms
choose to adopt when they do and why a specific firm may lead a winning or dominant coalition. This extends the theoretical discussion of Wernerfelt and Karnani (1987) and integrates prior empirical work in a larger framework. The research also has normative and positive value especially with respect to investments in R&D, learning and alliances.

4.1 LITERATURE REVIEW

An innovation is a solution to a problem. Factors such as technological bottlenecks, scarcity of critical resources, abundance of particular inputs, shocks in price or supply of inputs or changes in demand generate problems or barriers for firms and the pursuit of returns (Dosi, 1988). Resolving the problem requires some new approach and implementation of a change in technological product or process.

Technological development and innovation are characterized by uncertainty, path dependency, accumulation, tacitness and degree of appropriability (Dosi, 1988; Teece, 1996). Initial development, exploration and exploitation of new knowledge is marked by uncertainty over the correctness of the approach (will this solve the problem? Is this the best way to solve the problem?) as well as the degree of market acceptance should a solution be developed.

However, the technological uncertainty is moderated by the path dependent and cumulative nature of development. That is, the set of potential solutions tends to emerge from prior work. Problem solving activities generate models and specific procedures.
relating fruitful avenues of exploration and those that have failed. Techniques and approaches that work are preserved and those that fail are discarded. These models and practices disseminate through the interested community and form the core of further inquiry. Dosi has described this as a “technological paradigm” or highly directional pattern of solutions. It is both exemplar and a set of heuristics, an outlook or perspective on relevant problems (Dosi, 1988). This paradigm develops over time: new solutions are likely to be close to or based upon prior solutions and the body of decisions forms the paradigm. Thus, change tends to evolve along certain paths while others are not explored.

This is the case at both the industry or community level (the level at which a paradigm is established) and at the firm level. Firms can draw upon public information and from other firms, but in general search and development builds upon existing knowledge and competencies (Teece, 1996). Over time, particular skills and approaches are developed. As Dosi puts it, “what the firm can hope to do technologically in the future is narrowly constrained by what it has been capable of doing in the past” (Dosi, 1988). This path dependency strongly implies heterogeneous capabilities in developing or imitating new technological solutions.

A basic model of technological development could be described as a community of investigators pursuing related problems and solutions along the lines of the prevailing paradigm. Developments are cumulative, building on the work that has been done before both at the industry and firm levels. Firms within the community develop specific
knowledge bases and competencies as a result of their unique experiences. Most important, the types of solutions are generally a function of what the firm or industry has done before.

Technological change along these lines has been characterized as incremental (Anderson and Tushman, 1990) or regular (Abernathy and Clark, 1985) innovation. Incremental innovations refine and improve existing products and processes and draw upon existing competencies within the firm (Anderson and Tushman, 1990; Henderson and Clark, 1990). They are oriented toward improvements in performance or cost and can have significant impact on the market strength of innovators (Abernathy and Clark, 1985). Incremental innovation occurs when product design has standardized and design variability has been reduced.

Nonetheless, important or radical innovations do emerge and these often have the effect of not only destroying the current paradigm but also restructuring the industry. Such innovations may render obsolete the competencies firms have developed within the context of the existing paradigm (Anderson and Tushman, 1990) and represent a completely new way of perceiving and solving problems. Anderson and Tushman describe the overall process as a technology cycle wherein the emergence of a radical innovation is followed by an “era of ferment”. Firms in this period seek to understand the underlying solution in the innovation and judge their ability to adopt or emulate it and, if they can, when to do so (Anderson and Tushman, 1990). Competition emerges between the older technology and the innovative replacements and within the new technological
regime. Proponents of the existing base are usually correct in asserting that the innovation is crude and does not work well. In some cases, the relevance to current customers is also questionable (Christensen, Suarez et al., 1998). This conflict often leads to substantial improvement in existing products. Within the new technology, competition emerges because initial innovation is typically crude and experimental and alternative versions are introduced as firms seek to not only adopt the innovation but differentiate themselves in doing so.

The era of ferment ends when a dominant design emerges from the competition between and within technologies. A dominant design is a single variant that establishes market superiority. Anderson and Tushman (1990) have defined dominance as at least 50% of the implementations of a new technology in a particular configuration. Typically, such a design reflects compromises and adaptations made by technology suppliers as customers indicate preferences over features (Anderson and Tushman, 1990; Tushman and Murmann, 1998). Suarez and Utterback have described this as a best compromise, permitting the product to be sold to the widest number of users (Suarez and Utterback, 1995).

A different view suggests that as product complexity increases, the more that sociopolitical and institutional interests affect the outcome (Tushman and Murmann, 1998). For instance, market power of a single producer may set a standard and so may industry committees and coalitions of firms. Because of the compromises that generally
are made to form a dominant design, these outcomes rarely lead to the original innovation emerging as the standard nor to best technologies as a standard. That is, “dominant designs lie behind the technological frontier” (Tushman and Murmann, 1998).

The introduction of a radical innovation need not necessarily lead to a dominant design. The era of ferment preceding that design may be interrupted by the emergence of yet another revolutionary technological change, beginning the cycle over again. Further, when market demand is low or governments become involved in the process, dominant designs may not emerge (Teece, 1996; Tushman and Murmann, 1998). If a dominant design does emerge, then the period following that emergence has been called an “era of incremental change.” A new paradigm has developed when the focus of innovation switches to improvements in performance and cost characteristics around the core technology and experience or learning curve effects begin to emerge. This persists until a new radical innovation or “technological discontinuity” is introduced and the cycle begins again (Anderson and Tushman, 1990).

An innovation becomes a dominant design when a sufficiently large number of firms in an industry have adopted it through decisions to use or produce (Anderson and Tushman, 1990). Firms are grouped based on the technology selected and the competition is between the groups or coalitions, which represent alternative new technologies as well as the older, threatened technology (Katz and Shapiro, 1986). Coalitions in an economic sense are defined as “a group of players (e.g., economic or political agents) who decide to act together, as one unit, relative to the rest of the players” (Hart and Kurz, 1983). Strictly
speaking, this definition is somewhat too strong for dominant design dynamics in that the firms need not formally “decide to act together”: the sense of desired outcome comes directly from the choice of technological option. Here, coalitional structures are a notion of convenience and are the partition of industry firms into the one or two sets of technology adopters where members gain value from their own actions and from the coalition itself. These have been described as hedonic coalitions (Dreze and Greenberg, 1980).

Motivations for choosing one coalitional structure over another develop from the desire to maximize the value of outcomes under uncertainty and other environmental characteristics. In examining how firms should operate under such conditions, Wernerfelt and Karnani (1987) noted that if first mover advantages exist, early action is preferable. However, even if they do not, early action is suggested if the firm has a preference for a particular alternative and, by acting, can influence the ultimate outcome at the industry level. Some firms, by virtue of their size and resources, have more options. They can wait until uncertainty is more completely resolved or hedge their risk by investing in alternative competing technologies (Wernerfelt and Karnani, 1987). In the following section, I develop a framework for the considerations implicit in choosing entry and the subsequent effects on the emergence of a dominant design.
4.2 THEORETICAL DEVELOPMENT

The literature on diffusion and adoption from the management perspective focuses on when the adoption occurs (and subsequent effects) and variables driving the adoption decision. The theoretical underpinning of these decisions is one of rational expectations: firms adopt when and if they have a compelling reason to do so. That is, the expectation of utility is higher under the selected technology than under any of the alternatives (Farrell and Saloner, 1986; Katz and Shapiro, 1986, Katz and Shapiro, 1992; Choi, 1997). The factors that enter the calculation can be segregated into firm level (ability to enter, firm size, and rivalry) and environmental (uncertainty, scope of returns).

While subsets of these have been investigated in a large number of empirical and theoretical analyses, little has been done to link them on a larger scale. In particular, research has tested the effects of one or some of these on the adoption decision. I integrate these in an overall discussion of the entry decision and relate them to outcomes such as the probability that a new technology emerges as a dominant design, the effect of the variables on bandwagoning or herd behavior, and the likelihood that initial technology leaders persist as winners. If regularities emerge, this weakens the idea that the process by which dominant design emerges is inherently unpredictable.

I focus on three major hypotheses in this essay: 1) factors affecting the entry timing decision, 2) factors affecting the replacement of older technology with new and 3) factors affecting which new technology wins. While the first two are fairly self-explanatory, the
third requires more discussion. In a discussion of increasing returns economies, Arthur (1989) has argued that asymmetry such as size difference between innovators should present an advantage to the larger in terms of the likelihood that that technology would win. If this was always so, then the competition between technologies would be uninteresting. Therefore, in this set of hypotheses, I seek to outline some of the conditions under which the smaller innovator might succeed. The structure of the analysis centers around industries where two competing innovations are introduced within the context of an existing technology and producers.

4.2.1 Uncertainty

I begin with an examination of the environmental factors. Uncertainty in innovation adoption has been extensively studied in the management and economics literature and enters the discussion in several ways. First, firms may be uncertain over which of several competing innovations will succeed (e.g., VHS versus Beta videotape technologies). On a larger scale, there may be uncertainty over whether any form of the innovation will succeed (e.g., stereo AM radio). Wernerfelt and Karnani (1987) characterize these as supply and demand uncertainty and are both examples of market uncertainty. I focus here on demand uncertainty as I incorporate supply uncertainty elsewhere in the model. The economics literature has considered uncertainty (usually in the form of duopoly games) and shown that high levels tend to retard adoption as firms enter a waiting game, seeking to make another firm resolve the uncertainty about the merit of the technology (Cowan, 1991; Jensen, 1992; Hoppe, 2000). Other analyses in increasing returns indicate that
potential adopters would prefer to wait in order to avoid being stranded by an early and losing choice (Farrell and Saloner, 1986). Still, situations where technologies are subject to increasing returns can yield just the opposite condition. Uncertainty can generate “excess momentum” as early adopters compel defensive and similar adoptions by those who might have preferred the other technology (Choi, 1994; Choi, 1997).

The inability to forecast winners in a technology race means that early entrants are exposed to higher risk of failure (Audretsch, 1995; Christensen, Suarez et al., 1998) or at least additional costs to switch to a winning technology (Tegarden, Hatfield et al., 1999). On the other hand, moving early and picking the right technology can result in improved positions for firms especially if there are learning curve or lead-time effects (Lieberman and Montgomery, 1988; Lieberman and Montgomery, 1998). It follows from this that if there are significant first mover advantages or an ability to influence the outcome, firms may choose to move early (Wernerfelt and Karnani, 1987). However, neither of these factors depends on any environmental uncertainty but specific characteristics of the market and the firm, respectively. All else equal, lower levels of risk should lead to quicker adoption (Hannan and McDowell, 1984). When uncertainty is high firms may be reluctant to commit to a particular technology until further information develops because of the opportunity cost of such investment if rivals are more productive with current technology investment. If all uncommitted firms behave this way, a winning coalition may never emerge. In short, uncertainty encourages conservative behavior. This should have predictable effects at the industry level, which leads to the following hypotheses:
H1a: as market uncertainty increases, firms will enter later

H2a: as market uncertainty increases, the likelihood of a new technology emerging as a winner decreases

H3a: as market uncertainty increases, the likelihood that the initially leading technology becomes the dominant design increases

4.2.2 Returns to adoption

Increasing returns to adoption arise from learning by doing, coordination by technical groups and through the presence of network externalities (Cowan, 1991; Mookherjee and Ray, 1991; Islas, 1997). The fundamental insight of studies in increasing returns (IR) economies is that competition between technologies will result in dichotomous, winner take all outcomes. Markets are not split with majority and minority participants but rather one technology prevails and the other disappears.

These markets have been characterized as path dependent and self-reinforcing. Path dependency implies that multiple outcomes are possible and the one that occurs is a function of small events early on. Self-reinforcement occurs when adoption increases eventual share. From an economic perspective, the focus has been on both the indeterminacy of outcomes and the fact that the structure of such markets can lead to domination by inferior technologies provided they achieve an early lead. As noted earlier, IR markets can exhibit excess inertia if no firm is willing to assume the risk of adoption and subsequently being stranded. Excess momentum is also a stranding problem as
expectations regarding outcomes lead adopters to choose not on preferences but on beliefs about the final technology winner (Katz and Shapiro, 1986; Arthur, 1989; Choi, 1994; Choi, 1997).

The rational expectations framework has implications for coalition formation and choice. As returns to coalition size increase, firms should anticipate that payoffs will be increasingly skewed. While the theoretical analyses provide reasons for expecting either early or late entry as a decision rule, inherent asymmetries in the industry argue for more predictable outcomes (Arthur, 1989). For reasons discussed below, specific firms may be motivated to enter early, seeking to influence the final structure of the industry. Given that early events in increasing returns markets are important, I expect that as the IR shift parameter increases, such entry will encourage bandwagon or herd adoption. If so, this will also be reflected at the aggregate level. I hypothesize:

\[ H1b: \text{as the IR shift parameter increases, firms will enter later} \]

\[ H2b: \text{as the IR shift parameter increases, the likelihood of a new technology emerging as a winner increases} \]

\[ H3b: \text{as the IR shift parameter increases, the likelihood that the initially leading technology becomes the dominant design increases} \]
4.2.3 Knowledge Overlap

The ability to enter is a fundamentally organizational issue. Once an innovation has been introduced, firms can imitate, counter-innovate (a different solution to the same problem) or defer, possibly not entering at all. I focus here on the imitation and deferral decisions and take as a point of departure the notion that imitation is not simple but requires substantial knowledge and capabilities. To the extent that innovations solve problems in a novel way, they include “new” knowledge developed by the innovating firm. If other firms are to imitate or emulate the innovation, they must be able to capture and use that information. Although the innovating firm may intend that the knowledge be proprietary, spillover, worker transfer, reverse engineering and the public nature of patents and other property rights protection measures allows knowledge to be captured by other firms which erodes the rent generation capability of innovation.

The opportunity to gain the information begins with the introduction of the product for much of the relevant knowledge is embedded in it and, once introduced, becomes something of a public good available to competitors. If this knowledge (even if captured) cannot be used, the innovator is alone in the new market, generating above normal rents. This is the reward for innovation and the foundation of patent and copyright law. The overall appropriability of technical knowledge is then a function of both the inherent difficulty of replication due to knowledge gaps and legal constraints (Dosi, 1988). It is well known, though, that patents do not offer complete protection from imitation (Mansfield, Schwartz et al., 1981); firms, if able, can invent around the protections and
appropriate some of the gains (Liebeskind, 1996). Teece observes that when patents and copyrights are strong, this dissemination of knowledge is constrained; however, he also notes that truly strong property rights regimes are not common (Teece, 1996). Under weaker regimes, others often ultimately share knowledge developed in one firm.

The ability of firms to imitate an innovation is heterogeneous. Those best positioned to imitate are the firms that can learn quickly how to unravel the knowledge implicit in the innovation and reapply it in the new organizational context (Jensen, 1988). The more complex the innovation or the more it incorporates new knowledge, the more difficult this is to do. The key is apparently knowledge similarity or how much knowledge the prospective imitators and the innovating firm have in common (Schewe, 1996). Cohen and Levinthal describe this as “absorptive capacity” or the ability to recognize and value new knowledge, incorporate it within the organization and then apply it to commercial ends. Assimilating and deploying new knowledge depends upon some prior related knowledge since learning is cumulative and the outcome of learning is greatest when the object of learning has some relation to what is already known. The cumulative nature of absorptive capacity implies strong path dependency: if prior learning is required to assimilate new knowledge, lack of such learning means that firms are unprepared to evaluate and use new information when it manifests. Since learning is costly and requires time, lack of investment in absorptive capacity in prior periods makes it “more costly to develop a given level of it in a subsequent period” (Cohen and Levinthal, 1990).
This has been investigated in several recent studies. Mowery, Oxley and Silverman have used cross citation of patents (Mowery, Oxley et al., 1996) and added common citation of patents (Mowery, Oxley et al., 1998) as measures of technological overlap to evaluate construction and performance of equity and non-equity alliances. They found that the ability to absorb information or capabilities from a partner was related to pre-alliance overlap of patent portfolios (1996, 1998) and that the overlap between joint venture partners increased after alliance formation (1998). Schewe found that among German mechanical and electrical engineering firms, successful imitation depended on investment in research and a history of being among industry leaders in innovation. His results suggested that imitation is possible only when “the technical and usage related product attributes of the innovation are known and understood” (Schewe, 1996).

Prior relevant knowledge also affects the timing of entry. If competing firms are already in the process of developing similar products or if important capabilities are accessible, the less lead-time the innovator will have (Mitchell, 1989; Zander and Kogut, 1995). The ability of some Japanese firms to quickly imitate or offer “improved” innovations is not only a function of investment in research and research consortia but also competitive information acquisition and management (Bolton, 1993).

Absorptive capacity suggests a barrier to imitation that rests on the side of the imitator, not the innovator, due to prior investments in learning. A necessary requirement for imitation is adequate knowledge about the innovation or knowledge overlap. With high overlap, a firm is capable of imitating quickly while low overlap suggests that the firm
has little option but to wait until adequate knowledge has been acquired. High knowledge overlap has been described here as a necessary condition for early entry or imitation. However, in itself, it is not sufficient under certain circumstances.

Consider an industry where two competing technologies have been introduced. If a firm has high knowledge overlap with both innovating firms, ceteris paribus, it should be indifferent to which one succeeds. However, to the extent that entry requires a commitment of resources along a particular learning direction, it will be disincented to choose early. If the firm entered and chose incorrectly, it would be disadvantaged relative to competitors that chose the winning technology. This occurs whether the firm changes its decision (beginning a new learning process and sacrificing some of its earlier investment) or stays with the original choice, in which case it will be confined to a minority share of the market. This becomes more important as industry and firm level learning or experience curve effects increase. Since these are a function of cumulative production and the winning coalition of technology adopters should dominate sales, costs on the winning technology will decline more rapidly than costs for the loser (Ross, 1986). Firms that stay with a losing technology choice thus face several competitive disadvantages.

