Assembling the Elephant:

A review of empirical studies on the impact of technical change upon incumbent firms

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Abstract

This paper reviews 16 empirical studies of the impact of technological change upon incumbent firms. While all 16 studies have strong internal validity, their external validity is unclear. These studies employ different definitions, use different taxonomies, and rely on differing causal mechanisms. Their evidence, though extensive, draws largely upon US contexts. This complicates an assessment of their cumulative external validity. An overall analysis concludes that there is a need to expand our research to other countries, because the impact of technical change may differ across countries. The paper integrates these phenomena into a new paradigm with three dimensions that condition the impact of technical change: the management of complexity, the external linkages of innovating firms, and the institutional environment.

"It was six men of Indostan
To learning much inclined,
Who went to see the Elephant
Though all of them were blind,
That each by observation
Might Satisfy his mind….

[each of the six men touches a different part of the elephant]

…. And so these men of Indostan
Disputed loud and long,
Each in his own opinion
Exceeding stiff and strong.
Though each was partly in the right,
They all were in the wrong!"

- John Godfrey Saxe[1],

Introduction

The study of the impact of technical change upon innovating organizations has attracted a number of researchers, who have collectively conducted a variety of interesting studies on how a significant change in technology resulted in various impacts upon firms competing in particular industries. These studies are of great interest to organizational scholars, because they reveal both the abilities and constraints upon a firm's ability to change (Barnett and Carroll, 1995). They provide a dynamic context for much of the recent work in managing new product development (Brown and Eisenhardt, 1995). They have also helped to inform economic theories of industry evolution (Nelson and Winter, 1982). And the challenges posed by innovation are of deep interest to managers as well (Christensen, 1997; Tushman and O'Reilly, 1997).

However, theories of the impact of innovation upon firms have not yielded much in the way of a general understanding. Their cumulative impact has been hindered by the lack of consistent terminology, which in turn has yielded a variety of causal explanations for the impact

[1]Many citations of this story can be found, cf., http://www.cs.cmu.edu/afs/cs/user/johnmil/public/www/poems/BlindMen.html

of innovation upon firms and industries. In addition, the phenomenon has been studied primarily in the US, raising the possibility that the research to date may only document a special instance of a more general phenomenon. As the pace of technological advance continues and perhaps accelerates, scholars and managers alike require a deeper understanding of what factors explain the differing organizational impact of innovation in different settings.

These issues prompted me to take stock of the state of our academic knowledge on this subject. This paper will compile these studies, and then look for common themes that recur, and isolate differences in the results of the literature. I will pay particular attention to causal mechanisms, and introduce evidence from comparative work on the impact of innovation that has not been incorporated into the literature so far. This comparative work raises some anomalies in causality that may qualify some of the earlier findings. The paper concludes by proposing a synthesis organized around three dimensions of innovation that integrate the results of these empirical studies with these anomalies. These dimensions are: the management of complexity within the firm; coordination with outside firms; and the institutional environment surrounding firms. This synthesis, in turn, may permit a definition of a future research agenda for the study of innovation and organization. In this way, we can begin to assemble a picture of the larger "elephant" of innovation and its impact upon organizations in a more global context.

A Review of Empirical Studies on the Impact of Innovation upon Incumbent Firms

The empirical work studying the impact of innovation upon incumbent firms in a single industry shares some common characteristics that unite it as a literature. The primary interest of this literature is in organizations, and how they respond to innovation. Generally, the literature treats technological changes as an exogenous event, which creates an opportunity to examine the response of organizations to that shock. This focus distinguishes this literature from another, closely related literature on dominant designs and industry evolution. While there are many points of common interest, that literature typically analyzes the character of technology quite closely, and treats it as an endogenous element to be explained. Tushman and Anderson (1986: 439) typified this approach in saying that "technology [is] a central force in shaping environmental conditions". As a result, there is a greater emphasis in that literature on the causes of technological shifts, and the resulting impact on the evolution of the industry and the number of participants in the industry. There is less examination of how incumbent firms respond to those shifts, and what factors influenced those responses. An excellent recent review of this literature can be found in Tushman and Murmann (1998).[2]

All the empirical studies reviewed below are grounded in observations of technical innovation in one or at most a few industries, which are followed over an extended period of time. They draw from multiple disciplines to analyze and interpret the experience of firms in the focal industry or industries they study. They pay particular attention to whether and how incumbent firms respond to technological shocks. Many studies also examine the response of newly entering firms to these same events. This common research strategy has been deployed across a large number of industries.

Because of the complexity of the phenomenon being studied, the studies in this literature face a tradeoff between internal and external validity in their research design. This tradeoff is usually resolved in favor of internal validity: conducting detailed study of a very small number of industries to increase the chances of accurately capturing the experience in those industries. Left

[2] As will be seen below, certain seminal studies reviewed in Tushman and Murmann (1998) are also reviewed here, indicating that there is not as clear a dividing line between studies of dominant designs and studies of the organizational impact of innovation as one might like. Nonetheless, by restricting attention to a relatively small number of studies, I believe that I am able to uncover important themes that might be obscured in a review of a much larger body of work.

unresolved in this choice is the issue of external validity: to what extent the findings of incumbent firms in one industry apply to the experience of firms in other industries. Not only is the impact of innovation in an industry over many years a complex question, it is one that is likely to differ among industries. And, as I will discuss below, it is also likely to differ across countries. Because this literature has chosen to focus on internal validity, the issue of external validity has to this point not received sufficient attention. I believe that enough empirical work now has been done to allow us to examine this question.

To advance our understanding and to directly assess the external validity of this literature, I selected sixteen studies to review in some detail. I chose these studies because they met three criteria that helped me consider external validity questions. One, each of the studies empirically examined one, or at most a few, industries. Two, each followed its industry(s) over an extended period of time, so that technological shifts were observed. Three, each study focused on the response of incumbent firms to these shifts as its dependent variable. It is likely that the reader can think of one or more studies missing beyond those chosen. Given the burgeoning research interest in this area, such omissions are perhaps inevitable. In order to gain insight into external validity questions, though, I felt that the total number of studies had to be kept small enough to permit examination of each study, and to compare its findings with those of the other studies.

Table 1 shows a summary of each of the studies reviewed. The table includes columns that display the industry(s) each one examined, the geography from which its evidence was drawn, its unit of analysis, its research design, its direction of causality, its typology of innovation, and its predictions of when incumbents will and will not adapt to innovation shocks.

[Table 1 about here]

For my starting point in this review, I began with Utterback and Abernathy's first study (1975). While there were antecedent studies that examined the impact of innovation on firms in detail in a single industry, Abernathy and Utterback's work (Utterback and Abernathy, 1975; Abernathy and Utterback, 1978) was the pioneering effort to link technological change at the firm level to a model of industry evolution, and to derive implications for firms either already in the industry, or for new entrants to the industry.

In their first study, they developed a stage model for process development and another model for product development, and then linked these to the firm's innovation strategy. The process model involved three stages, from uncoordinated, to segmented, to systemic. The product development model was conceived as being one of three approaches: performance maximizing, sales maximizing, or cost minimizing. They described how they integrated these constructs together into a contingency framework as follows:

> "The essence of our argument is that characteristics of the innovative process and of a firm's innovation attempts will vary systematically with differences in the firm's environment and its strategy for competition and growth, and with the state of development of process technology used by a firm, and by its competitors." (1975: 640)

They reanalyzed data from 5 industries collected by an earlier study (Myers and Marquis, 1969), and found a distinct pattern that matched a firm's process choices with its product development approach. They argued that firms were more likely to succeed when they used the appropriate strategy choices of product and process development, for the right stage of industry evolution.