On the other hand, firms that have a much higher overlap with one innovator versus the other should be highly motivated to choose early if their choice helps influence the decision of later entrants (Wernerfelt and Karmani, 1987). In the presence of such asymmetries, firms would prefer that the technology they know most about prevail, as
this reduces costs and time of entry. Deferring entry could result in being forced into selecting the less desirable technology if it is winning or deciding not to adopt at all. Even if the firm does not have sufficient size to dominate the market, entering with a particular technology sends a signal about the attractiveness of that innovation. This should still obtain even if the absolute degree of overlap is not as high as that possessed by other firms.

At an aggregate level, the influence of knowledge overlap asymmetry should still be apparent but in a less obvious way. Assessing knowledge overlap at an industry level is in this case not particularly informative. Previously, I have used knowledge asymmetry to motivate an adoption decision, which occurs at some particular time. An industry level measure of knowledge would suggest a collective and simultaneous decision, which does not occur. Following the earlier argument regarding earliest adopters versus firms with high but symmetric overlap, the effect of knowledge asymmetry emerges as a signal from first adoption. Such an adoption should be the result of high and asymmetric overlap and the effect should be most evident in the case of first adoption of the technology from the smaller innovator. Here, the signal should have the effect of making that technology more likely to win. I hypothesize:

\[ H1c: \text{as knowledge overlap asymmetry increases, firms will enter earlier} \]
H2c: *early adoptions of new technology increase the likelihood that new technology replaces the old*

H3c: *first adoptions of the initially lagging technology decrease the likelihood that the initially leading technology becomes the dominant design*

### 4.2.4 Adopter and innovator size

The role of size in the entry decision is argued to have contradictory effects. Schumpeter (1950) noted that large firms should be more innovative due to greater investment in R&D and because they can better appropriate innovation rents due to capabilities in marketing and production (Hannan and McDowell, 1984). This argument has been extended to the complexity and composition of the firm and is generally characterized as the extent of role specialization. Larger organizations should have more distinct specialization in work, which develops a deeper knowledge base. The deeper this base, the more the firm can innovate or adopt innovations (Dewar and Dutton, 1986; Daminpour, 1996). Size insulates firms from the risk of failure from investment in any one innovation (Hannan and McDowell, 1984; Rosenbaum, 1989) and conveys higher post-adoption returns (Jensen, 1988). Conversely, inertia and bureaucracy should increase with firm size and these are hypothesized to have a negative effect on adoption. Smaller organizations should be more nimble and adaptable, increasing innovation adoption (Daminpour, 1996; Schoenecker and Cooper, 1998). Larger size may also lead firms to defer entry as size alone can tip the design battle: large firms can wait until they have more certainty about outcomes (Wernerfelt and Karnani, 1987).
The empirical results of testing size are mixed. In a meta-analytic study, Daminpour (1996) found that firm size was significantly and positively related to innovation adoption as environmental uncertainty increased. However, size negatively affected the creation and implementation of innovations after uncertainty was controlled. Specific studies of the ATM banking, steel and medical imaging industries found that size was not a significant predictor of innovation adoption (Oster, 1982; Hannan and McDowell, 1984; Mitchell, 1989). In the concrete industry, size was negatively and significantly related to earlier adoption (Rosenbaum, 1989). Schoenecker and Cooper found in an analysis of two computer industries that size was a positive and significant predictor of innovation adoption in minicomputers but not significant (though positively signed) for PCs (Schoenecker and Cooper, 1998).

A related line of research has examined the effect of specialized assets on the timing and probability of adoption. For instance, a direct sales force and R&D expenditures were significant indicators of early entry in the minicomputer market (Schoenecker and Cooper, 1998). Mitchell’s studies of the medical imaging industry found that possession of a direct sales force and share of market (itself a proxy for other specialized assets such as R&D and manufacturing systems) were both associated with likelihood of entry while presence of the sales force was also related to early entry (Mitchell, 1989). Industry experience was not significant when share was included in the models, the implication being that share is a function of experience.
Size enters this discussion in two ways: the size of the potential adopter and the size of innovators. While the results on testing for effect by adopter size are mixed, I distinguish between adoption by technology users and producers. The difference is one of threat to the main business; for users, the new technology is a tool, while for producers it is the very reason for existence and the effects of wrong choice being more profound. In the general discussion of how coalitions develop in increasing returns markets, it has been observed that adoption sends a signal to other users about the desirability of a particular technology which should influence subsequent adopters (Katz and Shapiro, 1986; Choi, 1997). In this case, the size of the adopter sends a particular signal about the likelihood of the chosen technology achieving dominant status. Wernerfelt and Karnani (1987) propose that the larger the firm, the later it enters so as to maximize the effect of the entry. Here, I offer a clarification: large firms may not be first adopters but in order to affect outcomes, they still need to enter relatively early. That is, large firms can best utilize the value of size through entry prior to the emergence of a dominant design.

The sum and difference in size of innovators should play a role in decisions and outcomes. At the individual firm adoption level, contemporaneous changes in the sizes of coalitions will signal likely outcomes. Up to a point, some firms may wait to enter. However, as the final shape of the adoption process emerges, firms that have not chosen may be constrained in their choices. Specifically, it may be clear which technology will win so adoption of the other, especially at a late date, does not offer a good return. To the extent that very late potential adopters have lesser capabilities for emulation, it may make more sense to not adopt at all. At the aggregate level, as the collective size of the
innovators increases, we should expect that uncertainty about the chances of the new
technology will diminish: the larger the sum of innovator size, the more likely new
technology would supplant the old. The effect of sum of size on which technology wins is
less clear. Here, the difference in size should matter more. For instance, innovations by
market leaders often set a standard for the rest of the industry. A well-known example is
IBM’s introduction of their version of a personal computer. Although Apple, Osborne
and others were producing PCs, the IBM move almost immediately set a standard in
architecture and operating systems. Furthermore, if the size of an entrant sends a signal
regarding a technology, so to should differences in size among innovators. To
summarize, I hypothesize:

\[ H1d: \text{ large firms will adopt new technologies earlier } \]

\[ H1e: \text{ as the difference in coalition size increases, firms will be less likely to } \]

\[ \text{ adopt } \]

\[ H2d: \text{ the greater the sum of innovator size, the more likely new technology will } \]

\[ \text{ replace the old } \]

\[ H3d: \text{ the greater the difference in innovator sizes, the more likely the larger } \]

\[ \text{ innovator will win } \]

The notions of absorptive capacity and knowledge overlap illustrate what is required to
be an early adopter of a technology. The choice rules of knowledge overlap asymmetry
and preference for a winning coalition clarify the factors that may motivate the decision
to enter or defer at a given stage of the game. Environmental and industry level
conditions moderate the effects of resources and development. A summary of the predictor variables and their effects is shown in Table 4.1. In the next section, I will develop the agent-based model that illustrates how choices and sequences unfold under various conditions.

4.3 DATA AND METHODS

4.3.1 Simulation background

Agent based computational economic (ACE) models represent an alternative exploratory mechanism to inductive and deductive models and are useful for quasi-empirical investigations. They are particularly suited to problems of choice and motivation for choice and in modeling how large scale social effects emerge from self-motivated micro behavior (Tesfatsion, 2000). Schelling in particular demonstrated how simple rules governing the choices a person makes can lead to illustration of how segregation or partitioning emerges on a larger scale (Schelling, 1978). That the use of ACE models is a relatively recent practice is due to the spread of low cost, powerful computing and the development of object oriented programming.

An agent-based model provides needed flexibility in testing the propositions in this paper. One implication, for example, is that the order in which firms join a coalition is predicated on which firm leads in innovation. Standard cross-sectional analysis is historic so discussion of alternative outcomes can only be speculation. Obviously, the speculation can be overcome through more testing over a range of conditions but this sacrifices the
ability to hold certain firm or industry conditions constant. That is, initial conditions can be changed in an agent-based model holding agent characteristics constant in a way that inductive empirical studies cannot. An ACE model can test many feasible combinations of innovation leaders and state variables in an industry and how these affect coalition formation.

The objective of this exercise is to identify how the proposed attributes of knowledge overlap, share and rivalry affect the choice and timing of technology adoption under specific exogenous conditions. For the purposes of this model, I construct an artificial industry of ten firms endowed with randomly generated relevant attributes. Firm share is the outcome of a random generation on a uniform distribution such that each random number is converted to a proportional share of the sum of the ten numbers. The rivalry array is constructed as an array of random numbers drawn on a uniform distribution. I assume that truly rivalrous relations are not common nor are they symmetric (e.g., the locally owned restaurant may regard the national chain as a serious rival but this perception is not reciprocated). True rivalries are constrained to approximately 15% of all pairwise relations. This was selected after investigation found no prior empirical reason to specify a particular level and experimentation showed that this level permitted some variance in outcomes. The array is converted into 1/0 outcomes based on the value of the random number. Similar to the Axelrod, et al (1995) study, the primary effect of this is through a recalculation of coalition size with the contribution of rivals excluded. The knowledge overlap array is constructed through random generation of values based on a normal distribution. This reflects the idea that firms in an industry tend to share a certain
level of knowledge but that knowing a great deal or little about another firm should be less common than knowing an intermediate amount. The normal distribution of overlap scores captures this effect.

Uncertainty is a random draw from a uniform distribution [.5,1]. The lower bound is selected based on the idea that firms would not introduce an innovation if they perceived a less than even chance of success. The IR shift parameter is based on a logistic function such that the expectation of share under the technology chosen by firm $i$ is

$$\frac{\text{share}_i}{\text{share}_f} \times \frac{1}{1 + e^{-\gamma x}}$$

where $\text{share}_i$ is the share of the technology coalition, $x = \text{share}_i - .5$ and $\gamma$ is the shift parameter. Higher values of $\gamma$ represent more skewed outcomes. To cover an array of conditions, four values of $\gamma$ are chosen to reflect particular post-design outcomes: 80%, 50%, 20% and 5% of original market share on a coalition level. Thus, a losing coalition representing 40% of pre-innovation market share could expect a post-dominant design share of 32% under a $\gamma$ of roughly 7.5.

Following Axelrod, et al (1995), profit maximization is not used as a measure of desirability in the choice between prospective alliances. Rather, firms expect that they will do better in one alliance or the other based on firm and alliance attributes, which should lead to better profit performance. Firms therefore rate alliances based on expected utility from knowledge use, coalition size and rivalry avoidance. The technology
alternatives are considered to be perfect substitutes from a consumer perspective. This simplification was made to focus on the firm, industry and environmental factors. The game is over when all firms evaluate their comparative utilities and decide not to move.

Data for analysis takes two forms: event specific and summary outcomes. Running the coalition formation process for all possible two-firm innovation leader combinations under particular structural shift and uncertainty parameters generates the basic information. Since there are ten firms, there are \( n(n-1)/2 = 45 \) possible two-firm combinations. In tracking firm histories or records of decisions, then, there are eight such histories per lead-firm combination and these are run under each of the four IR shift factors. While the range of shift and uncertainty parameters can be theoretically bounded at a relatively small number of typical values, it is not as easy to constrain the rivalry, share and overlap state variables. These are virtually infinite in their combinations so selecting any one set of variables as representative would probably not be a robust solution.

As a solution, five each of the randomly generated share, rivalry and overlap arrays are developed and the simulation combines them at random. Of the 125 possible combinations, 100 are run under the condition that no combination be repeated. For the coalition summary data, 200 runs are made. Duplication of industry characteristics thus occurs at most twice and since the uncertainty draw is random, the probability of completely identical initial conditions is zero. This generates a set of approximately 180,000 firm histories so, in order to hold the level of output to a tractable level, the
events are randomly sampled for analysis. Firm histories are sampled by selecting 12.5% of the firms for tracking under 12.5% of the IR shift factors. This should yield an approximate .0156 sampling rate on all histories. Coalition histories are tracked at 10% of all combinations.

Agent based models have generally been developed through the use of object oriented programming languages such as Basic, C and C++ or through specialized languages such as the Santa Fe Institute’s Swarm modeling language. Since the structure and processes of this simulation are not particularly demanding from an analytic perspective, Visual Basic is used as the development tool. For specific information on the assumptions and conditions in the simulation, see Appendix C. For simulation code, see Appendix D.

4.3.2 Dependent variables

Hypothesis 1 examines the effect of overlap asymmetry on entry timing. The dependent variable is when a firm joins a particular coalition through product introduction (join). For this hypothesis, firm history data is used. That is, every period the firm has a chance to make a decision is captured with no entry designated 0 and entry coded 1. Data collection for the firm is ended on entry or truncated at twenty cycles. Hypotheses 2 uses a dichotomous variable capturing whether old technology or the sum of new technology adoptions exceeds 50% of available share (newwin). If the final state of the simulation run shows that old technology holds in excess of 50% share, the outcome is coded 0. The dependent variable for Hypothesis 3 is a dichotomous variable that indicates for
outcomes where new technologies replace the old whether the dominant new technology is associated with the initially larger or smaller innovator (coded smallwin). As the outcome of interest is the case where smaller innovators end up leading winning coalitions, this is coded 1 when it occurs and 0 when the larger innovator leads the winning coalition.

4.3.3 Independent variables

The independent variables are generally the specific conditions of the state variables or some transformation of them. All three hypotheses use two common predictor variables. Uncertainty (uncer) ranges between 0 and .5, i.e., between complete certainty that the market will accept new technology and an estimated 50% chance that the innovation will be accepted. The market shift values (gamma) range from 7.5 to 21 with higher values representing greater returns to share. Details on the range of gamma are found in Appendix 1.

Hypothesis 1 uses several more predictors. The absolute value of differences in knowledge overlap (abs overlap) between the two leadfirms is measured from the perspective of a given potential adopter and is therefore firm specific. The maximum of these overlap scores on a firm by firm basis is called max overlap. Firm size is captured through a variable called share. The contemporaneous change in the difference in size between the two new technology coalitions, measured as share, is termed change. Cycle is the time variable and indexes the firm-event history. Hypothesis 2 uses as a predictor
the cycle in which either new technology was first adopted \textit{(first adopt)}. Hypothesis 3 includes a similar variable. \textit{Small adopt} is a dichotomous variable coded 1 if the technology introduced by the smaller innovator is the first adopted, 0 otherwise. Both H2 and 3 include the sums of and absolute differences in the shares of the innovating leadfirms and are termed \textit{initial sum} and \textit{initial dif} respectively.

\textbf{4.3.4 Models}

The hypotheses in this paper employ related techniques. H1 (a test of entry time at the firm level) is a question of when some event occurs. The relevant characteristics of this data are that they are reported in discrete duration form and, relatedly, exhibit clumping in particular periods. This is common to many econometric studies in that the process of interest occurs in continuous time but reporting constraints only show the larger, discrete period in which the event occurs (Beck, Katz et al., 1998). There are several methods for analyzing data from continuous time event studies, the most popular of which is the semi-parametric Cox proportional hazards model. Fully parametric hazard models exist but their use requires \textit{a priori} specification of the underlying hazard function. The correct distribution is not often evident. The results from a Cox specification have been shown to be robust in that they closely approximate the outcomes from use of the correct parametric model (Kleinbaum, 1996). The Cox model is usually written as

\[ H(t,X) = H_0(t) \exp \left[ \sum_{i=1}^{p} \beta_i X_i \right] \]
The hazard or risk of failure at time $t$ is then the product of $H_0(t)$, representing the baseline hazard, and an exponential term where $X$ represents the vector of time independent predictors. In the proportional hazards approach, the hazard ratio is assumed to be constant over time and only the parameters in the exponentiated portion are estimated, hence the semi-parametric designation. A major concern with using this model comes from the continuous time assumption in that ties under continuous time should not occur but are a common feature of discrete duration data. Several methods have been developed to manage ties but are limited in their scope (Kleinbaum, 1996).

As a solution, the Cox model has been extended to treat grouped duration data. Beck, Katz and Tucker (1998) demonstrate that the complementary log-log model (cloglog) can be derived from the continuous Cox form. The data are modified from the “normal” presentation of records that indicate either that an event occurred or that the subject exited the study without such an event occurring (right censoring) to a form that describes a complete subject-time history. The resulting dependent variable is not the period in which an event occurs (as in the Cox model) but a dichotomous “event did/did not occur” in a given period. The cloglog transformation generates the model

$$P(y_{t,i} = 1 | x_{t,i}) = h(t | x_{t,i}) = 1 - e^{-e^{-b_0 - b_1x_{t,i}}}. 
$$

This approach manages well with grouped duration data and has the added benefit of being a maximum likelihood estimator, as the baseline hazard is no longer excluded from the estimation. However, the derivation from the Cox model implies that the underlying assumption of proportional hazards still applies which may not be a reasonable assumption for economic data (Jenkins, 1995). Given the same data structure as that
imposed on the cloglog model, recent work has adapted the logit model to the problem (Jenkins, 1995; Beck, Katz & Shumway, 2001).

The logit form of the hazard model is an intuitive extension of the usual form:

$$P(y_{i,t} = 1 | x_{i,t}) = h(t | x_{i,t}) = \frac{1}{1 + e^{-e^{x_{i,t}^T \beta + y_{i,t} \gamma}}$$

where \( y_{i,t} = 1 \) implies a “failure” or adoption. The logit link has also been derived from a continuous time duration model but does not assume proportional hazards (Jenkins, 1995). Shumway (2001) has demonstrated that this is also a consistent and efficient maximum likelihood estimator. Beck, Katz and Tucker (1998) show that the cloglog and logit models are virtually identical in their estimations over a broad range of event probabilities. In particular, they find that only when a large number of observations have a likelihood of failure exceeding 50 percent will the models differ much. In the case of this study, the maximum mean probability of failure is .06, well within the range for unrestricted choice of model. Given that the logit model is well understood and easily estimated, I use it to test H1. The dependent variable is join and the models are:

a) \( p(\text{join} = 1) = f(\text{cycle}) \) (establishing the baseline hazard)

b) \( p(\text{join}=1) = f(\text{cycle}, \text{uncert}, \text{gamma}, \text{share}, \text{difference}, \text{abs overlap}, \text{max overlap}) \)

c) \( p(\text{join}=1) = f(\text{cycle}, \text{uncert}, \text{gamma(indicator)}, \text{share}, \text{difference}, \text{abs overlap}, \text{max overlap}) \)

d) \( p(\text{join}=1) = f(\text{cycle}, \text{uncert}, \text{gamma}, \text{share}, \text{difference}, \text{abs overlap}, \text{max overlap}, \text{time interactions}) \)
e) \( p(\text{join}=1) = f(\text{cycle, uncert, gamma, share, difference, abs overlap, max overlap, time interactions, main effects interactions}) \).

Collectively, H2 and H3 resemble a classic nested logit problem. H2 tests whether the new technologies replace the old. H3 tests whether the ultimate winning new technology coalition was also the largest at the outset (i.e., led by the larger of the two innovators). However, the two questions are qualitatively distinct from a nested logit problem. Specifically, H2 inquires as to whether new technologies in sum gain sufficient share to displace the incumbent technology. A multinomial or nested logit problem would inquire if \textit{either} new technology replaced the old. If new technologies do succeed, H3 does not inquire as to the nominal identity of the winner but investigates the different problem of the link between outcome and relative innovator size. Therefore, these two hypotheses are not nested and can be treated separately. As the outcomes are dichotomous, I specify logit models for each.

The general form of discrete outcome models is (Hosmer and Lemeshow, 1989; Liao, 1994):

\[
p(y = 1) = F \left[ \sum_{k=1}^{K} \beta_k X_k \right]
\]

In the logistic transformation, the general cdf, \( F \), is replaced by the specific logistic cdf \( L \) such that

\[
\pi(y = 1) = \frac{e^{\beta_i X_i}}{1 + e^{\beta_i X_i}}
\]
\[ \pi(y = 0) = \frac{1}{1 + e^{\theta_{1}x_{1}}} \]

The logit of this form, g(x), yields the log odds through

\[ g(x) = \ln \left( \frac{\pi(x)}{1 - \pi(x)} \right) = \beta_0 + \beta_k X_k \]

where the logit is linear in parameters and may be continuous.

The specific models here are

H2: \( p(\text{newwin=1}) = f(\text{gamma, uncert, initial sum, initial dif, first adopt}) \)

with model b substituting indicator variables for gamma and model c

including select interactions of the main effects variables

H3: \( p(\text{smallwin =1}) = f(\text{gamma, uncert, initial sum, initial dif, small adopt}) \)

with model b substituting indicator variables for gamma and model c

including select interactions of the main effects variables

4.4 RESULTS AND DISCUSSION

The simulation was run two hundred times with random draws for each of the three state variables. Eighty three of the possible configurations were used twice, forty used once and two were never drawn. The data were partitioned into event and summary records. Events were recorded as firm decisions on joining and the summary data represents sampled outcomes of innovation introduction under a specific set of state variables. Both event and summary records were randomly sampled from the total data generated with approximately 31,000 event history records and 3,800 coalition outcomes observed.
respectively. As the data sets were sampled separately and represent different processes, the summary statistics and correlations are listed in Tables 4.2 and 4.3. Table 4.4 summarizes the analysis outcomes versus the expected results.

**4.4.1 Hypothesis 1**

Hypothesis 1 used the discrete duration logit model to test the effect of variables on when firms made the decision to join a coalition. Results are shown in Table 4.5. Model A is a baseline model suggested by Beck, Katz, and Tucker (1998) to test for duration dependence. If the effect of the time variable is not significant, then the data are duration independent. In this case, the likelihood ratio test rejects the null of no significance as the LR $\chi^2$ is 81.1 with a related probability of 0.0000. This evaluation follows Shumway’s (2001) recommendation for correction of overall model statistics. Since the firm-cycle data are not independent, the number of observations must be modified to reflect this. Shumway recommends dividing test statistics by the average number of firm-cycles: doing so yields the above noted statistic and leads me to conclude that time effects are present.

Figure 4.1 plots the baseline and full Model E hazard functions. Model B is the primary specification, model C distinguishes the levels of gamma and model D adds time-effect interactions. Model E includes interactions between main effects. Following Hosmer and Lemeshow (1989), I report significant interactions and members of groups of interactions where at least one proved significant.
The results of the H1 tests are mixed. Uncertainty does not turn out to be a significant factor in the decision as to when firms adopt in any model as a main effect. However, the interaction between uncertainty and time or cycle is negative and significant. This implies that uncertainty acts as a brake on adoption over time. All else equal, we should expect that firms constrained to consider late adoption due to firm specific factors will be less likely to adopt as uncertainty increases. I conclude for H1a.

The results for IR market shift are at least initially consistent with the hypothesis. As gamma increases (i.e., as the scope of returns to adoption increase), adoption occurs later. The implications of gamma in indicator variable form are particularly interesting. Gamma2 through gamma4 represent the 50%, 20% and 5% of prior share levels of the variable. Here, each of these is significantly different from the effect of gamma at the 80% level (gamma = 7.5371) but do not differ among themselves. Model D includes the effect of the time interaction with gamma. This is positive and significant, though the main effect is now insignificant.

Two observations come to mind as a result. First, there appears to be little difference between the effect of the three highest levels of gamma. They are significant in their effect with respect to gamma1 but insignificant among themselves. This would imply that, to the extent this simulation captures behavior, we could expect that firms need not face absolute outcomes but only fairly highly skewed ones to evoke a particular adoption pattern. Second, given this pattern of behavior, neither the excess momentum nor excess
inertia theories of adoption dynamics (Katz and Shapiro, 1986; Choi, 1997) really
captures what happens. The overall implication of the results is that high gamma
generates a waiting game until outcomes are clearer, at which point adoption is
accelerated.

In part c of H1, I proposed that as knowledge overlap asymmetry increased, entry would
occur earlier. Absent the maximum overlap variable, this is the case. However, once max
overlap is included, the absolute value of overlap difference is negative and significant.
This is an outcome of the distribution of abs overlap, which will have its highest possible
value when max overlap for one firm is very high. When max overlap enters the
equation, it accounts for the effect of both high values and the absolute differences. Abs
overlap now includes the effect of mid and lower level maximum overlap values. In this
case, firms may have a relatively high overlap but lack sufficient knowledge to enter
quickly. In fact, unless the technology they know most about wins without their
contribution, they may never enter at all. The absxcyc (absolute value by cycle)
interaction clarifies this: knowing more about the lagging technology than the leading
significantly reduces the chances the firm will adopt at all. Strictly speaking, I reject H1c
as the absolute difference in knowledge overlap is not a sufficient cause of adoption and
may not even be necessary. However, a combination of high difference in overlap and a
high maximum overlap value would collectively indicate early choice.

I evaluated two sets of interactions for the knowledge variables. The relationship between
abs overlap and max overlap is interesting in that the terms are not unbounded. If firms
have a very low overlap maximum, then (since max overlap is lower-bounded at a theoretical limit of 0), abs overlap is low. That is, at the lowest levels of max overlap, abs overlap should be very small. The scatterplot of abs overlap versus max overlap is shown in Figure 4.2. I developed a set of indicator variables to capture the combinations of low, medium and high scores for each of abs overlap and max overlap or absolute difference by maximum overlap (olxmaxl-8). Relative to firms that had both low abs overlap and max overlap scores, the results indicate that higher levels increase the likelihood of adoption. However, it is important to note that even firms with low abs overlap scores were more likely to adopt if they also had at least medium level max overlap scores. Interestingly, there appears to be no significant difference in adoption likelihood between firms with low abs overlap and high abs overlap as long as max overlap is high.

The interactions with time are negative and significant, suggesting that firms with high max overlap and abs overlap scores that have not entered prior to period t are less likely to do so in period t than firms with lower scores. This is understandable: if a firm with a high score has not entered, it should mean that the scores favor the lagging technology and the knowledge stocks of the firm are becoming marginalized. Given that H1c emphasized the role of knowledge difference versus knowledge magnitude, I reject the hypothesis. A more complete approach would combine ability (max overlap) and motive or direction (absol) in predicting adoption. More precisely, while firms with high asymmetries may choose to commit to a particular technology early, the magnitude of the overlap will influence when the product is introduced. Absent a relatively high level of
overlap, firms will be delayed in entry and to the extent the competitive landscape has changed, the introduction may be moot. Therefore, with high overlap asymmetry may not enter at all.

The role of *share* is as expected in that the coefficient is positive and significant. Larger firms are at any point more likely to adopt than are smaller firms. The interaction term with time reinforces this: firms that have not adopted up to time \( t \) are more likely to as size increases. There is, as noted earlier, a subtlety in the Wernerfelt and Karnani (1988) argument used to orient the discussion of the effect of size. They argue that large firms should be more likely to wait to adopt so as to utilize their size most effectively. The limit to this argument is that in order for the effect of size to be important, the firms must adopt early enough to have impact. The analysis at this point shows that among all firms sampled, size is related to adoption timing. However, among firms that adopt, an OLS regression of cycle on size shows that as firm size increases, adoption tends to occur later \( (t = 3.65, p=.0000) \) which is consistent with the results of the size-time interaction. The explanatory value of this regression is slight but the significance makes it interesting. Among all firms, then, large firms do tend to adopt earlier but are not necessarily first or earliest adopters. This outcome may help illuminate some of the conflicts in the empirical results where the if and when questions are sometimes not explicitly separated. It also helps resolve the effect versus motivation argument in Wernerfelt and Karnani (1988). I conclude for H1d.
The change in the size of the adopting coalitions (*difference*) was hypothesized to decrease the likelihood of adoption. The results from models C and D strongly support this. Consistent with the adoption hazard curve in Figure 1, firms that are going to adopt tend to do so early. The pattern of earlier adoptions affects the balance of power between the coalitions. In terms of the firm specific predictors discussed above, asymmetries in knowledge overlap can become irrelevant if the outcome favors the wrong innovation. Similarly, after a point, the value of size is minimized as outcomes are decided and no adoption decision can change the outcome. Therefore, firms that do not choose relatively early are more likely to make no adoption decision at all. If the new technology fails to replace the old, this is a good decision. However, if new technology does succeed and eventually eliminates the old, non-adopting firms can be forced out of the market. I conclude for H1e.

### 4.4.2 Hypothesis 2

Innovations do not always succeed. Stereo AM, the rotary Wankel engine and IBM’s OS2 are examples of how promising developments never actually prevailed or even survived in the market. Hypothesis 2 tests the effect of the hypothesized variables on the likelihood of new technology collectively replacing the old. In this, the simulation assumes that if total implementations of new technologies exceed .5 of total market share, then new technology succeeds. The dichotomous dependent variable *newwin* is coded 1 if new technologies gain at least 50% market share, 0 otherwise. The results, shown in Table 4.6, are generally as expected.
As uncertainty about the new technology increases, the likelihood of new technology success falls. This was anticipated but it is an interesting outcome considering the results from H1. There, uncertainty as a main effect was not significant but the interaction with time was. The effect shows clearly here: in conditions of high uncertainty, the adoption process slows down enough that the likelihood of new technology success is diminished.

The market shift $\gamma$ variable also has a negative effect on the likelihood of new technology survival. While this is opposite the hypothesis, it is consistent with the results from H1 as a main effect. It is informative to examine the separate levels and the interactions of gamma. In terms of the particular levels of $\gamma$, a test using the second level as a base indicates that the relationship between $\gamma$ and the likelihood of new technology success is nearly monotonic. New technology is more likely to succeed under low levels of gamma and more likely to fail under high levels. This matches generally with the H1 results indicating that adoption was less likely as gamma increased. While there is a plateauing effect in the main effects indicator model, this disappears when interactions are added. The interactions with $firstjoin$ indicate that later first adoptions under low gamma are negatively related to new technology success. Conversely, there was little difference between the upper three levels of gamma. I interpret this to suggest that late first adoptions are more reasonably associated with new technology success under high $\gamma$ than low. Firms appear to defer making decisions until some other firm has provided a signal when IR shifts are high (Katz and Shapiro, 1986). This is
reinforced with the results of the *gamma-time* interaction from H1. Strictly speaking, I reject H2b but note that the effect of *gamma* is not linear enough to capture in a hypothesis of this form.

The result for *initial sum* seems counter-intuitive in the sense that the larger the innovators collectively, the fewer firms need to join either coalition to make the new technology successful. To unpack this result, I note highest *initial sum* results when the largest firms in a given industry are technology innovators and the firms that must decide to adopt are relatively small. Recalling the results from H1 where it was shown that large firms tend to adopt earlier relative to small firms, I suggest that the adoption process can get stalled. That is, if only relatively small firms remain to make the adoption decision, none of which can unilaterally have a significant impact on the outcome, there is little motivation to adopt. I reject H2d.

The effect of *first adopt* is negative and highly significant. In other words, the later the first adoption of either new technology, the less likely new technologies replace the old. This is intuitively appealing. The interactions have been previously examined.

### 4.4.3 Hypothesis 3

Hypothesis 3 examines the effects of the predictors on the likelihood that the smaller innovator in terms of size would emerge as the winner. This is motivated by the observation that, especially when increasing returns characterize a market, asymmetries
such as size should be to the advantage of the larger innovator (Arthur, 1989). The conditions under which this may not be so should be of interest, particularly from a normative perspective. I address only outcomes where new technology supplanted the old. Results are shown in Table 4.7. In this analysis, the dependent variable larsna is coded 1 if the smaller innovator wins and 0 otherwise. Model A is the main effects model, Model B includes indicator variables for gamma and Model C includes interaction terms. Overall, the models show fairly high explanatory power in this process: Model C has a pseudo $R^2$ of .39.

The dichotomous variable small adopt is coded 1 if the first adoption by any firm is the technology sponsored by the smaller innovator, 0 otherwise. This variable as a main effect and in interactions is the key to this analysis. Small adopt is positive and very significant in all models, meaning that if the first technology adopted is sponsored by the smaller firm, the likelihood of the smaller innovator eventually winning is greatly increased. This could be interesting from a manager’s perspective. Recalling that firm effects such as size and knowledge stocks were significant predictors of early adoption in H1, the link here would be developing some way to encourage early adoption of the smaller innovator’s technology.

This has implications for the strategy that innovators may adopt regarding the information they share with rivals. One of the rewards for innovation is the chance to gain superior returns from the deployment of a unique asset. On the other hand, as the results from the balance of the predictors in this model show, overcoming the
disadvantages of relatively small size is difficult. This leaves the smaller innovator facing smaller returns, particularly in increasing returns economies. In these cases, a policy of sharing information through alliance or licensing may help resolve the design battle. A pertinent historical example is that of Sony versus JVC in the Beta and VHS conflict. Sony had a proprietary technology and was much larger than JVC. However, JVC’s practice of licensing the technology to a wide number of potential adopters and Sony’s refusal to do so meant that the disadvantage JVC faced in size and penetration into the market was overcome. This practice has been directly linked to the success of the VHS format (Cusumano, Mylonadis et al., 1992).

The effect of the remaining variables with respect to the likelihood of small innovator success is mixed. Initial uncertainty is insignificant in every model. I had earlier proposed that uncertainty would encourage conservative choices by adopters, reinforcing the lead that the larger innovator had. However, this is clearly not the case. Given the results from H1 and H2, it appears that uncertainty affects the rate of adoption but not the actual choice between technologies. I reject H3a.

The effect of gamma as a single main effect is negative and significant. Interestingly, the effects of gamma as an indicator variable are very nearly the same as in H2 except that the plateauing effect is more pronounced. At least over the range of gamma values tested, there appears to be two levels of response. Low gamma (relatively small effect on post-dominant design market share) is weakly and positively related to small innovator success while all three higher levels have approximately the same effect. Put differently,
increasing gamma tends to reinforce the advantage of large innovators. The interactions with first complicate matters, though. Relative to the gamma2-small adopt interaction, first adoption under low gamma is negatively related to success while high gamma shows a strong and positive relationship. Put differently, we see some evidence of herd behavior (Choi, 1994, Choi, 1997). From a risk management perspective, this makes sense: if the risks of wrong choice under high gamma generally inhibit adoption, then a positive signal regarding some new technology should turn gamma into a spur because now the risks lie in not adopting. As a main effect, I conclude for H3b but note that the interactions make this a contingent outcome. The coefficient for initsum is negative but the effect of the variable is never significant. The effect of initial dif is as anticipated: the larger the difference between innovators, the more likely the larger will win.

In summary, small innovators are more likely to win if first adoption in an industry is of their technology. This effect is more pronounced as increasing returns effects become more important.

CONCLUSION

This essay has sought to explore the effects of and linkages between various factors affecting the adoption decision in the wake of innovation and the subsequent, higher level emergence of dominant designs. The use of a simulation permitted the examination of a large number of firm, industry and environmental variables in varying combinations, something that is difficult to attain with actual innovation and adoption events.
The primary findings of this essay are several. First, the effect of increasing returns is not necessarily uniform. Arguments finding either excess inertia or momentum in adoption under high IR conditions do not capture the complexity of what happens. Firms appear to play a waiting game as gamma increases but the receipt of a signal can tip the outcome quite quickly. All else equal, though, a signal should never occur as firms would all prefer to wait (Katz and Shapiro, 1986). That one does is due to asymmetries in firm specific characteristics, specifically, knowledge stocks and size. Relatedly, the effects of increasing returns may not be strictly monotonic. There appears to be a plateau where a range of IR values has similar effect in all three models. If this is the case, then the dynamics associated with the extreme outcomes of high IR markets may have broader application.