This contingency argument continues throughout the rest of the studies. The answer to the question, "how should a firm organize itself for innovation?" is, "it depends". There is no single "best" way to organize for innovation across all circumstances; rather, the firm must make an assessment of its situation, and respond accordingly. In one sense, all that the subsequent studies have shown is that there are many different situations that affect whether and how a firm can respond to innovation.

Abernathy and Utterback (1978) developed this perspective further in the context of a single industry. They analyzed the evolution of the auto industry, and found that its development was marked by the introduction of numerous significant technologies. Certain of these technologies became "dominant designs" - paradigms of how technologies should link together that became widely accepted throughout the industry. Prior to the arrival of these designs, competition among firms occurred through differing product technologies and approaches. After the establishment of such designs, firms either conformed to the new paradigm, or were forced out of the market. Those firms that remained, competed within the new paradigm on the basis of process improvements rather than on the previous basis of new product technologies.

As Table 1 shows, the industries they observed in their studies were confined to the US. The unit of analysis was these dominant designs. The direction of causality was that the emergence of the dominant design (through an unspecified process), which shifted the basis of competition within an industry from product-based competition to process-based competition. The research design was historical in nature, selecting dominant designs ex post, and reconstructing their impact upon the auto industry. In contrast to the earlier (1975) study, they re-mapped the characterization of technology to "radical" or "evolutionary", on the basis of whether, ex post, a technology displaced incumbent firms (radical), or entrenched them (evolutionary). Incumbent firms in their theory succeeded when they either established or followed a dominant design, and shifted their focus to process improvements. Incumbents failed when they did not adopt the dominant design, or failed to compete on process improvements.

A later book by Utterback (1994) extended these contingent concepts to a variety of industries. This volume documented the ongoing research he has conducted since his pathbreaking articles with Abernathy. The book detailed the technological history of various industries, including typewriters, airplanes, light bulbs, glass, ice, and photography. The paradigm of the dominant design was found in each of these industries, transforming the basis for competition in each, and usually displacing incumbent firms. Here, he reported as well the ability of older technologies to evolve further, in a "last gasp" of productivity increase that delayed the demise of those technologies. Incumbent firms typically entrenched themselves in pursuing these further incremental improvements, and overlooked the greater long term potential of newer, more radical approaches to technology.

Another study in this period came from Cooper and Schendel (1976). Using a very similar methodology to the original Utterback and Abernathy (1975) study, they surveyed the impact of 22 technology substitutions in a number of industries ex post, and tracked how incumbents reacted to them. In contrast to Abernathy and Utterback, Cooper and Schendel found that it wasn't the character of the technology itself that determined whether incumbent firms could shift to the new technology; rather, it was the decision of incumbent firms whether or not to invest in the new technology and discontinue investment in the old technology. The causality in their study was that incumbent firms must aggressively pursue the new technology, and abandon any further investment in the old technology, in order to survive the technology transition. Incumbents that shifted their investments to the new technology succeeded, while those that did not make the shift failed.

Another study in this vein came from Foster (1986). Using retrospective analysis of previous industries and technology shifts by tracing the logistic rate of technical diffusion (the so-called "S curve"), he followed Cooper and Schendel in arguing that incumbent firms have the ability to respond to technical change, but do not always have the incentive to do so. He noted the incentive conflicts created by new technologies that undercut much of the value of the earlier technology to incumbent firms. This conferred an advantage upon attacking firms, which did not face such incentive conflicts. He also reported that while incumbents in the old technology resisted the new technology quite vigorously, they were also able to push the old technology further. However, this merely delayed the inevitable displacement of incumbents from the new technology. He attributed the failure of many incumbent firms in the face of technical change not to the character of the technology, but rather to the cognitive errors managers made in comprehending the challenge posed by the innovation to their firms. Managers overestimated the potential for further improvement in their old technology, and underestimated the potential threat from the new technology, a pattern also found by Utterback (1994) above.

An important division in the causal mechanism that drives incumbent responses to innovation arises between these studies, a division that will persist throughout the studies that follow. One branch of this literature argues that the nature of the technology largely determines its impact on organizations, following Abernathy and Utterback. If the character of the technology is essentially "radical"[3], its impact upon incumbent firms will be quite severe. If the character is incremental, the impact will be quite benign, or even favorable to incumbent firms. A second branch of the literature, following Cooper and Schendel, Foster, and Utterback (1994) argues that the impact of technical change is determined less by its internal character, and more

[3] Note that radical innovation in the organizational literature is not the same as radical in the economic literature, nor does incremental have the same meaning. See Henderson (1993b) for a lucid discussion and subsequent hypothesis testing, of economic and organizational uses of these terms.

by the response of managers to the innovation. If managers can avoid myopia and act decisively, then they can successfully incorporate the new technology.

A second wave of studies came out in the mid-1980s that argued that the earlier categorization of technology as either overthrowing or dislodging incumbent firms was too simplistic. Abernathy and Clark (1985) also reviewed the history of the US automotive industry, but argued that the earlier work by Abernathy suppressed an important dimension that conditioned the impact of technical change. To the earlier dimension of the character of the technology (now termed “technical-production linkages”), they added the “market-customer linkage” dimension. These two dimensions created four quadrants, each with different implications for the ability of incumbent firms to respond to technical change. In particular, incumbent technological changes that were linked to real market needs were likely to be successful. Those incumbent changes that maintained technical-production linkages, but were uncoupled from a real market need, were not likely to succeed.

A second important study in this era came from Tushman and Anderson (1986). They improve upon the earlier studies by employing a more exhaustive methodology for classifying technologies, and gathering sufficient data to permit quantitative tests of their hypotheses. They also selected industries that had largely undiversified firms, to reduce the impact of environmental conditions outside the industry (p. 447).[4] Data for all three of their industries came from US firms. This study proposed an evolutionary model of punctuated equilibrium, where periods of relative quiescence (incremental change) are interrupted by periods of discontinuous change. They then divided discontinuous change into two further types:

[4] This choice to select the sample so as to reduce environmental influences suggests that, at some point, we need to readmit those influences into our understanding. Further comparative evidence discussed later in this paper also calls for renewed attention to these influences.

"competence enhancing" change and "competence destroying" change. While the terms are defined differently though, the Tushman and Anderson story remains technologically determined: it is the nature of the (discontinuous) technical change that determines its impact upon existing firms. Incumbents prospered when they met with competence enhancing technologies, and failed when they encountered competence destroying technologies.

A later study by Anderson and Tushman (1990) extended this analysis. They dropped the airline industry from their earlier study and added the glass industry. They introduced more detailed measures of firm responses to technical change by explicitly analyzing the number of product designs introduced into these industries before and after a technological discontinuity. Here, the discontinuity was a dominant design. While the punctuated equilibrium story continued, they introduced an important new factor, the number of new entrants into the industry, into their analysis. They explicitly tracked the role of new entrants into the industry as a key element in the ferment created by competence destroying technology. It was these entrants, who are the carriers of the new competence destroying technology, who displaced incumbent firms.[5]

Another influential study in this literature came from Henderson and Clark (1990). Their work was based on an earlier extensive study of all of the projects completed in the photolithography industry since its inception (Henderson, 1988), a population that consisted largely of US firms, but also included two Japanese firms. Examining the frequent turnover of incumbent firms in the photolithography industry, they argued along with Abernathy and Clark that viewing the impact of technical change along a single dimension was too simplistic.