Second, adoption may first be a function of firm characteristics but environmental factors do play a role. This is particularly evident with respect to uncertainty and has implications for the success of new product introductions. In particular, if the core stocks of knowledge in an industry are not sufficient to encourage early adoption, the innovation may not replace the old technology. Put differently, one implication of this paper is that under uncertainty, innovations will emerge as replacements for an existing technology quickly or not at all.

Finally, the effect of first adoption on technology outcomes is potentially important. Given the disadvantages that small innovators face, the finding that first adoption is such
a strong predictor of ultimate outcomes has implications for strategies of knowledge sharing with presumed rivals. Certainly, in industries where standards are expected (*de jure* or *de facto* high IR markets), we do find frequent examples of sharing as alliances and coalitions seek to tilt the outcome their way. The tradeoff to sharing is a more competitive market and potential loss of rents that might otherwise accrue to the inventor. The calculations of when sharing pays off and when it does not are not undertaken here but it is expected that given the form of the simulation, derivation would be possible.

I anticipate several directions for future research. Foremost among these is identifying a real-world innovation event that has many of the characteristics studied here. Specifically, I am seeking an event of competing technologies introduced into an existing industry where the adoption by firms from the outside is minimal. Provided knowledge overlap values can be established, it would be interesting to fit the empirical data into the simulation to check on how well historic and simulated outcomes match up.

Wernerfelt and Karnani (1988) proposed that innovation adoption by firms be predicated on preference for or the ability to influence particular outcomes. This paper has explored the conditions under which such decisions might actually generate the desired outcome.
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Table 4.2 Summary statistics and correlation matrix for event data (continued)
Summary statistics and correlation matrix for event data

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Table 4.3 Summary statistics and correlation matrix for summary data (continued)
Table 4.3 (continued)

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Summary statistics and correlation matrix for summary data
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Table 4.4 Summary of predictors, hypotheses and expected outcomes versus results. As the predictor variable increases, the expected effect is noted.
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Table 4.5 Results of Hypothesis 1 tests (continued)
Table 4.5 (continued)

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*  significant at p<.10
** significant at p<.05
*** significant at p<.01

Results of Hypothesis 1 tests
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<td>0.1862</td>
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<tr>
<td>n</td>
<td>3,530</td>
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<td>3,530</td>
</tr>
</tbody>
</table>

* significant at p<.10
** significant at p<.05
*** significant at p<.01

Table 4.6 Results of Hypothesis 2 tests
<table>
<thead>
<tr>
<th></th>
<th>Model A Main effects</th>
<th>Model B indicator</th>
<th>Model C interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>uncert</td>
<td>0.576</td>
<td>0.497</td>
<td>1.510</td>
</tr>
<tr>
<td></td>
<td>(0.782)</td>
<td>(0.797)</td>
<td>(1.070)</td>
</tr>
<tr>
<td>gamma</td>
<td>-0.015</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.005)**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>gammal</td>
<td></td>
<td>0.262</td>
<td>0.816</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.159)**</td>
<td>(0.198)***</td>
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<td>gamma3</td>
<td></td>
<td>0.045</td>
<td>0.039</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.159)</td>
<td>(0.171)</td>
</tr>
<tr>
<td>gamma4</td>
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<td>-0.294</td>
<td>-0.251</td>
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<tr>
<td></td>
<td></td>
<td>(0.164)**</td>
<td>(0.179)</td>
</tr>
<tr>
<td>initial sum</td>
<td>-1.341</td>
<td>-1.299</td>
<td>-1.144</td>
</tr>
<tr>
<td></td>
<td>(1.101)</td>
<td>(1.103)</td>
<td>(1.112)</td>
</tr>
<tr>
<td>initial dif</td>
<td>-12.475</td>
<td>-12.519</td>
<td>-14.882</td>
</tr>
<tr>
<td></td>
<td>(1.693)***</td>
<td>(1.696)***</td>
<td>(2.464)***</td>
</tr>
<tr>
<td>small adopt</td>
<td>3.267</td>
<td>3.270</td>
<td>3.653</td>
</tr>
<tr>
<td></td>
<td>(0.114)**</td>
<td>(0.114)**</td>
<td>(0.148)**</td>
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<td>uncxsmall</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(1.535)</td>
</tr>
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<td>gam1xsmall</td>
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<td></td>
<td>-1.206</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.257)**</td>
</tr>
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<td>-0.030</td>
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<tr>
<td></td>
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<td></td>
<td>(0.036)</td>
</tr>
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<td>gam4xsmall</td>
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<td></td>
<td>0.058</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.040)</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>(3.378)</td>
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<td>Constant</td>
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<td>-1.506</td>
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<td>1240.57</td>
<td>1242.57</td>
<td>1279.26</td>
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<td>P $&gt;\chi^2$</td>
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<td>0.0000</td>
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<td>pseudo R$^2$</td>
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<td>0.3763</td>
<td>0.3874</td>
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<tr>
<td>n</td>
<td>2,630</td>
<td>2,630</td>
<td>2,630</td>
</tr>
</tbody>
</table>

* significant at p<.10
** significant at p<.05
*** significant at p<.01

Table 4.7 Results of Hypothesis 3 tests
Figure 4.1 New technology adoption hazard curves: baseline and full models
Figure 4.2 Scatterplot of abs overlap versus max overlap. Dummy interactions between knowledge overlap and maximum overlap noted in sectors numbered 3-8
CHAPTER 5

Three essays have examined how innovation adoption and the emergence of a dominant design are affected by increasing returns to adoption and standardization. Increasing returns can affect the payoff to adoption decisions and significantly increase the risk in making the wrong choices. The primary findings of this dissertation are that increasing returns effects do shape dominant designs. Further, while appear to make significant commitments to particular innovations before dominant designs emerge, they also engage in risk-reducing strategies such as alliances in the same technological context.

The first essay (chapter two) used the experiences of firms in the Ethernet industry for the period 1994-2000 to examine how standards are formed under conditions of conflict over design and the need to bring an agreement to the market in short order. While standards development organizations have emerged as a general solution to avoiding market battles to set de facto standards, they are also subject to delay due to political maneuvering and the inertia that comes from the need for a high level of consensus. Using data from contemporaneous industry sources and interviews with executives, I investigated how limited scope consortia develop to resolve potential institutional failure. These groups form to coordinate the development of a technological solution when the relevant knowledge is distributed over a number of firms and no one of them can unilaterally impose a standard through market actions. Unlike other, independent fora and alliances.
the LSCs work in the context of an SDO and generate the documentation to support a new standard. This method of quick coordination is increasingly often employed in other venues.

Essay two (chapter three) uses data from the network products industry to test hypotheses regarding the timing of acquisitions. Since these are increasing returns markets, the decision to adopt a particular technological approach is risky in the sense that wrong choices can yield zero or negative returns. When risk is high, some scholars have argued that a real options approach through incremental investment and delayed commitment to innovation is indicated. Conversely, others have argued that high uncertainty and the need to integrate knowledge mean that firms should acquire early. Data on 155 acquisitions in this industry were used to test these theories. The results indicate that firms do not use a real options strategy if the option is preliminary investment in the target through some form of alliance. However, if the acquisition is the option, the results are consistent.

Chapter Four (essay three) integrated several streams of literature in developing a simulation to assess the effect of a set of firm specific and environmental variables on the adoption decision and the subsequent emergence of a dominant design. Over several hundred combinations of variables, the results indicate that increasing returns do affect the timing of entry for firms and that bandwagoning is an important factor. Firm knowledge about the innovators is also key and leads to earlier adoption. At an industry level, market competition and sequential, independent adoption suggest that the presence
of high returns to adoption can reduce the likelihood that new innovations succeed but that early adoption by some firm can offset this. Similarly, small innovators can be successful if the initial industry adoption is of their product. Implications for managerial action are discussed.
APPENDIX A

Ethernet networking

Networks at the simplest level are collections of two or more connected computers with the objective of sharing files and peripherals such as printers. The systems range from local area to metropolitan sized and finally to wide area networks. Each has a fundamentally different structure but the focus here is on LANs. Aside from the computers, LANs require other elements including network interface cards (NICs), a connection medium such as twisted pair wiring, coaxial cable or fiber optic cable and an operating system. Almost always, networks also include a device such as a hub, switch or router to act as a data concatenator and connection point for the computers. LANs can be aggregated up along a backbone or cable connection between the hubs, which need not run at the same speed as the hub to node connection.

A critical element of the network lies in the media access control (MAC) protocol or how the system handles traffic. The MAC is required to prevent nodes from transmitting onto channels occupied with other transmissions. The two primary approaches are the Ethernet CSMA/CD approach and the IBM sponsored token ring. The token ring solves the access problem by circulating a token or right to transfer from node to node in the ring. If a station or node has data to transfer, it waits until the token passes to it and then replaces
the token with the data frame. When the data frame returns to the transmitting node, the
token is replaced and passes to the next node. CSMA/CD (carrier sense multiple
access/collision detection) is the MAC used by Ethernet systems sharing a common
transmission medium. In this approach, a node monitors the channel until no active
transmitter is detected. At that point, the node transmits the data frame and monitors for
collision or the event of two nodes transmitting simultaneously. If this is detected, the
node sends a “jam sequence” then waits a random period of time to transmit the data
again. Both the token ring and CSMA/CD MACs are half-duplex, that is, nodes can
receive or transmit but not both at the same time. Full duplex transmission is possible but
not as a common carrier: these connections are typically between repeaters, hubs or
routers along the backbone.

By the early 1990’s, token ring and Ethernet had emerged as the two most popular
techniques for networking. However, the split in the market was one-sided: Ethernet
accounted for about 80% of the total LAN implementations by 1994 (Fisher, 1994).
Robert Metcalfe developed the Ethernet at Xerox’s Palo Alto research Center (PARC) in
1973. Initially configured to operate at a speed based on the internal clock of the Alto
computer, early Ethernet had a transmission rate of about three megabits per second
(Mbs). Interestingly enough, it was an innovation without substantial demand even
internally (computer users were satisfied with exchanging disks rather than transmitting
files) until the laser printer was developed at PARC and placed in the network (Hiltzik.
1999).
In 1980, Xerox allied with Digital Electronics Corporation and Intel (the DIX group) to make Ethernet commercially available. A critical step in this decision was to allow any firm to manufacture Ethernet components such as network interface cards, cables, and other elements for a one-time licensing fee of $1000. Hiltzik (1999) observes that one of the driving reasons behind this decision by Xerox to forego complete control was to try to take advantage of sales of peripheral products such as laser printers. In contrast to the openness of the Ethernet approach where components were competitively provided, IBM’s token ring proprietary technology required only IBM products in those implementations. By 1984, the Ethernet was standardized through IEEE committee 802.3 based on 10Base5 coaxial cabling. Token Ring was standardized under 802.5 at about the same time. These systems were entirely incompatible and could not communicate other than over a translating bridge.

Over the next decade, Ethernet was revised several times to update and improve the cabling technologies it would support, particularly unshielded twisted pair wiring which is the same cable used in telephones. This was a major advance since office buildings were already equipped with the wiring and the 1990 802.3I standard led to a great expansion in Ethernet installations (Techfest, 1999). Network backbones using FDDI capable of supporting higher transmission speeds were being deployed but the fundamental speed to the desktop was still at 10Mbs. This transmission rate constraint was generating potential problems, particularly under the increases in data flow demand. This led to the proposals regarding Fast Ethernet and the alternative AnyLAN technologies.
APPENDIX B

Data sources for Intel and Lucent acquisitions


Excel Switching Corporation (1999) SEC Schedule 14A Proxy filing


Intel Corporation (1999) “Intel to acquire Level One for approximately $2.2 billion in stock-for-stock merger” Intel Corporation press release, Mar. 4, 1999

Intel Corporation (1999) “Intel to acquire Dialogic for approximately $780 million” Intel Corporation press release, June 1, 1999


Level One Communications (1998) SEC Schedule 14A Proxy filing


Lucent Technologies (1998) “Lucent Technologies purchases MassMedia Communications, Inc.: Purchase of Massachusetts firm adds enhanced voice, data and
video internetworking capabilities to rapidly expanding data networking portfolio.”
*Lucent Technologies press release, July 28, 1998*


*Lucent Technologies press release, Aug 28, 1998*


Mosaic, Inc. (1999) SEC Schedule 14A Proxy filing

Octel Communications Corp. (1999) SEC Schedule 14A Proxy filing


160
Shiva Corporation (1998) SEC Schedule 14A Proxy filing


Spectran Corporation (1999) SEC Schedule 14A Proxy filing


APPENDIX C

Innovation adoption simulation

This simulation develops data on which firms adopt innovations and when they do so under a set of state variables describing an industry. It also collects data on final adoption outcomes at an industry level. The industry is composed of ten firms. The primary variables for this simulation include specifications of uncertainty, scope of returns to adoption, knowledge overlap, rivalry and firm size. Random selection is used extensively and I note that within the simulation, the Visual Basic pseudo-random generator is used.

The value for uncertainty reflects the expectation of the firms in the industry regarding the likelihood of user acceptance of the innovation. Values of less than .5 are not included as I assumed that no firm would develop and introduce a product of there was a less than even chance of adoption. There may in fact be such events but in terms of the simulation, high values of uncertainty almost always meant that adoption was stifled. The values vary for each run of the simulation and are drawn from a uniform distribution on [0.5,1].

The scope of returns to adoption is captured through a variable called gamma and is based on a version of the logistic function. Values were selected to approximate the
shares of coalitions after a dominant design had emerged under four returns to adoption regimes. Low values of gamma indicate less change in the final shares of the winning and losing coalitions compared to their pre-innovation shares. The values of gamma used represent 80%, 50%, 20% and 5% of pre-innovation share. In other words, if a coalition controlled 40% of the market prior to an innovation, under the lowest value of gamma those firms would control 32% of the market (80% of the original share) after the dominant design was established. The general idea is that given the contest between two innovations, firms that select the losing design are damaged in terms of market presence while those that adopt the ultimately victorious design are strengthened. The issue is the degree of change. My assumption is that some firms may prefer to be major forces in a smaller market than to adopt the winning design late and suffer latecomer disadvantages (Wernerfelt and Karnani, 1987; Christensen, Suarez et al., 1998).

The returns are generated from:

\[
\frac{\text{share}_i}{\text{share}_J} = \frac{1}{1 + e^{-\gamma x}}
\]

where share, is the share of firm i, share, is the share of coalition J (of which i is a member) modified by the logistic function. The effects of the four levels of gamma are illustrated in Figure 4.3.

The rationale for this approach is derived from Arthur’s (1988) paper in which he demonstrated the lock-in effect of increasing returns markets. The approach is simple mathematically. He showed that given preferences by adopters between two technologies,
they will adopt the less preferred technology when the number of adopters of that
technology are sufficiently high. For instance, he showed that those who prefer
technology A will choose B if

\[ n_A - n_B < \frac{(b_R - a_R)}{r} \]

where \( n_A \) and \( n_B \) are the number of prior adopters of the relevant technologies, \( b_R \) and \( a_R \) are the preferences over the technologies with \( a_R > b_R \) and \( r \) is a factor describing the type of return where positive values indicate increasing returns. While Arthur demonstrated that in the limit, values of \( r \) greater than 0 lead to lock in or choice of one technology or the other only, two observations are important.

First, the value of \( r \) is not constrained above. Given the result show above, it is easy to see that if preferences are held constant, increasing \( r \) means that the difference between adopters sufficient to lead an adopter to choose the less preferable technology decreases. That is, high values of \( r \) can lead to lock in very quickly while low values can prolong the market argument. Second, lock in occurs in every case but over some (large) number of adopters. If the number of potential adopters is not large (as is often the case among a set of producers), the absolute outcomes Arthur noted may not occur. Instead, we should expect some more or less skewed distribution of adoption among firms that tends to but not necessarily achieves a dichotomous outcome. These two effects should lead to expectations about the division of market shares such that high values of \( r \) imply that firms are more willing to adopt a leading technology despite other preferences. The gamma formula presented above captures the result of these expectations.
The values for knowledge overlap, rivalry and size are randomly generated arrays using Microsoft Excel®. Overlap is derived from a normal distribution $[.2, .8]$. Here I assume that firms in an industry share a certain level of knowledge but that no firm knows everything about another. This is obviously but perhaps trivially true. Empirical tests using common patent citations as a measure of overlap (Mowery, Oxley et al., 1996; Stuart and Podolny, 1996; Mowery, Oxley et al., 1998) may exhibit complete overlap but this should be rare. Therefore, I constrain the overlap to the values noted. Size and rivalry are derived from uniform distributions. For the purposes of generating large sample results, five each of the knowledge overlap, size and rivalry arrays were created and the simulation combines them at random as a set of variables for each run.

The simulation develops adoption outcomes for each possible pair of firms as innovators. I assume that the innovations are introduced simultaneously and that firms may choose to adopt one with appropriate investments in learning about that innovation, defer by investing in learning about both or decide not to invest at all. The key factors are knowledge overlap which determines how quickly a firm can learn enough to introduce a competitive product, the size of the coalitions that have already adopted the innovations, the scope of rivalry and the effects uncertainty and returns to adoption. The utility to each firm for adoption is based on expected share at the conclusion of the game (this follows Axelrod, et al (1995)).

Firms are endowed with relative knowledge overlap with respect to the innovators. The higher the overlap, the more a firm knows about an innovator. I also assume that some
minimum level of overlap is required to successfully introduce a competitive product. I arbitrarily made this value equal to 90% knowledge overlap. Given a set of overlap values, a firm can invest in learning. Here, I draw upon the idea of absorptive capacity or that the more firms know about a field, the quicker they can learn new information (Cohen and Levinthal, 1990). In order to capture this, I randomly assigned each firm a learning rate that varied between 5% and 10% of the overlap base with the idea that they invest to make up the difference in knowledge through learning. In this example, firm i needs to make up the 20% differential in knowledge and could do so at a rate of 3.5% to 7% per cycle. Depending on the rate draw, firm i could introduce a product in three to six cycles. The investment for learning is the same for all firms without regard for the learning rate. This merely captures the idea that some firms are better at learning than others. In the simulation, firms assess overlap and generate an expected entry time based on learning rate and knowledge difference.