[5] In a later article (Anderson and Tushman, 1991), they developed implications of their findings for managers. These findings were summarized in four lessons: 1) expect technical discontinuities, 2) expect ferment within the industry after a discontinuity, 3) expect newcomer firms to enter, and 4) expect an industry shakeout. These lessons told managers what to watch for, but provided little scope for managerial action. In later work, Tushman expanded the role for managerial action (Tushman and O'Reilly, 1997).

However, they departed from Abernathy and Clark in their classification of the second dimension of technology. The earlier dimension of "technical-production" was expanded into two dimensions, one that categorized core component technologies, and a new dimension that categorized the knowledge of how these components integrated together into a system. This new dimension effectively supplanted the earlier Abernathy and Clark dimension of market-customer linkage.

Henderson and Clark traced the evolution of the photolithography industry through four different shifts in technology. While these products were vital to semiconductor manufacturing, and while the semiconductor customers were the exclusive market for this equipment (which may explain why the earlier market-customer linkage dimension was suppressed here), photolithography equipment makers nonetheless encountered great difficulty when a new generation of technology arose. The leader in each generation of technology was late to enter the new technology, if it entered at all, and a new firm took the leadership position in each new generation of technology. Henderson and Clark attributed this upheaval to the impact of these new technology generations on the systems knowledge of the incumbent equipment supplier. While the core technologies did not greatly change during this period, the way they combined together into systems did change, and this apparently caused incumbent firms not to understand the new technologies in time to adopt them before new competitors established strong positions. Incumbents succeeded when their existing systems knowledge effectively integrated the component technologies, but failed when new systems concepts were required to integrate these components.

The mechanism creating organizational upheaval in Henderson and Clark's study was thus not the changes in the character of the technology itself, but rather the changes in how the company organized and integrated the technology components into systems products. This mechanism was at least potentially amenable to managerial action, a point Henderson (1996) explored in her discussion of the ability of one firm, Canon, to successfully develop multiple generations of photolithographic equipment, when competing firms were unable to do so.

A related analysis of the same phenomenon in Henderson (1993b) linked these findings back to both the economic and organizational literatures. She showed that radical innovation could displace incumbent firms for rational reasons (i.e. incumbents rationally declined to pursue a technology that rendered their existing assets obsolete), and that radical innovation could displace incumbent firms for organizational reasons (due to cognitive limits and inertia). She demonstrated that empirical tests of photolithographic firms' responses that examined economic reasons without controlling for organizational reasons produced noisy, inconclusive results. She found evidence that both economic and organization factors explained incumbent displacement in photolithography.

A detailed longitudinal study of the DRAM industry by Burgelman also found two dimensions to the ability of incumbent firms to respond to technological change. Burgelman obtained unusually deep access to participating DRAM incumbents, and was therefore able to provide a convincing account of the challenges incumbents faced in that industry. As the DRAM industry expanded in production volumes, the critical skills and competences required for success also changed.[6] To persist and succeed in this changing industry, incumbents needed to be able to perceive the required competences that the industry now demanded, and then organize themselves to obtain those competences. For example, firms like Micron were able to realize the need for high volume precision manufacturing, and transform themselves into such a supplier.

Firms such as Intel, which had developed strong capabilities in product design, were slow to perceive the need for such high yield production capabilities. Their inertia caused them to exit an industry they had initially created. Thus, Burgelman's study shows that incumbents must align their internal strategies to the demands of the environment in which they compete.

A related research program by Christensen examined the impact of technological change upon incumbent firms in the hard disk drive industry (Christensen, 1992, 1993; Christensen and Rosenbloom, 1995; Christensen and Bower, 1996). Combining archival research on US firms with extensive field work, he showed that architectural changes in disk drive technologies usually followed a pattern similar to that noted by Henderson and Clark. Changes in how disk drive components were integrated often created serious disruptions for incumbent firms, while new entrants were able to enter the industry and exploit opportunities resulting from these new architectures.

In contrast to Henderson and Clark, though, Christensen found that the primary reason for the challenges faced by US incumbent hard disk drive firms did not relate to cognitive difficulties in perceiving the opportunities offered by a new form factor of hard disk drive. To the contrary, his field work revealed that many incumbent firms had early prototypes that embodied the systems knowledge required to successfully integrate the components into the new form factor. Christensen's causal mechanism for the displacement of incumbent firms by architectural change instead hearkened back to the earlier dimension of market-customer linkages in Abernathy and Clark (1985) that was suppressed in Henderson and Clark (1990).

In Christensen's study with Rosenbloom (1995), they discussed the role of what they termed the Value Network in conditioning the impact of technical change upon incumbent firms.

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[6] This shift hearkens back to Abernathy and Utterback's distinction between product and process technologies, where

This network was a web that connects the suppliers of disk drive components with the manufacturers of hard disk drives, on through to the customers of disk drives and their eventual applications for the storage devices. They showed that the amount of hard disk storage capacity demanded by particular segments of the market grew at a slower rate than the rate at which incumbent firms could provide storage capacity. The ability of storage suppliers to provide increased capacity at a greater rate than desired by the market disrupted the Value Network that connected the firms, creating opportunities for new firms and new form factors to enter. This disruption was what generated the displacement of incumbent firms, as incumbent firms followed their technology upmarket, while new entrants exploited new technology trajectories to enter the established markets.

In related work (Christensen and Bower, 1996), Christensen linked the disruption of the *external* Value Network to the inertia created by the *internal* resource allocation process inside incumbent hard disk drive firms. They showed that established disk drive firms listened carefully to their established customers, and their internal resource allocation procedures channeled funds among competing projects towards those projects that served these established customers. When architectural changes such as new form factors emerged that served their established customers, they found that US incumbent hard disk drive firms had little difficulty adjusting to the new technology. This type of technology they termed “sustaining”. When new form factors emerged that served different customers in remote markets that did not interest current customers, though, these same incumbents were late to enter the new form factors, and generally ineffective when they entered. This type of technology was termed “disruptive”.

firms in young industries compete on product dimensions, and then must compete later on process dimensions.

Following the thread linking back through Foster to Cooper and Schendel, Christensen's work suggested that it is not the character of the technology that determines its impact upon competing firms; rather it is the organizational response to the technology that explains its impact. In particular, the way firms managed vertical linkages in the value chain with suppliers and customers, and the way they managed internal resources, determined whether incumbent firms could adapt to a new innovation.[7] This implied a greater scope for managerial action than is suggested in technologically determined explanations. He developed the possible ways incumbent firms might respond to technological change further in later work (Christensen, 1997).

Mitchell (1989) examined the effect of innovation upon firms in the medical diagnostic equipment industry. He probed the emergence of new subfields within medical equipment which were enabled by technical advances in imaging and related technologies. Drawing evidence from the population of firms selling into the US[8] from 1959 through 1988, he modelled whether and when an incumbent firm enters into an emerging subfield. In contrast to earlier studies, he did not develop a typology of innovation, nor did he explicitly frame this study in the context of a specific typology.