In each cycle, firms compare the value of adopting an innovation or doing nothing. Some key components of the evaluation include:

1) expectation of final coalition size. This is bounded on the low end by the current size if firm i is a member or current size plus firm i. The high end is (1 - share of alternate coalition). The working value is the midpoint of the two.

2) influence of rivalry. Following Axelrod, et al (1995). I assume here that firms would prefer to avoid rivals if possible. I enforce this by removing the rival's share from the coalition size calculations. This lowers the ultimate size of
coalitions and makes them less valuable to an adopter, the degree of which varies with gamma.

3) time of entry. Incorporating the work of Wernerfelt and Kamani (1987) and Christensen, Suarez and Utterback (1998), firms that enter a winning coalition early enjoy some first mover benefits in terms of enhanced share. Late entrants are penalized. Estimates are based on an expected dominant design cycle with the window of opportunity being that cycle plus or minus two. Entries within the window do not experience increased or decreased share as a function of timing.

4) the cost of switching if the firm has previously decided to adopt the other innovation. I impute a cost to switching that is designed to retard changes based on a coalition taking a lead. Firms face costs in learning new skills, changing the development approach and in areas such as training, advertising and so on.

A coalition around an innovation can win or lose and the effects will be different. The total value of a decision is the sum of the value if the coalition joined wins and the value if it loses. Firms decide which, if any, coalition they should join by comparing 15 cycle net present value assessments of returns discounted at 10%. This value flows are constructed based upon current share (which is assumed to hold until the firm introduces a new product) or until new technology takes a 50% or greater share of the market. At that point, the value of the existing technology begins to dissipate and eventually goes to zero.
Once the NPVs are generated, firms select one action if it is sufficiently larger than the alternatives. In order to avoid problems of measurement noise in the simulation and in the real world, I assumed that only results that were at least 5% greater than alternatives would be a sufficient indication of action. If the results were less distinct, the firm was considered indifferent between them. I ordered the results for each firm and developed a sequential comparison so the choices under indifference were consistent. For instance, if a firm was indifferent between adopting A or B but preferred either to doing nothing, the outcome was a decision to invest in both. If the firm was indifferent between adopting A or doing nothing, I randomized the outcome to choice between the two but not to include any investment in B.

Upon decision, the firm invests in learning. The levels of knowledge were updated with each cycle. Once sufficient learning was accumulated, the firm introduced the product and the values for coalition size changed. This affects the valuations estimated by other firms in subsequent cycles. The simulation is run for 25 cycles for each pair of leadfirm innovators. The next level is varying the value of gamma. Once all firms have been run for each level of gamma, that run of the simulation terminates.

I emphasize that all firms evaluate their positions in each round, even if they have already adopted an innovation. While the simulation is written so as to discourage easy, cost free switching, it will happen if the returns to doing so are greater than the costs. This is
particularly important in the case of high returns to adoption as I anticipated that some innovators may be inclined to switch.

The event of interest is the introduction of a product or the entry into a particular coalition by a given firm. Due to the number of runs undertaken for this analysis and the fact that I am generating event histories, I decided to sample what specific firms did, identifying them prior to recording the outcomes. A sampling rate of roughly .125 for the gamma values and .125 on the firms was used. In other words, the chance that a given firm under a given gamma was selected is about 1.56%. A firm was tracked until it entered a coalition or failed to enter by the twentieth cycle. Thus, event histories for firms range from three cycles to twenty and the latter are, with few exceptions, right censored data. This generated an overall data set of approximately 31,000 observations. The summary data for coalitions was likewise sampled at a rate of 10%. Output was written to text files, concatenated and then written to Stata 7.0 for analysis.
Figure C.1 Four Gamma values and their effect on post dominant design share
Option Explicit

Option Base 1

' introducing variables and arrays
Private overlap(10, 10) As Single
Private riv(10, 10) As Integer
Private share(10, 2) As Single
Private coal(10, 9) As Single
Private learn(10, 4) As Single

' initializing coal
Public Sub cmd3_Click()

    Dim A As Integer
    Dim B As Integer
    Dim intRow As Integer
    Dim intCol As Integer

    For A = LBound(coal) To UBound(coal)
        For B = LBound(coal, 2) To UBound(coal, 2)
            coal(A, B) = 0
        Next B
    Next A

End Sub

Private Sub cmd4_Click()

' looping variables

Dim leadfirmA As Integer
Dim leadfirmB As Integer
Dim cycle As Integer
Dim gamma As Single
Dim gamcheck As Integer
Dim gamrand As Single
Dim firmcheck(10, 1) As Integer
Dim firmrand As Single
Dim writecheck(10, 1) As Integer
Dim uncert As Single
Dim inituncert As Single
Dim workuncert As Single
Dim initsum As Single
Dim bigcyc As Integer
Dim record As Integer
Dim record2 As Integer

'load state variable arrays

Dim intRow As Integer
Dim intCol As Integer
Dim shareslct As Single
Dim rivslct As Single
Dim olslct As Single
Dim scorecheck(125, 1) As Single
Dim score As Single
Dim selectsh As Integer
Dim selectrv As Integer
Dim selectol As Integer
Dim x As Integer
Dim caseres(1, 3) As Integer

Open "C:\VBFiles\Paper3\scorecheck.txt" For Input As #5
For intRow = LBound(scorecheck) To UBound(scorecheck)
  Input #5, scorecheck(intRow, 1)
Next intRow
Close #5

For bigcyc = 1 To 50
  'select share array

  Randomize
  shareslct = Int((Rnd * 5) + 1)

  Randomize
  olslct = Int((Rnd * 5) + 1)

  Randomize
  rivslct = Int((Rnd * 5) + 1)

  score = ((shareslct - 1) * 25) + ((rivslct - 1) * 5) + (olslct)
scorecheck(score, 1) = scorecheck(score, 1) + 1

For x = 1 To 5
    If sharestct = x Then
        selectsh = x
        Exit For
    End If
Next x

caseses(1, 1) = selectsh

Select Case selectsh

Case 1

    Open "C:\VBFiles\Paper3\share1.txt" For Input As #3
    For intRow = LBound(share) To UBound(share)
        For intCol = LBound(share, 2) To UBound(share, 2)
            Input #3, share(intRow, intCol)
        Next intCol
    Next intRow
    Close #3

Case 2

    Open "C:\VBFiles\Paper3\share2.txt" For Input As #3
    For intRow = LBound(share) To UBound(share)
        For intCol = LBound(share, 2) To UBound(share, 2)
            Input #3, share(intRow, intCol)
        Next intCol
    Next intRow
    Close #3

Case 3

    Open "C:\VBFiles\Paper3\share3.txt" For Input As #3
    For intRow = LBound(share) To UBound(share)
        For intCol = LBound(share, 2) To UBound(share, 2)
            Input #3, share(intRow, intCol)
        Next intCol
    Next intRow
    Close #3

Case 4
Open "C:\VBFiles\Paper3\share4.txt" For Input As #3
For intRow = LBound(share) To UBound(share)
  For intCol = LBound(share, 2) To UBound(share, 2)
    Input #3, share(intRow, intCol)
    Next intCol
  Next intRow
Close #3

Case 5

Open "C:\VBFiles\Paper3\share5.txt" For Input As #3
For intRow = LBound(share) To UBound(share)
  For intCol = LBound(share, 2) To UBound(share, 2)
    Input #3, share(intRow, intCol)
    Next intCol
  Next intRow
Close #3

End Select

' select overlap array

For x = 1 To 5
  If olslct = x Then
    selectol = x
  Exit For
  End If
Next x

caseres(1, 3) = selectol

Select Case selectol

Case 1

Open "C:\VBFiles\Paper3\overlap1.txt" For Input As #1
For intRow = LBound(overlap, 1) To UBound(overlap, 1)
  For intCol = LBound(overlap, 2) To UBound(overlap, 2)
    Input #1, overlap(intRow, intCol)
    Next intCol
  Next intRow
Close #1

Case 2
Open "C:\VBFiles\Paper3\overlap2.txt" For Input As #1
For intRow = LBound(overlap, 1) To UBound(overlap, 1)
    For intCol = LBound(overlap, 2) To UBound(overlap, 2)
        Input #1, overlap(intRow, intCol)
    Next intCol
Next intRow
Close #1

Case 3

Open "C:\VBFiles\Paper3\overlap3.txt" For Input As #1
For intRow = LBound(overlap, 1) To UBound(overlap, 1)
    For intCol = LBound(overlap, 2) To UBound(overlap, 2)
        Input #1, overlap(intRow, intCol)
    Next intCol
Next intRow
Close #1

Case 4

Open "C:\VBFiles\Paper3\overlap4.txt" For Input As #1
For intRow = LBound(overlap, 1) To UBound(overlap, 1)
    For intCol = LBound(overlap, 2) To UBound(overlap, 2)
        Input #1, overlap(intRow, intCol)
    Next intCol
Next intRow
Close #1

Case 5

Open "C:\VBFiles\Paper3\overlap5.txt" For Input As #1
For intRow = LBound(overlap, 1) To UBound(overlap, 1)
    For intCol = LBound(overlap, 2) To UBound(overlap, 2)
        Input #1, overlap(intRow, intCol)
    Next intCol
Next intRow
Close #1

End Select

'selecting rivalry array

For x = 1 To 5
    If rivilstct = x Then
        selectriv = x
End
Exit For
End If
Next x

cases(1, 2) = selectRiv

Select Case selectRiv

Case 1

Open "C:\VBFiles\Paper3\rivalry1.txt" For Input As #2
For intRow = LBound(riv, 1) To UBound(riv, 1)
   For intCol = LBound(riv, 2) To UBound(riv, 2)
      Input #2, riv(intRow, intCol)
      intCol
   Next intCol
Next intRow
Close #2

Case 2

Open "C:\VBFiles\Paper3\rivalry2.txt" For Input As #2
For intRow = LBound(riv, 1) To UBound(riv, 1)
   For intCol = LBound(riv, 2) To UBound(riv, 2)
      Input #2, riv(intRow, intCol)
      intCol
   Next intCol
Next intRow
Close #2

Case 3

Open "C:\VBFiles\Paper3\rivalry3.txt" For Input As #2
For intRow = LBound(riv, 1) To UBound(riv, 1)
   For intCol = LBound(riv, 2) To UBound(riv, 2)
      Input #2, riv(intRow, intCol)
      intCol
   Next intCol
Next intRow
Close #2

Case 4

Open "C:\VBFiles\Paper3\rivalry4.txt" For Input As #2
For intRow = LBound(riv, 1) To UBound(riv, 1)
   For intCol = LBound(riv, 2) To UBound(riv, 2)
      Input #2, riv(intRow, intCol)
      intCol
   Next intCol
Next intRow
Close #2

Case 5

Open "C:\VBFiles\Paper3\rivalry5.txt" For Input As #2
For intRow = LBound(riv, 1) To UBound(riv, 1)
   For intCol = LBound(riv, 2) To UBound(riv, 2)
      Input #2, riv(intRow, intCol)
      Next intCol
   Next intRow
Close #2
End Select:

Open "C:\VBFiles\Practice\learning.txt" For Input As #4
For intRow = LBound(learn) To UBound(learn)
   For intCol = LBound(learn, 2) To UBound(learn, 2)
      Input #4, learn(intRow, intCol)
      Next intCol
   Next intRow
Close #4

'initial uncertainty declaration:

Do

Randomize
uncert = Rnd
inituncert = uncert

If uncert >= 0.5 Then
   Exit Do
End If
Loop

'gamma variable declaration
Dim loopcount As Integer

For loopcount = 1 To 4

If loopcount = 1 Then
   gamma = -7.5371
Else
   If loopcount = 2 Then
gamma = -13.86
Else
  If loopcount = 3 Then
    gamma = -24.4235
  Else
    gamma = -38.918
  End If
End If
End If

Randomize
gamrand = Rnd
If gamrand <= 0.125 Then
  gamcheck = 1
Else
  gamcheck = 0
End If

'leadfirm A & B variable declaration

For leadfirmA = 1 To 9
  For leadfirmB = (leadfirmA + 1) To 10
    initsum = share(leadfirmA, 1) + share(leadfirmB, 1)
  Next y
  Dim y As Integer
  For y = 1 To 10
    If y <> leadfirmA And y <> leadfirmB Then
      Randomize
      firmrand = Rnd
      If firmrand <= 0.125 Then
        firmcheck(y, 1) = 1
      Else
        firmcheck(y, 1) = 0
      End If
      Else
        firmcheck(y, 1) = 0
      End If
    Next y

'learning rate as a random draw between .05 and .1

For y = 1 To 10
Dim learnrand As Single
Dim pace(10, 2) As Single

Do

Randomize
learnrand = Rnd

If learnrand >= 0.05 Then
    If learnrand <= 0.1 Then
        pace(y, 1) = 1 + learnrand
        pace(y, 2) = 1 + learnrand / 2
        Exit Do
    End If
End If

Loop
Next y

'overlap variables
Dim ola As Single
Dim ob As Single
Dim comcycleA As Integer
Dim comcycAdef As Integer
Dim comcycleB As Integer
Dim comcycBdef As Integer
Dim defcycle As Integer
Dim obj As Single
Dim olgain As Single
Dim entrycycle(10, 4) As Integer
Dim uncyc As Integer
Dim uncheck As Single
Dim curcyc As Integer
Dim zyc As Integer

'coalition size and rivalry variables
Dim sharecoal As Single
Dim shareriv As Single
Dim coalsum As Single
Dim conc As Single
Dim meanola As Single
Dim meanolb As Single
Dim olaps As Single
Dim olapumb As Single
Dim learnrate As Single
Dim n As Integer
Dim l As Integer
Dim firstjoin(1, 2) As Integer

'summary variables and arrays
Dim u(10, 13) As Single
Dim counter As Integer
Dim counterA As Integer
Dim counterB As Integer
Dim counterC As Integer
Dim join(10, 1) As Integer
Dim curshare(30, 3) As Single

'calling array loads

Call cmd3_Click

c0al(leadfirmA, 1) = leadfirmA
c0al(leadfirmA, 2) = share(leadfirmA, 1)
c0al(leadfirmA, 3) = cycle
join(leadfirmA, 1) = 1
cycle = 0

c0al(leadfirmB, 4) = leadfirmB
c0al(leadfirmB, 5) = share(leadfirmB, 1)
c0al(leadfirmB, 6) = cycle
join(leadfirmB, 1) = 1

cycle = 0

c0alsum = 0

For n = 1 To 10
  c0alsum = c0alsum + share(n, 1) ^ 2
Next n

c0nc = c0alsum

olapsuma = 0
olapsumb = 0
For l = 1 To 10
  olapsuma = olapsuma + overlap(l, leadfirmA)
  olapsumb = olapsumb + overlap(l, leadfirmB)
Next l

meanola = olapsuma / 10
meanolb = olapsumb / 10

'generated data arrays
Dim check1(10, 7) As Single

'cycle loop

For cycle = 1 To 30

'calculating overlap values

For y = 1 To 10

'Entry cycle for A

If cycle = 1 Then
    ola = overlap(y, leadfirmA)
    learn(y, 1) = overlap(y, leadfirmA)
Else
    if learn(y, 1) < 1 Then
        ola = learn(y, 1) * learn(y, 2)
        learn(y, 1) = ola
    Else
        ola = 1
        learn(y, 1) = ola
    End If
End If

If ola > 0.8 Then
    comcycleA = 0
    comycAdef = 0
Else
    obj = 0.8 / ola
    comcycleA = 1
    comycAdef = 1
    For x = 1 To 20
        olgain = pace(y, 1) ^ comcycleA
        If olgain > obj Then
            Exit For
        Else
            comcycleA = comcycleA + 1
        End If
    Next x
For x = 1 To 40
    olgain = pace(y, 2) ^ comcycAdef
    If olgain > obj Then
        Exit For
    Else
        comcycAdef = comcycAdef + 1
    End If
Next x
End If

entrycycle(y, 1) = comcycleA
entrycycle(y, 2) = comcycAdef

'entrycycle for B

If cycle = 1 Then
    olb = overlap(y, leadfirmB)
    learn(y, 3) = overlap(y, leadfirmB)
Else
    If learn(y, 3) < 1 Then
        olb = learn(y, 3) * learn(y, 4)
        learn(y, 3) = olb
    Else
        olb = 1
        learn(y, 3) = olb
    End If
End If

If olb > 0.8 Then
    comcycleB = 0
    comcycBdef = 0
Else
    obj = 0.8 / olb
    comcycleB = 1
    comcycBdef = 1
    For x = 1 To 15
        olgain = pace(y, 1) ^ comcycleB
        If olgain > obj Then
            Exit For
        Else
            comcycleB = comcycleB + 1
        End If
    Next x
End If

For x = 1 To 30
olgain = pace(y, 2) ^ comcycBdef
If olgain > obj Then
    Exit For
Else
    comcycBdef = comcycBdef + 1
End If
Next x
End If

entrycycle(y, 3) = comcycleB
entrycycle(y, 4) = comcycBdef

Next y

For y = 1 To 10    'determining coalition share A
    sharecoal = 0
    shareriv = 0
    For x = 1 To 10
        If coal(x, 1) > 0 Then
            sharecoal = sharecoal + share(coal(x, 1), 1)
            shareriv = shareriv + share(coal(x, 1), 1) * riv(y, coal(x, 1))
        End If
    Next x
    check1(y, 1) = y
    check1(y, 2) = sharecoal
    check1(y, 3) = shareriv

'determining coalition share B

    sharecoal = 0
    shareriv = 0
    For x = 1 To 10
        If coal(x, 4) > 0 Then
            sharecoal = sharecoal + share(coal(x, 4), 1)
            shareriv = shareriv + share(coal(x, 4), 1) * riv(y, coal(x, 4))
        End If
    Next x
check1(y, 4) = sharccoal
check1(y, 5) = shareriv