Instead, the causality driving his analysis was based upon economic incentives. The firm's incentive to enter was contingent on the costs of delay (firms rationally want to wait and see what the risks and benefits of entry might be, particularly if the new subfield might substitute for sales of their current products), versus the risks of being pre-empted by the entry of rival firms, who might become entrenched before the firm could establish itself in the new field (if the

[7] The examplar shift that illustrated this distinction between the technology itself and the external linkages surrounding it is the shift from 3.5" to 2.5" drives, which, while embodying a new set of physical and technical challenges, served an established market that was using 3.5" drives. Most 3.5" firms were able to make the shift to 2.5" drives with little disruption.

firm waited too long). The underlying assumption here is that incumbents are not cognitively limited, and that new technologies pose no particular difficulty for their entry choices. In one carefully constructed analysis,[9] he found evidence that incumbents that perceive a threat to their core products are more likely to enter. He also reported findings that incumbents that possess relevant specialized assets are more likely than other rivals to enter into a new subfield. The rival firms were either other incumbents, or related diversifying firms, who might possess similar technical or market assets.[10]

Mitchell (1992) extended this research by explicitly comparing and contrasting the role of market-related supporting assets (such as a direct sales force) to the role of technically related assets, such as prior experience in similar technological areas, in the behavior of medical equipment firms. He found evidence indicating that market-related assets were associated with greater incumbent survival, and with higher market shares, while incumbents with prior technical experience encounter a more mixed set of outcomes. Prior technical experience exhibited a slightly negative effect upon incumbent survival and short term share. For those incumbents that manage to persist through the transition, though, he found evidence that then there was a positive effect on longer term market share. These findings qualify the earlier causality in Mitchell (1989), which was driven by rational calculation. The 1992 study found that prior technical experience may impair incumbents' initial adaptation to innovation, resulting in a "trap" (p. 342) within an inferior technical trajectory, and "mistakes" (p.343). His chain of causality here

[8] While the data are drawn from US sales, 103 of Mitchell's population of 436 entrants were headquartered outside the US (Mitchell (1989: 221). He found that US firms differed from non_US firms in their probability of entry into new subfields, but did not explore possible causes of those differences.
[9]One example of Mitchell's more thorough analysis is his explicit treatment of the issues of right-censorship, i.e., the condition where a firm is in the sample but has not (yet) entered a new subfield.
[10] There apparently were few if any de novo startup entrants in Mitchells' population.

hearkened back to Henderson and Clark (1990): these errors occur not for rational reasons, but due to the cognitive limitations that accompany prior technical experience.

Sull (1997; Sull et al, 1997) has recently published results from a detailed study of incumbent behavior in the US tire industry. There are at least two characteristics of this research program that are relevant to findings of causality in the previous literature. One is that the technology transition from bias ply to radial ply tires that Sull studied was an obvious transition to incumbent tire manufacturers. Because it was signaled well in advance of the event, and because it was not a particularly complex technological change, the usual cognitively limited causal explanations for incumbent difficulties with technology transition ought not to apply. Incumbents ought to have known what was coming, and ought to have known what to do to respond to it, well in advance of having to do it.

The other salient characteristic of this research program is that Sull had unusually deep access to internal records of the incumbent tire firms, and so was able to reconstruct detailed records of investment at the individual tire plant level for each of the US incumbent firms. This unusually detailed evidence indicated that, despite the obvious character of the technical shift, US incumbent tire firms nonetheless stumbled badly in responding to the radial technological transition. The causal explanation he offered for this finding derived from the commitments that management at each incumbent firm had to stakeholders of each firm, including customers, employees, and the surrounding community. These commitments were apparently strong enough to prevent incumbent firms from taking actions such as tire plant closures or conversions that would have preserved many hundreds of millions of dollars in shareholder value.

A research program by Tripsas (1997a, 1997b) examined the impact of technological change in the typesetter industry. Tracking the events of a century in that industry, she identified three separate waves of technical change that hit the firms in the industry. Interestingly, while these changes were quite extensive, not all of the leaders in the industry were displaced. Many firms indeed were driven out, but a few persisted.

This persistence prompted her to examine the mechanisms that appeared to promote this longevity, despite the turbulent technical environment. She found that the presence or absence of key complementary assets (Teece, 1986) such as manufacturing, sales networks, and font libraries, enhanced the ability of incumbent firms to survive the technological shift. She also found that firms with "external integrative capability" were better able to respond to non-incremental innovation shocks. This integrative capability included internal investments in research and development that improved the firm's absorptive capacity to access knowledge from the external environment. It also included investments in transferring knowledge throughout the firm, particularly investments that promoted the sharing of knowledge across functional groups such as R&D, manufacturing, and sales.

A final mechanism she found that enhanced longevity was the existence of dispersed research sites in different locations. These different sites appeared to stimulate rivalry between the sites on the one hand, and promoted greater variation in technological approaches that a firm pursued on the other hand. Thus, while technological changes rendered the technology of one research site obsolete, the different technical path of another site sometimes enabled the incumbent firm to shift to that technology platform at the other site, instead of fighting a losing battle to sustain the now-obsolete technology base.

Issues of External Validity in the Innovation and Organization Literature

A key issue in these studies is the question of external validity: to what extent do the explanations for incumbent failure (or success) in the focal industry apply to the behavior of incumbent firms in other industries? One difficulty that has complicated any comparison across studies is the lack of a common definition of technology. How does the behavior of incumbent firms in an industry with "radical" technology (Abernathy and Utterback, 1978) compare with incumbent behavior in an industry with "new" technology (Cooper and Schendel, 1976)? How does this explain the behavior of incumbents confronting "competence destroying" technology (Tushman and Anderson, 1986) or "disruptive" technology (Christensen and Bower, 1996)?

A related issue is the lack of a common understanding of the relevant dimensions along which to classify innovation. The initial studies used a single dimension, either radical or incremental (Abernathy and Utterback, 1978) or old vs. new (Cooper and Schendel, 1976; also Foster, 1986), or even competence enhancing or competence destroying (Tushman and Anderson, 1986). Later studies have concluded that the phenomenon of incumbent success or failure in response to innovation has at least two dimensions. For Abernathy and Clark (1985), the key dimensions were "technical-production", and "market-customer linkage". Henderson and Clark (1990) effectively divided the technical production dimension into two: core technology concepts (embodied in component technology) vs. system linkage concepts that integrate the technology. While Christensen felt that this classification was useful, he found that within the quadrant of architectural innovation, the linkage of products to markets and customers remained important (hence the Value Network), and that this in turn conditioned the allocation of resources within firms (Christensen and Bower, 1996). Burgelman examined "product" and "process" dimensions, and whether incumbents' internal strategies were aligned with the demands of the external environment. Tripsas (1997b) elides distinctions between "architectural" and "competence destroying" innovations, and selects her data for variance along both of these dimensions. This suggests at least three dimensions are needed to understand the impact of innovation that is “architectural” in nature.

Beyond definitional and classification issues, there are empirical irregularities that are emerging in some of the above industries, which suggest we do not yet have an adequate understanding of the impact of technical change upon incumbent firms. Taken separately, these anomalies might suggest particular qualifications or extensions to the above literature. Taken together, though, they cumulatively challenge us to reframe the problem in a more general way. First, I will explore the individual inconsistencies, and then in the following section I will propose a more general framing of the problem, based upon the extant literature and these emerging anomalies.

External validity concerns can be seen clearly in the empirical work in photolithography and hard disk drives. The displacement of photolithographic equipment firms in Henderson and Clark’s (1990) study took place within a common Value Network, in the Christensen and Rosenbloom (1995) sense.[11] The customers for photolithographic equipment were all semiconductor firms, and the primary demand for new steppers emerged in the center of the established semiconductor market from established customers. The difficulty Henderson and Clark report seems to have been that the incumbent firms were unable to perceive the prospective importance of architectural changes in the technology, until it was too late to respond to more alert entrants.

This pattern is in sharp contrast to the pattern noted in hard disk drives. There, the incumbent firms had little difficulty creating prototypes of new form factor products, but

[11] This was also true of the technological transitions Sull studied in the tire industry, where the primary customers were the OEM customers (i.e. the Big 3), and, to a lesser extent, private label (e.g. Sears) and branded replacement channels. These all remained unchanged through the period of Sull’s study.

struggled greatly to channel resources to those form factors when these were not demanded by established customer base of hard disk drive firms. Thus, Henderson and Clark's causal displacement mechanism (information processing limitations of incumbent firms) does not appear to explain Christensen's empirical evidence. Similarly, Christensen's causal mechanism in the hard disk drive industry (disruption of the value network, combined with biases in the internal resource allocation process) does not appear to account for the empirical evidence reported by Henderson and Clark, which occurred in an industry where the value network remained unaffected.[12]

A further important issue in external validity is the comparison of the impact of technical change upon firms in the same industry in different countries. One recent study compares the impact of new form factors upon Japanese incumbent disk drive firms, vs. their well known impact upon US incumbent firms. The same form factor transitions that displaced numerous leading US firms, did not dislodge any of the leading Japanese disk drive firms (Chesbrough, 1999b).

This comparative history of hard disk drives (developed at length in Chesbrough, 1999a) points out a potentially serious issue for this entire literature, the issue of using data from largely <u>one</u> country to make inferences about the impact of technical change in <u>all</u> countries. In the studies reviewed here and summarized in Table 1, the data that supported most of the theories

[12] Christensen addresses this issue in his recent book (1997: 27), stating "One possible reason for these different results is that the successful entrants in the photolithographic aligner industry studied by Henderson brought to the new product a well-developed body of technological knowledge and experience developed and refined in other markets." This is consistent with Tripsas' "external integrative capabilities" finding in typesetting. However, this explanation would not account for the earlier generations of displacement, where many of the photolithographic entrants were themselves de novo firms, as they were in the hard disk drive industry, while the value network was left intact.

regarding the organizational impact of innovation came largely from US sources.[13] However, the conclusions that the authors draw from these studies are not limited to the US context. Anderson and Tushman, for example, make the claim that "Across these diverse product classes, sales always peak after a dominant design emerges. Discontinuities never become dominant designs, and dominant designs lag behind the industry's technical frontier" (1990: 604), with no reference to the specific US context of their empirical work. Henderson and Clark similarly claim without qualification that "We show that architectural innovations destroy the usefulness of the architectural knowledge of established firms, and since architectural knowledge tends to become embedded in the structure and information processing procedures of established organizations, this destruction is difficult for firms to recognize and hard to correct" (1990: 9).

In the hard disk drive industry, a comparison of how firms responded to the same technological shocks in the same industry in two leading industrialized countries demonstrates quite different organizational outcomes. This is difficult to explain with any of the mechanisms found in the extant literature reviewed in Table 1 above. The comparative nature of the study analyzes the same technology shifts in both settings at the same time, so technological distinctions such as incremental vs. radical, etc., cannot account for the disparity.

This comparative difference in the impact of innovation upon firms in the US vs. Japan is also emerging in other work on high technology industries, suggesting that we will need to focus greater attention on this. A recent detailed analysis of both US and Japanese firms in the semiconductor industry, for example, noted many differences in the reaction to technological change by each region's firms (West, 1997). The methods by which US firms organized teams,

[13] Henderson and Clark's sample included two Japanese firms, Nikon and Canon. But their field observations conclude as these firms become the industry leaders. Nikon's and Canon's subsequent persistence thus were not

approached new process development, and conducted experimentation, for example, differed in substantial ways from that ways in which Japanese firms approached these tasks. Moreover, while firms from each region have been "successful", these differences between US and Japanese firm have, if anything, widened in the past decade.

Another technologically intensive industry that appears to demonstrate significantly different organizational responses to innovation between the US and Japan is the biotechnology industry. A recent study by Darby and Zucker (1996) examined the role of "star" scientists in the biotechnology industry. They find that star scientists are strongly associated with the development of new enterprises in this industry. However, they report two significant differences between firms in the US vs. Japan in this regard. First, the number of firms created by star scientists in the US is much greater than the number created by similarly matched star scientists in Japan. And second, the method of firm entry differs as well when it does occur. 77% of the US entrants associated with star scientists were de novo startup organizations, while 88% of Japanese entrants were subunits of existing Japanese firms.

While Darby and Zucker do not examine displacement of incumbent firms directly, they show that the effect of human capital in this technologically intensive industry creates very different effects in both the mode and frequency of entry in the two different countries. Given the earlier studies that show that new entrants act as the agent of displacement of incumbent firms (Anderson and Tushman, 1990; Christensen, 1993), it is likely that incumbent displacement in this industry will differ between the two regions as well. Finally, in a recent survey of the international computer software industry (Mowery, 1996), a similar comparative pattern was found. Steinmuller (1996) recounted the strong influence of independent startup

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observed in their data. Tripsas' (1997) data include global market shares of US firms, and did contain one UK-based firms in the US computer software industry, while in the same volume Cottrell (1996) discussed the dominant role that established Japanese firms played in shaping the Japanese computer software industry. Unsurprisingly, Japanese incumbent software firms have persisted much longer than most of their US counterparts.

One could develop some potential explanations from the current literature for the difference in the comparative impact of technical change in one country vs. another. For example, Henderson (1996) examines the apparent ability of Canon to weather the architectural transitions that thwarted other competing firms. She suggests that Canon's managerial actions and strategic choices may explain its ability to adapt to architectural innovation, implying that cognitive limits are amenable to managerial action. Another possibility is that some of the mechanisms noted in Christensen's work (the value network, the internal resource allocation process) might differ between firms in each country, hence the different result. A third possibility is that previously latent mechanisms that are surfacing in the most recent published work such as dispersed R&D organizations within the firm, or firm linkages with universities (Tripsas, 1997b) are driving these differences. Perhaps these differ between countries, and provide different resource pools for incumbent firms. Sull's (1997) causal mechanism may be brought to bear here as well, to the extent that the depth of internal commitments of managers to stakeholders may differ across countries as well. As Burgelman (1994) points out, these internal commitments must remain aligned with the external environment, or they can lead to inertial strategic behavior by the incumbent.