Next y

curshare(cycle, 1) = check1(1, 2)
curshare(cycle, 2) = check1(1, 4)

If cycle > 1 Then
    If curshare(cycle, 1) + curshare(cycle, 2) > curshare(cycle - 1, 1) + curshare(cycle - 1, 2) Then
        curcyc = curcyc + 1
        curshare(cycle, 3) = curcyc
    Else
        curcyc = curcyc
        curshare(cycle, 3) = curcyc
    End If
End If

'generate random expectation of when dom design emerges

Dim design As Integer
Dim designa As Integer
Dim designshare As Integer
Dim lastshare As Single
Dim compshare As Integer
Dim AB As Single

If cycle = 1 Then
    compshare = 1
Else
    If cycle > 1 And lastshare = AB Then
        compshare = 2
    Else
        compshare = 3
    End If
End If

AB = check1(1, 2) + check1(1, 4)

Select Case compshare

Case 1
If AB < uncert Then
  uncert = uncert
Else
  uncert = AB
End If

design = 2 * Int(1 / (uncert * AB))
lastshare = check1(1, 2) + check1(1, 4)

Case 2

design = design

Case 3

If AB < uncert Then
  uncert = uncert
Else
  uncert = AB
End If

If check1(1, 2) > 0.5 Then
  design = 0
Else
  If check1(1, 4) > 0.5 Then
    design = 0
  Else
    design = 2 * Int(1 / (uncert * AB))
  End If
  lastshare = check1(1, 2) + check1(1, 4)
End If
End Select

For y = 1 To 10

Dim lowlim As Single
Dim uplim As Single
Dim mid As Single
Dim expect As Single
Dim value As Single
Dim wina As Single: wina = Format(wina, "fixed")
Dim losea As Single: losea = Format(losea, "fixed")
Dim winb As Single: winb = Format(winb, "fixed")
Dim loseb As Single: loseb = Format(loseb, "fixed")
Dim lowdes As Integer
Dim updes As Integer
Dim entry As Integer
Dim early As Single
Dim late As Single
Dim time As Single
Dim rivwma As Single
Dim rivlosea As Single
Dim rivwinb As Single
Dim rivloseb As Single
Dim altlowlim As Single
Dim altmid As Single
Dim valuea As Single
Dim valueb As Single
Dim valuedef As Single
Dim valueflow(25, 1) As Double
Dim rate As Double
Dim npvcycle As Integer
Dim learncost As Single
Dim switchcost As Single
Dim npva As Double
Dim npvb As Double
Dim npvdeta As Double
Dim npvdetb As Double
Dim npvdetfer As Double

'coalition success probabilities assuming uniform distribution

Dim psucca As Single
Dim psuccb As Single
Dim interm As Single

'Coalition A values

'calculating value of winning in A with committed strategy - requires conditional 'probabilities of coalition A winning under variety of circumstances

If check1(y, 2) < 0.5 Then
    If check1(y, 4) < 0.5 Then
        If coal(y, 1) > 0 Then
            interm = 1 - (check1(y, 2) + check1(y, 4))
            psucca = (interm - (0.5 - check1(y, 2))) / interm
            lowlim = 0.5
        Else
            If entrycycle(y, 1) = 0 Then
If check1(y, 2) + share(y, 1) > 0.5 Then
  psucca = 1
  lowlim = check1(y, 2) + share(y, 1)
Else
  interm = 1 - (check1(y, 2) + check1(y, 4))
  psucca = ((interm - share(y, 1)) - (0.5 - check1(y, 2) - share(y, 1))) / (interm - share(y, 1))
  lowlim = 0.5
End If
Else
  interm = 1 - (check1(y, 2) + check1(y, 4))
  psucca = (interm - (0.5 - check1(y, 2))) / interm
  lowlim = 0.5
End If
End If
Else
  psucca = 0
  lowlim = check1(y, 2)
End If
Else
  If coal(y, 1) > 0 Then
    psucca = 1
    lowlim = check1(y, 2)
  Else
    If entrycycle(y, 1) = 0 Then
      psucca = 1
      lowlim = check1(y, 2) + share(y, 1)
    Else
      psucca = 1
      lowlim = check1(y, 2)
    End If
  End If
End If

uplim = 1 - check1(y, 4)
If uplim <= 0.5 Then
  value = 0
Else
  mid = (uplim - lowlim) / 2 + lowlim
  expect = mid - 0.5
  value = (share(y, 1) / mid) * (1 / (1 + Exp(gamma * expect)))
End If

'generating the value exponent for early or late entry. Here,
'entry more than two cycles before dom design emerges pays off
'with a bonus in share while entry more than 1 cycle after dom des has
'a penalty

If design - 2 >= 0 Then
    lowdes = design - 2
Else
    lowdes = design
End If

updes = design + 1
tenry = 0
tearly = 0.9
tlate = 0.85

If entrycycle(y, 1) <= lowdes Then
    entry = entrycycle(y, 1) - lowdes
    time = early
Else
    If entrycycle(y, 1) >= updes Then
        entry = entrycycle(y, 1) - updes
        time = late
    Else
        time = 1
    End If
End If

wina = time ^ (entry) * value * psucca

'calculating value of losing in A with committed strategy.

If coal(y, 1) > 0 Then
    lowlim = check\1(1, 2)
Else
    lowlim = check 1(1, 2) + share(y, 1)
End If
uplim = 0.4999
mid = (uplim - lowlim) / 2 + lowlim
expect = mid - 0.5
value = (share(y, 1) / mid) * (1 / (1 + Exp(gamma * expect)))

losea = time ^ (entry) * value * (1 - psucca)

'calculating rivalry utility for A
'value of winning with rivals in coalition
uplim = 1 - check1(y, 4)
If uplim <= 0.5 Then
  value = 0
Else
  altlowlim = lowlim - (check1(y, 2) - check1(y, 3))
  mid = (uplim - altlowlim) / 2 + altlowlim
  altmid = (uplim - lowlim) / 2 + lowlim
  expect = mid - 0.5
  value = (share(y, 1) / altmid) * (1 / (1 + Exp(gamma * expect)))
End If

'generating the value exponent for early or late entry.

If design - 2 >= 0 Then
  lowdes = design - 2
Else
  lowdes = design
End If
updes = design + 1
teny = 0
early = 0.9
late = 0.85

If entrycycle(y, 1) <= lowdes Then
  entry = entrycycle(y, 1) - lowdes
  time = early
Else
  If entrycycle(y, 1) >= updes Then
    entry = entrycycle(y, 1) - updes
    time = late
  Else
    time = 1
  End If
End If
End If

rivwina = time ^ (entry) * value * psucca

'calculating rivalry value of losing in A with committed strategy.

If coal(y, 1) > 0 Then
  lowlim = check1(y, 3)
Else
lowlim = check1(y, 3) + share(y, 1)
End If
uplim = 0.4999
mid = (uplim - lowlim) / 2 + lowlim
expect = mid - 0.5
value = (share(y, 1) / mid) * (1 / (1 + Exp(gamma * expect)))

rivlosea = time^(entry) * value * (1 - psucca)

'input flow values into Flow array

Dim curval As Double
Dim intval As Double
Dim majority1 As Integer
Dim majority2 As Integer
Dim fushare As Integer
Dim growrate As Single

If AB < 0.5 Then
    majority1 = Int((design * 0.5) + 1)
    majority2 = Int((design * 0.75) + 2)
    growrate = 0.25 / (majority2 - majority1)
    fushare = 0
Else
    If AB < 0.75 Then
        majority1 = 0
        majority2 = Int((0.75 - AB) * 10) + 1
        growrate = (0.75 - AB) / majority2
        fushare = AB + growrate
    Else
        majority1 = 0
        majority2 = 0
        fushare = 0
    End If
End If

npvcycle = entrycycle(y, 1)
valuea = wina + losea + rivwina + rivlosea

If coal(y, 1) = 0 Then
    If join(y, 1) >= 1 Then
        If npvcycle = 0 Then
            switchcost = valuea * 0.25 * join(y, 1)
        Else
        End If
End If
switchcost = 0
learncost = 0.075 * share(y, 1)
End If
Else
switchcost = 0
learncost = 0.075 * share(y, 1)
End If
Else
switchcost = 0
learncost = 0
End If

rate = 0.1

For x = 1 To 25

If npvcycle > 0 Then
  If majority1 > 0 Then
    valueflow(x, 1) = share(y, 1) * (1 - uncert) - learncost - switchcost
    npvcycle = npvcycle - 1
    majority1 = majority1 - 1
    majority2 = majority2 - 1
  Else
    If majority2 > 0 Then
      valueflow(x, 1) = (share(y, 1) / (1 - fushare)) * (1.5 - 2 * fushare) - learncost - switchcost
      fushare = fushare + growrate
      majority2 = majority2 - 1
    Else
      valueflow(x, 1) = -learncost - switchcost
    End If
  End If
Else
  valueflow(x, 1) = valuea * uncert
End If

Next x

curval = 0
intval = 0

'NPV evaluation, discount rate = rate, cash flows are sums of utility

For x = 1 To 25
  curval = valueflow(x, 1) / ((1 + rate) ^ (x - 1))
intval = intval ÷ curval
Next x

npva = intval
'generating the value of a deferred decision. This assumes that firms
'can discern the winner at design - 2 cycles
'value for coalition A

Dim newentry As Integer
Dim defa As Single
Dim defb As Single
Dim deferred As Single

If check1(y, 2) < 0.5 Then
  If coal(y, 1) > 0 Then
    lowlim = 0.5
  Else
    If check1(y, 2) + share(y, 1) > 0.5 Then
      lowlim = check1(y, 2) + share(y, 1)
    Else
      lowlim = 0.5
    End If
  End If
Else
  lowlim = check1(y, 2)
End If

uplim = 1 - check1(y, 4)
If uplim <= 0.5 Then
  value = 0
Else
  mid = (uplim - lowlim) / 2 + lowlim
  expect = mid - 0.5
  value = (share(y, 1) / mid) * (1 / (1 + Exp(gamma * expect)))
End If

'generating the value exponent for early or late entry.

newentry = (entrycycle(y, 2) + 2 - design) / 2
If design - 2 >= 0 Then
  lowdes = design - 2
Else
  lowdes = design
End If
updes = design + 1
entry = 0
early = 0.9
late = 0.85

If newentry <= lowdes Then
    entry = newentry - lowdes
    time = early
Else
    If newentry >= updes Then
        entry = newentry - updes
        time = late
    Else
        time = 1
    End If
End If

If y = leadfirmA Then
defa = 0
Else
    If design - 2 < 0 Then
defa = 0
    Else
        If wina > 0 Then
defa = time ^ (entry) * value * psucca * (wina / (wina + rivwina))
    Else
defa = time ^ (entry) * value * psucca
    End If
End If
End If

'NPV evaluation for deferred decision

npvcycle = entrycycle(y, 2)

If join(y, 1) >= 1 Then
    If entrycycle(y, 1) = 0 Then
        switchcost = defa * 0.25 * join(y, 1)
    Else
        switchcost = 0
    End If
End If
End If

rate = 0.1
For x = 1 To 25
  If npvcycle > 0 Then
    If x <= design - 2 Then
      learmcost = share(y, 1) * 0.0375
      If AB < 0.5 Then
        valueflow(x, 1) = (share(y, 1) - learmcost - switchcost) * uncert
      End If
      npvcycle = npvcycle - 1
    Else
      valueflow(x, 1) = (1 / (1 + Exp(gamma * (0.5 - AB)))) * share(y, 1) - learmcost - switchcost
    End If
  Else
    learmcost = share(y, 1) * 0.075
    If AB < 0.5 Then
      valueflow(x, 1) = (share(y, 1) - learmcost - switchcost) * uncert
      npvcycle = npvcycle - 1
    Else
      valueflow(x, 1) = (1 / (1 + Exp(gamma * (0.5 - AB)))) * share(y, 1) - learmcost - switchcost
    End If
  End If
Else
  If AB < 0.5 Then
    valueflow(x, 1) = defa * uncert
  Else
    valueflow(x, 1) = defa
  End If
End If
Next x

'NPV evaluation
curval = 0
intval = 0

'no additional entry costs if already in this coalition

For x = 1 To 25
  curval = valueflow(x, 1) / ((1 + rate) ^ (x - 1))
  intval = intval + curval
Next x
npvdefa = intval

'B calculations

If check1(y, 4) < 0.5 Then
  If check1(y, 2) < 0.5 Then
    If coal(y, 4) > 0 Then
      interm = 1 - (check1(y, 2) + check1(y, 4))
      psuccb = (interm - (0.5 - check1(y, 4))) / interm
      lowlim = 0.5
    Else
      If entrycycle(y, 3) = 0 Then
        If check1(y, 4) + share(y, 1) > 0.5 Then
          psuccb = 1
          lowlim = check1(y, 4) + share(y, 1)
        Else
          interm = 1 - (check1(y, 2) + check1(y, 4))
          psuccb = ((interm - share(y, 1)) - (0.5 - check1(y, 4) - share(y, 1))) / (interm - share(y, 1))
          lowlim = 0.5
        End If
      Else
        interm = 1 - (check1(y, 2) + check1(y, 4))
        psuccb = (interm - (0.5 - check1(y, 4))) / interm
        lowlim = 0.5
      End If
    End If
  End If
Else
  psuccb = 0
  lowlim = check1(y, 4)
End If
Else
  If coal(y, 4) > 0 Then
    psuccb = 1
    lowlim = check1(y, 4)
  Else
    If entrycycle(y, 3) = 0 Then
      psuccb = 1
      lowlim = check1(y, 4) + share(y, 1)
    Else
      psuccb = 1
      lowlim = check1(y, 4)
    End If
  End If
End If
End If
uplim = 1 - check1(1, 2)
If uplim <= 0.5 Then
   value = 0
Else
   mid = (uplim - lowlim) / 2 + lowlim
   expect = mid - 0.5
   value = (share(y, 1) / mid) * (1 / (1 + Exp(gamma * expect)))
End If

'resetting the value exponent

If design - 2 >= 0 Then
   lowdes = design - 2
Else
   lowdes = design
End If

updes = design + 1
entry = 0
early = 0.9
late = 0.85

If entrycycle(y, 3) <= lowdes Then
   entry = entrycycle(y, 3) - lowdes
   time = early
Else
   If entrycycle(y, 3) >= updes Then
      entry = entrycycle(y, 3) - updes
      time = late
   Else
      time = 1
   End If
End If

winb = time ^ (entry) * value * psuccess

'calculating value of losing in B with committed strategy

If coal(y, 4) > 0 Then
   lowlim = check1(1, 4)
Else
   lowlim = check1(1, 4) + share(y, 1)
End If
uplim = 0.4999
mid = (uplim - lowlim) / 2 + lowlim
expect = mid - 0.5
value = (share(y, 1) / mid) * (1 / (1 + Exp(gamma * expect)))

loseb = time ^ (entry) * value * (1 - psuccb)

'generating the rivalry utility values for B

uplim = 1 - check1(y, 2)
If uplim <= 0.5 Then
    value = 0
Else
    alttlowlim = lowlim - (check1(y, 4) - check1(y, 5))
    mid = (uplim - alttlowlim) / 2 + alttlowlim
    altmid = (uplim - lowlim) / 2 + lowlim
    expect = mid - 0.5
    value = (share(y, 1) / altmid) * (1 / (1 + Exp(gamma * expect)))
End If

'generating the value exponent for early or late entry.

If design - 2 >= 0 Then
    lowdes = design - 2
Else
    lowdes = design
End If
updes = design + 1
time = 1
entry = 0
early = 0.9
late = 0.85

If entrcycle(y, 3) <= lowdes Then
    entry = entrcycle(y, 1) - lowdes
    time = early
Else
    If entrcycle(y, 3) >= updes Then
        entry = entrcycle(y, 3) - updes
        time = late
    Else
        time = 1
    End If
End If
rivwinb = time ^ (entry) * value * psuccb

'calculating rivalry value of losing in B with committed strategy.