The variety of possible explanations for these comparative differences demonstrates the limits to our knowledge of the organizational impact of innovation. Clearly, this emerging

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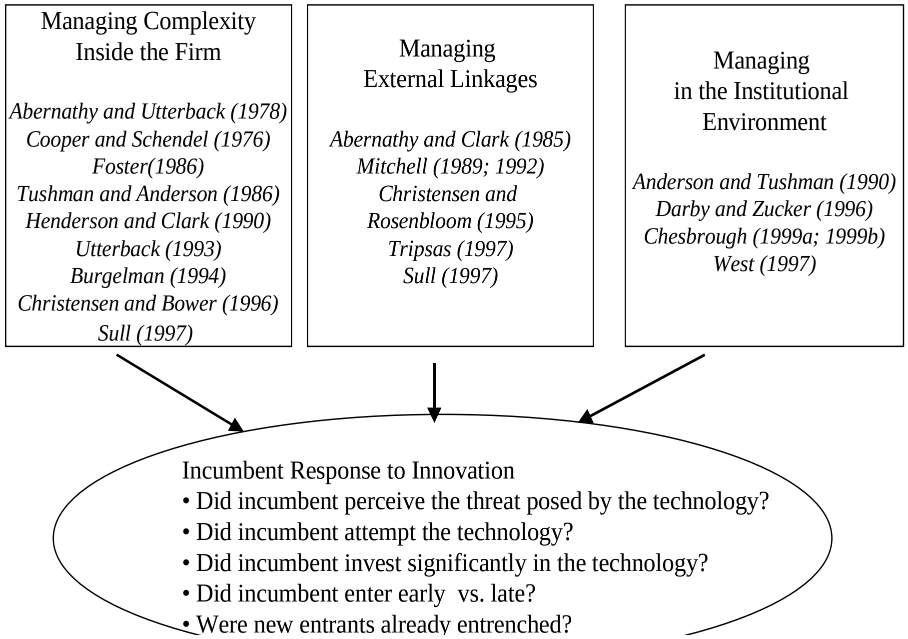
lab of a US firm.

comparative evidence requires greater investigation. In the meantime, we need to be more cautious in extending the claims of the current literature beyond the US context in which most of its evidence was collected. Moreover, we need to frame our approach to further work in this area so that we improve upon the limitations of the current research. Below, I offer one synthesis that attempts to develop such a frame.

Assembling the Innovation and Organization Elephant : Three Relevant Dimensions

It is evident from the extensive studies already conducted that the impact of innovation upon competing firms is too complex a phenomenon to be captured in a single dimension or a simple typology. This perhaps explains the proliferation of definitions and classifications that has arisen in this literature, as each study seeks to understand a different dimension of the problem. I sketch three dimensions that attempt to integrate the causal mechanisms and empirical findings drawn from the studies in Table 1 in what follows. The first dimension is one of managing technical complexity. The second dimension is managing linkages across organizations, while the third dimension is managing in different institutional environments. Figure 1 below illustrates these dimensions, and places the above empirical studies within this synthesis.

Figure 1
Three Organizing Dimensions
to Explain Incumbent Responses to Technological Change



Managing Technical Complexity

The first important dimension in this literature is the role of technical complexity and its impact upon incumbents' ability to respond to technical change. Complexity here means that technical interdependencies within a new technology are not fully identified or understood initially, so that changes in a technology have outcomes that cannot be fully predicted in advance. Previous heuristics for partitioning tasks may no longer be appropriate, so that new partitions may be needed. Technical innovation can be usefully viewed as creating "strong uncertainty" (Dosi, 1988), where the possible future states of the world are unknown. Firms in these environments cannot simply reason backward from a known future state to resolve technical issues; instead, they must adapt as they go along. This poses difficult technical coordination problems.

The early studies of Abernathy and Clark (1975), Cooper and Schendel (1976), and Foster (1986) center their explanations for incumbent displacement around issues of managing complexity. Tushman and Anderson's (1986) study of discontinuous innovations, which usher in a new era of technological ferment fits here. Henderson and Clark's (1990) notion of architectural knowledge as an organizational solution to managing complexity belongs here. Burgelman's (1994) alignment of internal strategic competence with external technology shifts fits as well. Christensen and Bower's (1996) analysis of internal resource allocation processes, along with Sull's descriptions of tire firms' R&D commitments to radial tires fall here as well.

This dimension suggests that the impact of innovation upon organizations may be explained at least in part by problems of internal coordination. Were there problems of aligning internal strategy (Burgelman, 1994) or incentives properly as a result of a technological shock? Was the earlier logic that integrated together the elements of a system overturned (Iansiti, 1997)? Were product development routines that proved effective at one time inappropriately applied in a different context? Did organizational routines that effectively managed innovation at one time become rigidities inside the firm later on (Leonard-Barton, 1992)? These questions arise from the complexity dimension of the impact of innovation upon incumbent firms.

Managing External Linkages

A second important dimension is the role of external linkages in the ability of firms to adapt to innovation. von Hippel's (1988) work reminds us that the customer is often integral to the innovation process. Linkage with suppliers can similarly be critical to the innovation process. New work on the impact of technical modularity on the organization of the project, and the boundaries of organizations working with the technology find that these types of technologies may promote marked shifts in firm organization and industry structure (Baldwin and Clark, 1999;

Novak and Eppinger, 1998). In cases where technology is not yet well characterized, internal organization may have advantages in controlling the development and timing of these complementary technologies (Chesbrough and Teece, 1996; Christensen and Chesbrough, 1999). When technologies have become well characterized, and where interfaces have become codified, organizations then can manage well through market mediated coordination (Monteverde, 1995). Displacement might be expected to result in situations where firms attempted to coordinate technical changes through inappropriate external linkages: an over-reliance upon external linkages in the former stage of technology, or an insufficient use of them in the latter stage of technology.

One facet of external linkages is managing vertical linkages between firms in a value chain. This dimension has been established already in the empirical innovation studies reviewed above. The "market-customer linkage" was featured as one of two dimensions of innovation in Abernathy and Clark (1985), and figures prominently in Christensen and Rosenbloom's (1995) "value network" concept as well, which places attention upon the coordination back into the supplier base, as well as forward with customers. Mitchell's analysis of the importance of market related assets to incumbent firm entry into related subfields (1989) and market share and survival (1992) reflect the benefits of these assets in managing these linkages. Tripsas' (1997) finding of "external integrative capability" similarly fits here as well.

Organizations appear to manage innovation more effectively when they couple technical change with customer needs, supplier capabilities, and complementary assets. Many of the industries examined required incumbent firms both to master the development of new complex components and to integrate those components into products or systems in a vertical value chain (e.g. automobiles, photolithography equipment, semiconductors, hard disk drives).

A second dimension of external linkages relates to the ability of the firm to access and absorb knowledge from the external environment (Cohen and Levinthal, 1990). Here, the internal investments made in research and development create a byproduct, namely the enhanced ability to identify, recognize and internalize findings from outside the firm. This may include Henderson's (1996) notion of building "architectural knowledge". A corollary element is the formal and informal mechanisms through which knowledge flows inside the firm and between firms (von Hippel, 1987, Appleyard, 1996). The firm's ability to integrate external knowledge with its internal activities was one crucial reason Mergenthaler was able to survive three different waves of technical change in the typesetting industry (Tripsas, 1997).