If coal(y, 4) > 0 Then
  lowlim = check1(y, 5)
Else
  lowlim = check1(y, 5) + share(y, 1)
End If

uplim = 0.4999
mid = (uplim - lowlim) / 2 + lowlim
expect = mid - 0.5
value = (share(y, 1) / mid) * (1 / (1 + Exp(gamma * expect)))

rivloseb = time ^ (entry) * value * (1 - psuccb)

'NPV calculations for coalition B

If AB < 0.5 Then
  majority1 = Int(designed * 0.5) + 1
  majority2 = Int(designed * 0.75) + 2
  growrate = 0.25 / (majority2 - majority1)
  fushare = 0
Else
  If AB < 0.75 Then
    majority1 = 0
    majority2 = Int((0.75 - AB) * 10) + 1
    growrate = (0.75 - AB) / majority2
    fushare = AB + growrate
  Else
    majority1 = 0
    majority2 = 0
    fushare = 0
  End If
End If
npvcycle = entrycycle(y, 3)
valueb = winb + loseb + rivwinb + rivloseb

If coal(y, 4) = 0 Then
  If join(y, 1) >= 1 Then
    If npvcycle = 0 Then

switchcost = valueb * 0.25 * join(y, 1)
learncost = 0
Else
switchcost = 0
!learncost = 0.075 * share(y, 1)
End If
Else
switchcost = 0
learncost = 0.075 * share(y, !)
End If
Else
switchcost = 0
learncost = 0
End If
rate = 0.1

For x = 1 To 25
If npvcycle > 0 Then
If majority1 > 0 Then
valueflow(x, 1) = share(y, 1) * (1 - uncert) - learncost - switchcost
npvcycle = npvcycle - 1
majority1 = majority1 - 1
majority2 = majority2 - 1
Else
If majority2 > 0 Then
valueflow(x, 1) = (share(y, 1) / (1 - fushare)) * (1.5 - 2 * fushare) - learncost - switchcost
fushare = fushare + growrate
majority2 = majority2 - 1
Else
valueflow(x, 1) = -learncost - switchcost
End If
End If
Else
valueflow(x, 1) = valueb * uncert
End If
Next x

curval = 0
intval = 0

'NPV evaluation, discount rate = rate, cash flows are sums of utility
For \( x = 1 \) To 25
  \[ \text{curval} = \text{valueflow}(x, 1) / ((1 + \text{rate})^{(x - 1)}) \]
  \[ \text{intval} = \text{intval} + \text{curval} \]
Next \( x \)

\[ \text{npvb} = \text{intval} \]

'NPV evaluation for deferred decision
If check1(y, 4) < 0.5 Then
  If coal(y, 5) > 0 Then
    \[ \text{lowlim} = 0.5 \]
  Else
    If check1(y, 4) + share(y, 1) > 0.5 Then
      \[ \text{lowlim} = \text{check1}(y, 4) + \text{share}(y, 1) \]
    Else
      \[ \text{lowlim} = 0.5 \]
    End If
  End If
End If
Else
  \[ \text{lowlim} = \text{check1}(y, 4) \]
End If

\[ \text{uplim} = 1 - \text{check1}(1, 2) \]
If uplim <= 0.5 Then
  \[ \text{value} = 0 \]
Else
  \[ \text{mid} = (\text{uplim} - \text{lowlim}) / 2 + \text{lowlim} \]
  \[ \text{expect} = \text{mid} - 0.5 \]
  \[ \text{value} = (\text{share}(y, 1) / \text{mid}) * (1 / (1 + \text{Exp}(<\text{gamma} * \text{expect}))) \]
End If

'generating the value exponent

\[ \text{newentry} = (\text{entrycycle}(y, 4) + 2 - \text{design}) / 2 \]
If design - 2 >= 0 Then
  \[ \text{lowdes} = \text{design} - 2 \]
Else
  \[ \text{lowdes} = \text{design} \]
End If

\[ \text{updes} = \text{design} + 1 \]
entry = 0
early = 0.9
late = 0.85
If newentry <= lowdes Then
    entry = newentry - lowdes
    time = early
Else
    If newentry >= updes Then
        entry = newentry - updes
        time = late
    Else
        time = 1
    End If
End If

If y = leadfirmB Then
    defb = 0
Else
    If desiga - 2 < 0 Then
        defb = 0
    Else
        If winb > 0 Then
            defb = time ^ (entry) * value * psuccb * (winb / (winb + rivwinb))
        Else
            defb = time ^ (entry) * value * psuccb
        End If
    End If
End If

npvcycle = entrycycle(y, 4)

If join(y, 1) >= 1 Then
    If entrycycle(y, 3) = 0 Then
        switchcost = defb * 0.25 * join(y, 1)
    Else
        switchcost = 0
    End If
End If
rate = 0.1

For x = 1 To 25
    If npvcycle > 0 Then
        If x <= design - 2 Then
            leancost = share(y, 1) * 0.0375
            If AB < 0.5 Then
                valueflow(x, 1) = (share(y, 1) - leancost - switchcost) * uncert
            End If
            If x = design - 2 Then
                leancost = leancost + (share(y, 1) * 0.0375)
            Else
                leancost = leancost + (share(y, 1) * 0.0375)
            End If
        End If
    End If
Next x
\[
\text{npvcycle} = \text{npvcycle} - 1
\]

Else
\[
\text{valueflow}(x, 1) = \left(1 / (1 + \text{Exp}\,(\gamma \times (0.5 - AB)))\right) \times \text{share}(y, 1) - \text{learncost} - \text{switchcost}
\]
End If

Else
\[
\text{learncost} = \text{share}(y, 1) \times 0.075
\]
If AB < 0.5 Then
\[
\text{valueflow}(x, 1) = (\text{share}(y, 1) - \text{learncost} - \text{switchcost}) \times \text{uncert}
\]
\[
\text{npvcycle} = \text{npvcycle} - 1
\]
Else
\[
\text{valueflow}(x, 1) = \left(1 / (1 + \text{Exp}\,(\gamma \times (0.5 - AB)))\right) \times \text{share}(y, 1) - \text{learncost} - \text{switchcost}
\]
End If

End If

Else
If AB < 0.5 Then
\[
\text{valueflow}(x, 1) = \text{defb} \times \text{uncert}
\]
Else
\[
\text{valueflow}(x, 1) = \text{defb}
\]
End If
End If
Next x

'NPV evaluation for B deferred

curval = 0
intval = 0

For x = 1 To 25
\[
\text{curval} = \text{valueflow}(x, 1) / ((1 + \text{rate}) ^ (x - 1))
\]
\[
\text{intval} = \text{intval} + \text{curval}
\]
Next x

npvdefb = intval

'value for taking no action at all

Dim npvnoact As Single

If AB < 0.5 Then
\[
\text{majority1} = \text{Int}\,(\text{design} \times 0.5) + 1
\]
\[
\text{majority2} = \text{Int}\,(\text{design} \times 0.75) + 2
\]
\[
\text{growrate} = 0.25 / (\text{majority2} - \text{majority1})
\]
fushare = 0.5 + growrate
Else
  If AB < 0.75 Then
    majority1 = 0
    majority2 = Int((0.75 - AB) * 10) + 1
    growrate = (0.75 - AB) / majority2
    fushare = AB + growrate
  Else
    majority1 = 0
    majority2 = 0
    fushare = 0
  End If
End If

For x = 1 To 25

  If x <= majority1 Then
    valueflow(x, 1) = share(y, 1) * (1 - uncert)
  Else
    valueflow(x, 1) = (1 / (1 + Exp(gamma * (0.5 - AB)))) * share(y, 1)
  End If
Next x

rate = 0.1
intval = 0
curval = 0

For x = 1 To 25
  curval = valueflow(x, 1) / ((1 + rate) ^ (x - 1))
  intval = intval + curval
Next x

npvnoact = intval + 1

defered = defa + defb

npvdef = npvdefa + npvdefb

npva = Format(npva, "fixed")
npvb = Format(npvb, "fixed")
npvdef = Format(npvdef, "fixed")
npvnoact = Format(npvnoact, "fixed")

'array U is the collection of utility or npv values
u(y, 1) = wina + losea
u(y, 2) = rivwina + rivlosea
u(y, 3) = winb + loseb
u(y, 4) = rivwinb + rivloseb
u(y, 5) = u(y, 1) + u(y, 2)
u(y, 6) = u(y, 3) + u(y, 4)
u(y, 7) = deferred
u(y, 8) = npva
u(y, 9) = npvb
u(y, 10) = npvdefer
u(y, 11) = npvnoact
u(y, 12) = check1(y, 3)
u(y, 13) = check1(y, 5)

Next y

For y = 1 To 10

Dim status As String
Dim outform As Integer
Dim outcome As Integer
Dim A As Variant
Dim B As Variant
Dim c As Variant
Dim D As Variant
Dim rand2 As Single
Dim rand2x As Variant
Dim rand3 As Single
Dim rand3x As Variant
Dim rand4 As Single
Dim rand4x As Variant
Dim writerand As Single
Dim randstat(10, 2) As Integer
Dim totaljoin As Integer
Dim oldif As Single
Dim olavg As Single
Dim dfishare As Single
Dim sumshare As Single
Dim coalition As String
Dim gammalt As Single
Dim uncertalt As Single
Dim updateun As Single
Dim joinycyc(10, 1) As Integer
Dim current(30, 13) As Single
Dim cursum As Single
Dim curdif As Single
Dim runtotal As Integer
Dim olxlead As Integer

' validity testing variables
Dim predcyc1 As Single
Dim predcyc2 As Single
Dim absdif As Single
Dim abs overlap As Single

rand2 = 0
rand2x = 0
rand3 = 0
rand3x = 0
rand4 = 0
rand4x = 0
counter1 = 1
counterl = 1

' first check of values
If u(y, 8) < 0 And u(y, 9) < 0 And u(y, 10) < 0 Then
    outform = 4
Else
    ' sorting four outcome values

If u(y, 8) > u(y, 9) Then
    If u(y, 8) > u(y, 10) Then
        If u(y, 8) > u(y, 11) Then
            A = u(y, 8)
        Else
            If u(y, 9) > u(y, 10) Then
                B = u(y, 9)
            Else
                D = u(y, 10): c = u(y, 11)
            End If
Else
    c = u(y, 9): D = u(y, 10): B = u(y, 11)
End If
Else
    If u(y, 9) > u(y, 11) Then
        c = u(y, 9): B = u(y, 10): D = u(y, 11)
    Else

If \( u(y, 10) > u(y, 11) \) Then
\[
D = u(y, 9): B = u(y, 10): c = u(y, 11)
\]
Else
\[
D = u(y, 9): c = u(y, 10): B = u(y, 11)
\]
End If
End If
End If
Else
\[
A = u(y, 11): B = u(y, 8)
\]
If \( u(y, 9) > u(y, 10) \) Then
\[
c = u(y, 9): D = u(y, 10)
\]
Else
\[
D = u(y, 9): c = u(y, 10)
\]
End If
End If
Else
If \( u(y, 10) > u(y, 11) \) Then
\[
A = u(y, 10)
\]
if \( u(y, 8) > u(y, 11) \) Then
\[
B = u(y, 8)
\]
If \( u(y, 9) > u(y, 11) \) Then
\[
c = u(y, 9): D = u(y, 11)
\]
Else
\[
D = u(y, 9): c = u(y, 11)
\]
End If
Else
\[
c = u(y, 8): D = u(y, 9): B = u(y, 11)
\]
End If
Else
\[
c = u(y, 8): D = u(y, 9): B = u(y, 10): A = u(y, 11)
\]
End If
End If
Else
If \( u(y, 9) > u(y, 10) \) Then
If \( u(y, 10) > u(y, 11) \) Then
\[
A = u(y, 9)
\]
If \( u(y, 8) > u(y, 10) \) Then
\[
B = u(y, 8): c = u(y, 10): D = u(y, 11)
\]
Else
If \( u(y, 8) > u(y, 11) \) Then
\[
c = u(y, 8): B = u(y, 10): D = u(y, 11)
\]
Else
\[
D = u(y, 8): B = u(y, 10): c = u(y, 11)
\]
End If
End If
Else

If \( u(y, 9) > u(y, 11) \) Then
\[ A = u(y, 9) \]
If \( u(y, 8) > u(y, 11) \) Then
\[ B = u(y, 8); D = u(y, 10); c = u(y, 11) \]
Else
\[ \text{If } u(y, 8) > u(y, 10) \text{ Then} \]
\[ c = u(y, 8); D = u(y, 10); B = u(y, 11) \]
Else
\[ D = u(y, 8); c = u(y, 10); B = u(y, 11) \]
End If
End If
Else
\[ B = u(y, 9); A = u(y, 11) \]
If \( u(y, 8) > u(y, 10) \) Then
\[ c = u(y, 8); D = u(y, 10) \]
Else
\[ D = u(y, 8); c = u(y, 10) \]
End If
End If
End If
Else
If \( u(y, 10) > u(y, 11) \) Then
\[ A = u(y, 10) \]
If \( u(y, 9) > u(y, 11) \) Then
\[ B = u(y, 9) \]
If \( u(y, 8) > u(y, 11) \) Then
\[ c = u(y, 8); D = u(y, 11) \]
Else
\[ D = u(y, 8); c = u(y, 11) \]
End If
Else
\[ D = u(y, 8); c = u(y, 9); B = u(y, 11) \]
End If
Else
\[ D = u(y, 8); c = u(y, 9); B = u(y, 10); A = u(y, 11) \]
End If
End If
End If

'Assigning match between sort and outcomes

If \( A * 0.95 >= B * 1.053 \) Then
\[ \text{outcome} = 1 \]
Else
If \( B * 0.95 > c * 1.05 \) Then
\[ \text{outcome} = 2 \]
Else
    If c * 0.95 > D * 1.053 Then
        outcome = 3
    Else
        outcome = 4
    End If
End If

Select Case outcome

Case 1
    If A = u(y, 8) Then
        outform = 1
    Else
        If A = u(y, 9) Then
            outform = 2
        Else
            If A = u(y, 10) Then
                outform = 3
            Else
                outform = 4
            End If
        End If
    End If
End If

Case 2

If randstat(y, 1) = 2 Then
    If randstat(y, 2) = 1 Then
        outform = 1
    Else
        If randstat(y, 2) = 2 Then
            outform = 2
        Else
            If randstat(y, 2) = 3 Then
                outform = 3
            Else
                outform = 4
            End If
        End If
    End If
End If
Else

rand2 = Rnd
rand2x = Int((rand2 * 2) + 1)

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If rand2x = 1 Then
    rand2x = A
Else
    rand2x = B
End If

If rand2x = u(y, 8) Then
    outform = 1
    randstat(y, 1) = 2
    randstat(y, 2) = 1
Else
    If rand2x = u(y, 9) Then
        outform = 2
        randstat(y, 1) = 2
        randstat(y, 2) = 2
    Else
        If rand2x = u(y, 10) Then
            outform = 3
            randstat(y, 1) = 2
            randstat(y, 2) = 3
        Else
            outform = 4
            randstat(y, 1) = 2
            randstat(y, 2) = 4
        End If
    End If
End If
End If
End If

Case 3

If randstat(y, 1) = 3 Then
    If randstat(y, 2) = 1 Then
        outform = 1
    Else
        If randstat(y, 2) = 2 Then
            outform = 2
        Else
            If randstat(y, 2) = 3 Then
                outform = 3
            Else
                outform = 4
            End If
        End If
    End If
End If
Else
  rand3 = Rnd
  rand3x = Int((3 * rand3) + 1)
End If

If rand3x = 1 Then
  rand3x = A
Else
  If rand3x = 2 Then
    rand3x = B
  Else
    rand3x = c
  End If
End If

If rand3x = u(y, 8) Then
  outform = 1
  randstat(y, 1) = 3
  randstat(y, 2) = 1
Else
  If rand3x = u(y, 9) Then
    outform = 2
    randstat(y, 1) = 3
    randstat(y, 2) = 2
  Else
    If rand3x = u(y, 10) Then
      outform = 3
      randstat(y, 1) = 3
      randstat(y, 2) = 3
    Else
      outform = 4
      randstat(y, 1) = 3
      randstat(y, 2) = 4
    End If
  End If
End If

Case 4

If randstat(y, 1) = 4 Then
  If randstat(y, 2) = 1 Then
    outform = 1
  Else
    If randstat(y, 2) = 2 Then
      outform = 2
    Else
      outform = 2
    End If
  End If
End If
If randstat(y, 2) = 3 Then
  outform = 3
Else
  outform = 4
End If
End If
Else
  rand4 = Rnd
  rand4x = int((4 * rand4) + 1)

If rand4x = 1 Then
  rand4x = A
Else
  If rand4x = 2 Then
    rand4x = B
  Else
    If rand4x = 3 Then
      rand4x = c
    Else
      rand4x = D
    End If
  End If
End If
End If

If rand4x = u(y, 8) Then
  outform = 1
  randstat(y, 1) = 4
  randstat(y, 2) = 1
Else
  If rand4x = u(y, 9) Then
    outform = 2
    randstat(y, 1) = 4
    randstat(y, 2) = 2
  Else
    If rand4x = u(y, 10) Then
      outform = 3
      randstat(y, 1) = 4
      randstat(y, 2) = 3
    Else
      outform = 4
      randstat(y, 1) = 4
      randstat(y, 2) = 4
    End If
  End If
End If
End If
End If

End Select

End If

'action based on npv values

Select Case outform

Case 1

oldif = overlap(y, leadfirmA) - overlap(y, leadfirmB); oldif = Format(oldif, "fixed")
olavg = (overlap(y, leadfirmA) + overlap(y, leadfirmB)) / 2: oldif = Format(oldif, "fixed")
difshare = share(leadfirmA, 1) - share(leadfirmB, 1); difshare = Format(difshare, "fixed")
sumshare = share(leadfirmA, 1) + share(leadfirmB, 1); sumshare = Format(sumshare, "fixed")
coalition = "A"
gammalt = gamma * -1
uncertalt = 1 - uncert: uncertalt = Format(uncertalt, "fixed")

If entrycycle(y, 1) = 0 Then 'no overwrite of firm in coalition
    If coal(y, 1) = y Then
        coal(y, 1) = y
        status = "already in A"
        learn(y, 2) = 1
        learn(y, 4) = 1
    Else
        counter1 = 0
        status = "entering A"
        coal(y, 1) = y
        coal(y, 2) = share(y, 1)
        coal(y, 3) = cycle
        coal(y, 4) = 0
        'clearing other coal
        coal(y, 5) = 0
        coal(y, 6) = 0
        coal(y, 7) = 0
        coal(y, 8) = 0
        coal(y, 9) = 0
        learn(y, 2) = 1
        learn(y, 4) = 1
        join(y, 1) = join(y, 1) + 1
        absdif = Abs(difshare)
abs overlap = Abs(oldif)
If share(leadfirmA, 1) > share(leadfirmB, 1) Then
  If overlap(y, leadfirmA) > overlap(y, leadfirmB) Then
    olxlead = 1
  Else
    olxlead = 0
  End If
Else
  If overlap(y, leadfirmA) > overlap(y, leadfirmB) Then
    olxlead = 0
  Else
    olxlead = 1
  End If
End If
If firstjoin(1, 1) = 0 Then
  firstjoin(1, 1) = cycle
End If
If ganccheck = 1 And firmcheck(y, 1) = 1 Then
  writecheck(y, 1) = 1
  runtotal = 0
  record = record + 1
  For x = 1 To cycle
    cursum = curshare(x, 1) + curshare(x, 2)
    curdif = curshare(x, 1) - curshare(x, 2)
    If x < cycle Then
      current(x, 1) = 0
    Else
      current(x, 1) = 1
    End If
    current(x, 2) = x
    current(x, 3) = uncertalt
    current(x, 4) = gammalt
    current(x, 5) = conc
    current(x, 6) = share(y, 1)
    current(x, 7) = sumshare
    current(x, 8) = difshare
    current(x, 9) = oldif
    current(x, 10) = olavg
    current(x, 11) = cursum
    current(x, 12) = curdif
    If x < join cyc(y, 1) Then
      current(x, 13) = 0
    Else
      current(x, 13) = 1
    End If
  Next x
current(x, 13) = 1
End If
Next x

Open "C:\VBFiles\Paper3\output\join3.doc" For Append As #35
For x = 1 To cycle
Write #35, record, current(x, 1), current(x, 2), current(x, 3), current(x, 4),
current(x, 5), current(x, 6), current(x, 7), current(x, 8), current(x, 9), current(x, 10),
olxlead, current(x, 11), current(x, 12), current(x, 13)
Next x
Close #35
End If
End If

Else
"writing firm to pool with committed learning"
status = "committed to A"
If coal(y, 7) = y Then
coal(y, 7) = y
learn(y, 2) = pace(y, 1)
learn(y, 4) = 1
Else
coal(y, 1) = 0
coal(y, 2) = 0
coal(y, 3) = 0
coal(y, 7) = y
coal(y, 8) = shace(y, 1)
coal(y, 9) = cycle
learn(y, 2) = pace(y, 1)
learn(y, 4) = 1
jincyc(y, 1) = cycle
End If
End If

Case 2
'B better than A

oldif = overlap(y, leadfirmB) - overlap(y, leadfirmA): oldif = Format(oldif, "fixed")
olavg = (overlap(y, leadfirmA) + overlap(y, leadfirmB))/2: oldif = Format(oldif, "fixed")

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difshare = share(leadfirmB, 1) - share(leadfirmA, 1): difshare = Format(difshare, "fixed")
sumshare = share(leadfirmA, 1) + share(leadfirmB, 1): sumshare = Format(sumshare, "fixed")
coalition = "B"
gammalt = gamma * -1
uncertalt = 1 - uncert: uncertalt = Format(uncertalt, "fixed")

If entrycycle(y, 3) = 0 Then
  If coal(y, 4) = y Then 'no overwrite of firm in coalition
    coal(y, 4) = y
    status = "already in B"
    learn(y, 2) = 0.95
    learn(y, 4) = 1
  Else 'writing new firm to coalition
    counterb1 = 0
    status = "enter B"
    coal(y, 4) = y
    coal(y, 5) = share(y, 1)
    coal(y, 6) = cycle
    coal(y, 1) = 0 'clear other coal
    coal(y, 2) = 0
    coal(y, 3) = 0
    coal(y, 7) = 0
    coal(y, 8) = 0
    coal(y, 9) = 0
    learn(y, 2) = 1
    learn(y, 4) = 1
    join(y, 1) = join(y, 1) + 1
    totaljoin = totaljoin + 1
    absdif = Abs(difshare)
    abs overlap = Abs(olddif)
  If share(leadfirmA, 1) > share(leadfirmB, 1) Then
    If overlap(y, leadfirmA) > overlap(y, leadfirmB) Then
      oixlead = 1
    Else
      oixlead = 0
    End If
  Else
    If overlap(y, leadfirmA) > overlap(y, leadfirmB) Then
      oixlead = 0
    Else
      oixlead = 1
    End If
  End If
  If firstjoin(1, 2) = 0 Then
    firstjoin(1, 2) = cycle
End If

If gamecheck = 1 And firmcheck(y, 1) = 1 Then
    writecheck(y, 1) = 1
    runtotal = 0
    record = record + 1

For x = 1 To cycle

    cursum = curshare(x, 1) + curshare(x, 2)
    curdif = curshare(x, 1) - curshare(x, 2)

If x < cycle Then
    current(x, 1) = 0
Else
    current(x, 1) = 1
End If

    current(x, 2) = x
    current(x, 3) = uncertalt
    current(x, 4) = gammalt
    current(x, 5) = conc
    current(x, 6) = share(y, 1)
    current(x, 7) = sumshare
    current(x, 8) = difshare
    current(x, 9) = oldif
    current(x, 10) = olavg
    current(x, 11) = cursum
    current(x, 12) = curdif

If x < joineyc(y, 1) Then
    current(x, 13) = 0
Else
    current(x, 13) = 1
End If

Next x

Open "C:\VBFiles\Paper3\output\join3.doc" For Append As #35
For x = 1 To cycle
    Write #35, record, current(x, 1), current(x, 2), current(x, 3), current(x, 4),
    current(x, 5), current(x, 6), current(x, 7), current(1, 8), current(1, 9), current(x, 10),
    olxlead, current(x, 11), current(x, 12), current(x, 13)
Next x
Close #35

End If
End If

Else
  status = "committed to B"
  If coal(y, 7) = y Then
    coal(y, 7) = y
    learn(y, 2) = 1
    learn(y, 4) = pace(y, 1)
  Else
    coal(y, 4) = 0
    coal(y, 5) = 0
    coal(y, 6) = 0
    coal(y, 7) = y
    coal(y, 8) = share(y, 1)
    coal(y, 9) = cycle
    learn(y, 2) = 1
    learn(y, 4) = pace(y, 1)
    joinycyc(y, 1) = cycle
  End If
End If

Case 3
  'mounting deferred learners to pool

Dim lead As Single
If coal(y, 1) = y Then
  lead = 1
Else
  If coal(y, 4) = y Then
    lead = 2
  Else
    lead = 3
  End If
End If

Select Case lead

Case 1
  status = "in A but learning B"
  coal(y, 1) = y
  coal(y, 2) = share(y, 1)
  learn(y, 2) = 1
  learn(y, 4) = pace(y, 2)
Case 2

status = "in B but learning A"
cal(y, 4) = y
cal(y, 5) = share(y, 1)
learn(y, 2) = pace(y, 2)
learn(y, 4) = 1

Case 3

If cal(y, 7) = y Then
  cal(y, 7) = y
  status = "deferred for A & B"

Else
  learn(y, 2) = pace(y, 2)
  learn(y, 4) = pace(y, 2)
  cal(y, 1) = 0
  cal(y, 2) = 0
  cal(y, 3) = 0
  cal(y, 4) = 0
  cal(y, 5) = 0
  cal(y, 6) = 0
  cal(y, 7) = y
  cal(y, 8) = share(y, 1)
  cal(y, 9) = cycle
  status = "deferred for A & B"
End If
End Select

Case 4

'no action is best choice

learn(y, 2) = 1
learn(y, 4) = 1
status = "no action"

End Select

calera = calera + caleral
ccalera = ccalera + ccaleral
Next y

Dim check2(10, 4) As Single
Dim forward(60, 6) As Single
Dim sharecoal2 As Single
Dim shareriv2 As Single

For y = 1 To 10     'updating coalition share A values
    sharecoal2 = 0
    shareriv2 = 0
    For x = 1 To 10
        If coal(x, 1) > 0 Then
            sharecoal2 = sharecoal2 + share(coal(x, 1), 1)
            shareriv2 = shareriv2 + share(coal(x, 1), 1) * riv(y, coal(x, 1))
        End If
    Next x
    check2(y, 1) = sharecoal2
    check2(y, 2) = shareriv2
    'updating coalition B values
    sharecoal2 = 0
    shareriv2 = 0
    For x = 1 To 10
        If coal(x, 4) > 0 Then
            sharecoal2 = sharecoal2 + share(coal(x, 4), 1)
            shareriv2 = shareriv2 + share(coal(x, 4), 1) * riv(y, coal(x, 4))
        End If
    Next x
    check2(y, 3) = sharecoal2
    check2(y, 4) = shareriv2
    Next y

'generating values for Forward multiplication array
Dim place As Integer
forward(1, 1) = 1
forward(1, 2) = 0
forward(1, 3) = share(leadfirmA, 1)
forward(1, 4) = share(leadfirmB, 1)
If forward(1, 3) > forward(1, 4) Then
    forward(1, 5) = 1
    forward(1, 6) = 0
Else
    forward(1, 5) = 0
    forward(1, 6) = 1
End If

If check1(1, 2) <> check2(1, 1) Or check1(1, 4) <> check2(1, 3) Then
    If place = 0 Then
        place = place + 2
    Else
        place = place + 1
    End If

    forward(place, 1) = place
    forward(place, 2) = cycle
    forward(place, 3) = check2(1, 1)
    forward(place, 4) = check2(1, 3)
    If forward(place, 3) > forward(place, 4) Then
        forward(place, 5) = 1
        forward(place, 6) = 0
    Else
        forward(place, 5) = 0
        forward(place, 6) = 1
    End If
Else
    place = place
End If

' control of cycling check

If countera + counterb = 20 Then
    counter = counter + 1
    countera = 6
    counterb = 0
Else
    counter = 0

counterA = 0
counterB = 0
End If

'If counter = 10 Then
  'Exit For
  'End If

Next cycle

For y = 1 To 10
  oldif = overlap(y, leadfirmB) - overlap(y, leadfirmA): oldif = Format(oldif, "fixed")
  olavg = (overlap(y, leadfirmA) + overlap(y, leadfirmB)) / 2: oldif = Format(oldif, "fixed")
  difshare = Abs(share(leadfirmA, 1) - share(leadfirmB, 1)): difshare = Format(difshare, "fixed")
  sumshare = share(leadfirmA, 1) + share(leadfirmB, 1): sumshare = Format(sumshare, "fixed")
  gammalt = gamma * -1
  absdif = Abs(difshare)
  abs overlap = Abs(oldif)
  uncertalt = 1 - uncert: uncertalt = Format(uncertalt, "fixed")
  If share(leadfirmA, 1) > share(leadfirmB, 1) Then
    If overlap(y, leadfirmA) > overlap(y, leadfirmB) Then
      olxlead = 1
    Else
      olxlead = 0
    End If
  Else
    If overlap(y, leadfirmA) > overlap(y, leadfirmB) Then
      olxlead = 0
    Else
      olxlead = 1
    End If
  End If
End If

If gamecheck = 1 And firmcheck(y, 1) = 1 Then
  If writecheck(y, 1) = 0 Then
    If runtotal <= 3 Then
      record = record + 1

    For x = 1 To 20
      cursum = curshare(x, 1) + curshare(x, 2)
      curdif = Abs(curshare(x, 2) - curshare(x, 1))
current(x, 1) = 0
current(x, 2) = x
current(x, 3) = uncertalt
current(x, 4) = gammalt
current(x, 5) = conc
current(x, 6) = share(y, 1)
current(x, 7) = sumshare
current(x, 8) = absdif
current(x, 9) = absol
current(x, 10) = olavg
current(x, 11) = cursum
current(x, 12) = curdif
current(x, 13) = 0
Next x

Open "C:\VBFiles\Paper3\output\join3.doc" For Append As #35
For x = 1 To 20
  Write #35, record, current(x, 1), current(x, 2), current(x, 3), current(x, 4),
current(x, 5), current(x, 6), current(x, 7), current(x, 8), current(x, 9), current(x, 10),
current(x, 11), current(x, 12), current(x, 13)
  Next x
Close #35

runtotal = runtotal + 1
End If
End If
End If

Next y

Dim f As Integer
Dim winstat(1, 10) As Variant
Dim e As Integer:
Dim mult As Integer
Dim winshare As Variant
Dim winvshr As Variant
Dim wincount As Integer
Dim wincy As Integer
Dim xcount As Integer
Dim olasum As Single
Dim olbsum As Single
Dim olcoun1 As Integer
Dim olcoun2 As Integer
Dim olavg As Single
Dim olbavg As Single
winstat(1, 1) = 1 - uncert: winstat(1, 1) = Format(winstat(1, 1), "fixed")
winstat(1, 2) = gamma * -1
winstat(1, 3) = conc
winstat(1, 4) = share(leadfirmA, 1)
winstat(1, 5) = share(leadfirmB, 1)
winstat(1, 6) = winstat(1, 4) + winstat(1, 5): winstat(1, 6) = Format(winstat(1, 6), "fixed")
winstat(1, 7) = Abs(winstat(1, 4) - winstat(1, 5)): winstat(1, 7) = Format(winstat(1, 7), "fixed")

If place = 0 Then
  winstat(1, 8) = "."
Else
  If check2(1, 1) + check2(1, 3) >= 0.5 Then
    If check2(1, 1) / (check2(1, 1) + check2(1, 3)) > 0.5 Then
      mult = 1
      winstat(1, 8) = 1

      'winstat(1, 10) = meanola - meanolb: winstat(1, 10) = Format(winstat(1, 10), "fixed")
      'For e = forward(place, 1) To forward(1, 1) Step -1
      '  mult = mult * forward(e, 5)
      '  If mult = 0 Then
      '    winstat(1, 9) = forward(e + 1, 2): winstat(1, 9) = Format(winstat(1, 9), "fixed")

      'Exit For
      'Else
      '  winstat(1, 9) = 0
      'End If
      'Next e
    Else
      mult = 1
      winstat(1, 8) = 2

      'winstat(1, 10) = meanolb - meanola: winstat(1, 10) = Format(winstat(1, 10), "fixed")
      'For e = forward(place, 1) To forward(1, 1) Step -1
      '  mult = mult * forward(e, 6)
      '  If mult = 0 Then
      '    winstat(1, 9) = forward(e + 1, 2): winstat(1, 9) = Format(winstat(1, 9), "fixed")

      'Exit For
      'Exit For
      'Else
      '  winstat(1, 9) = 0
      'End If

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'Next e

   End If
   Else
   winstat(1, 8) = ":"

   End If
End If

If winstat(1, 8) = 1 Then
   winshare = 1
Else
   If winstat(1, 8) = 2 Then
      winshare = 2
   Else
      winshare = 3
   End If
End If

Select Case winshare

   Case 1

      If winstat(1, 4) > winstat(1, 5) Then
         winvshr = 1
      Else
         winvshr = 0
      End If

   Case 2

      If winstat(1, 5) > winstat(1, 4) Then
         winvshr = 1
      Else
         winvshr = 0
      End If

   Case 3

      winvshr = ":"

   End Select

Randomize
   writerand = Rnd
'If writerand > 0.9 Then

'record2 = record2 + 1
'Open "C:\VBFFiles\Paper3\output\summ30.doc" For Append As #31
  'Write #31, record2, winstat(1, 1), winstat(1, 2), winstat(1, 4), winstat(1, 5), winstat(1, 6), winstat(1, 7), winstat(1, 8), winvshr, firstjoin(1, 1), firstjoin(1, 2), check2(1, 1), check2(1, 3)
  'Close #31
  'End If

'If winvshr <> "." Then
  'wincount = wincount + 1

  'For x = 1 To cycle
    'If curshare(x, 1) + curshare(x, 2) > 0.5 Then
      'xcount = x
      'Exit For
    'End If
    'Next x

'Else
  'wincount = 0
  'xcount = 20
'End If

'Dim winstat2(20, 12) As Single
'Dim zycy2 As Integer

'record2 = record2 + 1

'For x = 1 To xcount
  'winstat2(x, 1) = 1 - uncert: winstat2(x, 1) = Format(winstat2(x, 1), "fixed")
  'winstat2(x, 2) = gamma * -1
  'winstat2(x, 3) = conc
  'winstat2(x, 4) = curshare(1, 1): winstat2(x, 4) = Format(winstat2(x, 4), "fixed")
  'winstat2(x, 5) = curshare(1, 2). winstat2(x, 5) = Format(winstat2(x, 5), "fixed")
  'winstat2(x, 6) = curshare(x, 1)
  'winstat2(x, 7) = curshare(x, 2)

  'winstat2(x, 8) = curshare(x, 1) + curshare(x, 2): winstat2(x, 8) = Format(winstat2(x, 8), "fixed")
  'winstat2(x, 9) = Abs(curshare(x, 1) - curshare(x, 2)): winstat2(x, 9) = Format(winstat2(x, 9), "fixed")
  'winstat2(x, 10) = meanola: winstat2(x, 10) = Format(winstat2(x, 10), "fixed")

'winstat2(x, 11) = meanolb: winstat2(x, 11) = Format(winstat2(x, 11), "fixed")
'If winstat2(x, 8) > 0.5 Then
 'winstat2(x, 12) = 1
'Else
 'winstat2(x, 12) = 0
'End If
'Next x

'Open "C:\VBFiles\Paper3\output\coal2.doc" For Append As #21
 'For x = 1 To xcount
 'Write #21, record2, x, winvshr, winstat2(x, 1), winstat2(x, 2), winstat2(x, 3),
 winstat2(x, 4), winstat2(x, 5), winstat2(x, 6), winstat2(x, 7), winstat2(1, 8), winstat2(x, 9),
 winstat2(x, 10), winstat2(x, 11), winstat2(x, 12)
 'Next x
 'Close #21

'End If

'clearing values

totaljoin = 0
place = 0
counter = 0

For y = 1 To 10
 join(y, 1) = 0
Next y

For y = 1 To 10
 firmcheck(y, 1) = 0
Next y

For y = 1 To 10
writecheck(y, 1) = 0
Next y

For y = 1 To 10
randstat(y, 1) = 0
randstat(y, 2) = 0
Next y

curcyc = 0
olascum = 0
olbsum = 0
olcount1 = 0
olcount2 = 0
firstjoin(1, 1) = 0
firstjoin(1, 2) = 0
Next leadfirmB

Next leadfirmA

gamcheck = 0

Next loopcount

Print "bigcycle " & bigcycle & " complete"

Next bigcycle

Open "C:\VBFiles\Paper3\scorecheck.txt" For Output As #6
    For x = 1 To 125
        Write #6, scorecheck(x, 1)
    Next x
Close #6

End Sub
REFERENCES