The organizational ability to work effectively with complex components and access outside knowledge may usefully be viewed as an interesting example of the how and where to draw the boundary of the firm (Pisano, 1990). This would suggest new hypotheses about the organization of firms in response to a technological shock. Do we observe hazards that arise from incomplete contracts between linked firms in an industry? Are incumbent firms at risk because of these hazards? The case of firms in the personal computer industry depicted in Langlois (1992) provides one such example, where incumbent firms suffered from technical uncertainty that was greatly exacerbated by contractual hazards in the industry. A recent analysis of the impact of MR head technology upon Japanese disk drive firms also reported that firms that attempted to coordinate the introduction of this complex component into their drives via outside suppliers ran into problems that delayed their product launches. Japanese firms that managed this transition with internal suppliers solved the problems sooner, and gained market share as a result (Chesbrough and Kusunoki, 2001).

The Institutional Environment

An emerging third dimension in the literature derives from the new comparative evidence emerging from recent studies in technologically intensive industries, showing that the impact of innovation upon incumbent firms differs across countries. While Tushman and Anderson (1986) selected industries with minimal environmental disturbances by design, their later study (1990) considered environmental influences more explicitly. One prominent environmental feature they identified was the role of new entrants as "carriers" of competence destroying technologies into the industry (1990: Hypothesis 7, p. 617). The displacement of incumbent firms in many of the industries reported above (autos, biotechnology, hard disk drives, photolithography), appears to be driven as much by the success of entrant firms into those industries as it is by the failure of established firms. Entrant success may be viewed as the dual of incumbent failure.

Institutional differences between countries may explain part of the difference in the frequency and impact of startup firms that arise from technological change (Darby and Zucker, 1996; Chesbrough, 1999a). Understanding the reasons for successful entry of new firms into a focal industry may go a long way in particular to understanding the differences in the impact of technical change between incumbent firms in different countries in a single industry.

Another part of the institutional environment that affects the probability of success for both incumbents and entrants is the appropriability regime (Teece, 1986); the extent to which firms can capture the value they create when they shift to a new technology. This allows researchers to examine technological change through questions of incentives for incumbents vs. those of entrants from the earlier economics literature noted above. Anderson and Tushman (1990) took note of the potential importance of this influence:

> "When the competition process is artificially forestalled, dominant designs may not emerge. Such cases arise under regimes of high appropriability where a firm

> is able to build a thicket of patents around a technology and control its diffusion via strategic licensing decisions (Teece, 1986)." (p. 614)

A weak appropriability regime by definition involves an industry where innovating firms cannot protect their discoveries from rapid imitation from other firms through legal or institutional means. It may not be surprising that incumbents are more susceptible to being dislodged in such conditions.

However, there are other industries where the protection of innovation is stronger (Levin et al, 1987), which might qualify the findings of incumbent displacement in this literature. In "tight" appropriability regimes, incumbents may be relatively safe from new entrant firms, while the reverse may be true in "loose" regimes. Do we, for example, witness significant displacement of incumbents in industries like chemicals and pharmaceuticals (Henderson, 1993a) when technological change occurs, where the appropriability regime is considered to be much tighter? Is incumbent displacement inversely related to the strength of the appropriability regime? Anderson and Tushman (1990: 623) reported that two technical discontinuities they studied did not become dominant designs, due to the strength of patents held by the inventors of these technologies. It may be that appropriability needs to be admitted as an environmental variable that conditions the incentives for discovery of new technologies, and also conditions the ability of rival firms to imitate and thereby diffuse those discoveries (Merges, 1996). It may also be the case that the appropriability regime of an industry may vary between countries, so that US firms in an industry encounter a different appropriability regime than Japanese firms encounter even within that same industry (Chesbrough, 1999b).

These three dimensions provide a context for reviewing the causal chain of incumbent firms' responses to technical change established in the above empirical research. This is shown at the bottom of Figure 1. As Tripsas (1997b: 342-3) discusses, incumbent firms can fail to adjust to innovation shocks for a variety of reasons. Incumbents may not perceive the threat posed by the new innovation (Foster, 1986). They may fail to attempt (i.e. to invest in) the new technology, as was found in the studies of Cooper and Schendel, (1976), Foster (1986), and Utterback (1994). Or, they may invest, but may fail to garner enough resources to invest significantly enough to succeed, as Christensen and Bower (1996) and Sull (1997) found. Or, they may do this, but they do it too late, after new entrants have become established. Or, they may invest and manage well, but lack access to the requisite complementary assets that have been established by now-entrenched entrants, as evidenced in Mitchell, (1989; 1992) and Tripsas (1997a, 1997b). Finally, incumbent firms in one country may adapt to technological changes that displace incumbent firms in another country (Chesbrough, 1999b).

These dimensions may also inform the literature on dominant designs (see Tushman and Murmann, 1998). In the stylized version of dominant designs, the evolution of an industry begins with a condition of technological ferment, punctuated by the arrival of a dominant design, which issues in a subsequent condition of more gradual technical change. Applying the above framework, the dimension of managing complexity is most crucial during the period of ferment, since the level of technological uncertainty is so high. Identifying and accessing relevant knowledge, and being able to create products and services that compete on many dimensions of performance requires significant coordination within the firm.

In addition, the environment surrounding firms in this ferment impacts their choices in managing complexity. If the institutional environment promotes the formation of many firms, we might expect technological ferment to result in numerous new entrant firms, each with a contending product design. These firms may race to establish the winning dominant design.

This would imply a need for rapid decision-making on limited knowledge within firms, and would also require supporting institutions such as highly fluid labor markets to attract enough people, and fluid capital markets to access sufficient financial resources. If institutional conditions inhibit new firm formation, though, the ferment will likely play out within existing firms, where internal labor and capital markets will be required to channel resources into these new activities. Here we might expect to see new subsidiary organizations or new divisions of established incumbent firms to attempt to exploit opportunities in the ferment. Incumbent firms in this latter situation are less vulnerable to displacement by the technical changes.

After the arrival of the dominant design, the issues around managing complexity subside, due to the resolution of many technological uncertainties through the arrival of the dominant design. Now, the dimension of managing vertical and external linkages becomes more critical, as firms now must access the relevant customers, suppliers and partners to exploit the newly dominant design. These events shift the boundary of the firm and its relations with external firms.

Once more, the institutional environment may influence this phase of the technology's evolution. Where entry opportunities for new firms are plentiful, the arrival of a dominant design and its associated technical standards may promote horizontal specialization within the technology, creating a more modular industry structure (Grove, 1997; Baldwin and Clark, 1998). Individual firms may focus on particular elements within the technology, and strive to build relations with complementary players to establish sustainable positions in the technology.

In other institutional environments, though, the opportunity for greater specialization of equipment and people may instead result in a small number of participants who develop deep internal capabilities that are organized more vertically within the firm and its closely associated affiliates. The arrival of the dominant design in this instance will not yield a plethora of new entrants; rather, it will shift the competition from product elements to process elements without shifting the boundary of firms in this transformation.

Conclusion

This paper began by noting the issues of internal vs. external validity, and argued that our empirical work on the impact of technical change upon organizations to date has been designed to enhance internal validity. In general, the question of external validity is left open in these studies. The general approach of every study in this literature has been a contingent approach: the impact of technical change upon incumbent firms depends on the context: though the particular factors that condition the impact differ from study to study. Enough studies have been done now that we can assess the external validity of these studies, by “assembling the elephant” revealed from the individual pieces. Such an assessment is necessary, but is complicated by different definitions and typologies of technological change used in the different studies.

The causal mechanisms proposed by the individual studies can usefully be grouped into two types. One type places primary emphasis on the character of the technology, which induces problems with incumbents’ incentives. The other type focuses primarily upon the behavior of managers in response to changes in technology, which invokes organizational issues of cognition and inertia . Of course, these causal mechanisms need not be mutually exclusive, and elements of both may aid in our understanding (Henderson, 1993b).

New comparative evidence, however, suggests that this may not be the whole story: technological innovation may not have the same impact upon incumbent firms in an industry in the US that it does on firms in other advanced economies such as Japan. To account for these comparative differences across countries, we may also need to add consider the environment in which incumbent firms operate. A more general framework is needed to direct future research in this area. This framework is likely to remain contingent in nature, as the variety of findings from a number of industries defy any single causal explanation.

I propose a framework consisting of three dimensions that synthesize the findings of the literature on the impact of innovation upon competing firms. One is the challenge of managing technical complexity, and the associated internal coordination problems that this entails. A second dimension is the importance of external linkages with suppliers and customers, and the resulting boundary of the firm, to adjust to technical change. A third dimension is the institutional environment that promotes or inhibits the entry of new firms, along with the underlying appropriability regime that incumbent firms confront when they attempt to capture the value from the innovations they introduce. The influence of the institutional environment also extends our understanding of dominant designs and industry evolution. The institutional environment conditions the formation of new entrants, and the ability of firms to form external linkages. These are likely to have different effects in periods of technological ferment than the effects they will have in post-dominant design periods.

This synthesis raises new research questions, which hopefully will help guide the design of future research projects. Future research needs to account for technical complexity, measure or somehow control external firm linkages, and examine the effects of different environments upon innovating firms. In so doing, we may enhance our understanding of the organizational impact of technical change in an increasingly global technological context.

Table 1 - A Compilation of Empirical Studies of the Impact of Innovation in an Industry
(in order of presentation in the text)

Study	Focal Industry(s)	Geography	Unit of Analysis	Research Design	Direction of Causality	Dimensions of Innovation Typology	Incumbent Success when	Incumbent Failure when
Utterback & Abernathy (1975)	5 industries from Myers and Marquis (1969)	US	Product and process innovation in a focal industry	Match product development goals to process design by stage of industry	Firm innovation should vary with its strategy and with industry environment	product-based vs. process-based technology	Matches process choices and product goals to firm strategy	Process and product choices not matched, resources not focused
Cooper & Schendel (1976)	various	US	technology: old vs. new	select technology substitutions, studied 22 incumbent responses	must pursue new technology to avoid displacement	"old" vs. "new"	made sustained investments in new technology	continued to invest strongly in old technology
Abernathy & Utterback (1978)	automotive	US	character of technology	review of earlier technology history	character of technology entrenches or displaces firms	radical vs. evolutionary; product vs. process	technology is evolutionary; process based innovation	technology is revolutionary; product based innovation
Foster (1986)	various	various	old vs. new technology	review technology transitions, and track both old and new technologies	incumbents fight to maintain old technology, entrants attack with new technology	"old" vs. "new"	incumbents aggressively pursue new technology	incumbents continue to invest in old technology
Utterback (1994)	Various	Primarily US[14]	Dominant designs of "productive units"	History of industry technologies; pre- and post-dominant design	Arrival of dominant design shifts basis for competition	Incremental vs. radical; product vs. process	Overcomes inertia; organizes separate units	Incumbents entrench in previous technology

[14] "Though events in countries other that the US are covered in several parts of the book, the emphasis has been primarily on the origins and development of industries here" (Utterback, 1994: xxiii).

Abernathy & Clark (1985)	autos	US	character of technology	classify technologies & their impact on 4 quadrants	different innovation categories create different organizational outcomes	technical - production, market-customer	innovation linked to market need	innovation uncoupled from market
Tushman & Anderson (1986)	cement, airlines, minicomputer	US	category of technology	study history of technology in 3 industries selected to reduce environmental disturbances	character of innovation determines organizational impact	competence enhancing v. competence destroying	innovation is competence enhancing	innovation is competence destroying
Henderson & Clark (1990)	photolithography	US, 2 Japanese firms	categories of innovation	study incumbent responses to 4 generations of photolithographic technology	different innovation categories create different organizational outcomes	component technology vs. system integration	system integration unchanged	system integration disrupted
Anderson & Tushman (1990)	glass, cement, minicomputers	US, except glass US & UK	technology discontinuity; # models (designs) introduced	analyze # designs introduced pre- and post-discontinuity	technical discontinuity upsets incumbents, fosters new entrants	technology ferment -> incremental -> ferment (evolutionary cycle)	pioneers dominant design based on competence enhancing technology	entrant pioneers dominant design based on competence destroying technology
Burgelman (1994)	DRAMs	US	Product and process innovation in a focal industry	Longitudinal analysis of 6 product and process generations	Interaction between external forces and firm's internal strategy	Technology evolution from "specialty" to "commodity"	Internal strategy aligned with external environment	Internal inertia impedes alignment with external environment
Christensen & Rosenbloom (1995)	Hard disk drive industry	US	HDD form factor experience	generations of HDD form factors	sustaining form factor changes led by incumbents, disruptive changes led by entrants	trajectory of technology supplied, vs. technology demanded	innovation linked to current Value Network	innovation emerges outside current Value Network
Christensen	Hard disk	US	HDD form	generations of	internal	sustaining vs.	innovations	innovations

& Bower (1996)	drive industry		factor experience	HDD form factors	resource allocation process favors established customers	disruptive	sustain current customers	emerge away from current customers
Study	Focal Industry(s)	Geography	Unit of Analysis	Research Design	Direction of Causality	Dimensions of Innovation Typology	Incumbent Success when	Incumbent Failure when
Mitchell (1989)	Medical diagnostic equipment	US	Industry subfield	Incumbent entry decisions into emerging subfields	Conflicting Incentives: benefits of waiting vs. risks of being pre-empted	None offered	Entry occurs a) when core products at risk, b) if supporting assets exist	Incumbent delays too long, and/or lacks supporting assets
Mitchell (1992)	Medical diagnostic equipment	US	Industry subfield	Incumbent entry decisions into emerging subfields	Market resources and technical resources condition incumbent success	Study done within low transilience, or "modular" innovation context	Incumbents possess relevant market-related assets, but not nec. Technical assets	Related diversifiers posses relevant market-related assets and technical assets
Sull, 1997; Sull et al, 1997	Tire industry	US	Impact of radial tire technology	Incumbent investment into radial conversion	Internal commitments to customers, employees, and stakeholders limit conversion investment	None offered	Incumbents convert when ties are weaker; when outside CEO brought in	Strong ties to stakeholder constituencies inhibit necessary responses
Tripsas (1997a; 1997b)	Typesetter industry	US and UK	Three waves of radical technical change	Comparison of responses of three leading firms to 3 waves of change	Internal investment and dispersed R&D centers overcome organization inertia	Architectural; competence destroying; complementary investment	Investments in complementary assets, absorptive capacity, transmission; multiple R&D sites	Incumbents lack external integrative capability, complementary assets and lack multiple R&D sites

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