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WHAT DO WE REALLY KNOW ABOUT WHEN TECHNOLOGICAL INNOVATION IMPROVES PERFORMANCE (AND WHEN IT DOES NOT)?

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Abstract

Most approaches to innovation bear the implicit assumption that increased innovativeness leads to improved organizational performance. Thus more attention has been focused on innovativeness than on innovation performance – on novelty than on value. However recent empirical evidence calls into question the unqualified optimism surrounding innovation, and leads us to ask what we *really* know about when technological innovation improves performance.

In this paper, we seek to make a contribution by presenting the results of an exhaustive review of the existing knowledge of the outcomes of technological innovation. Our synthesis of the literature allows us to relate, in one parsimonious model, the drivers and moderators of the antecedents, technical outcomes, and performance outcomes of technological innovation and technological change. We also make sense of the proliferation of terms, and consequent terminological ambiguity, which characterize a lot of work on technological innovation. Finally, in the light of the model presented and recent developments in work on firm capabilities, we indicate possible avenues for further development of this critical area of research

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> "'If a man … make a better mousetrap than his neighbour, though he build his house in the woods, the world will make a beaten path to his door,' claimed Emerson. Yet the inventors of new mousetraps, and other gadgets too, are more likely to be found at the bankruptcy courts than in the millionaires' playgrounds of the Caribbean or the French Riviera" (Grant, 2002: 335).

Scholars and managers have spent the last two decades studying the drivers of innovation, and trying to increase firm innovativeness, respectively. These endeavors have been driven by the implicit but generally accepted assumption that increased innovativeness leads to improved organizational performance. Thus more attention has been focused on innovative*ness* than on innovation performance; on novelty than on value.

However, recent data is beginning to make some observers question the unqualified optimism surrounding innovation. Despite the emphasis on innovation and especially innovativeness, "evidence is growing that innovation processes in many industries are not yielding the benefits they should" (Linder, Jarvenpaa, and Davenport, 2003: 43). Although measures of innovativeness have increased, economic performance has not improved correspondingly (Kandybin and Kihn, 2004; Linder et al., 2003), and surveys repeatedly show that managers are unsatisfied by returns on growth in innovation (Andrew, 2005; Andrew and Sirkin, 2003). Thus "the unspoken truth seems to be that for a very large number of companies, innovation spending continues to rise, but it is generating neither enough profit nor competitive advantage" (Andrew, 2005: 7).

Furthermore, the empirical relationship between innovativeness and *firm* performance is yet to be demonstrated conclusively. As a whole, studies relating innovativeness to firm performance have provided ambiguous evidence (Li and Atuahene-Gima, 2001), and mixed results are common (Chandler and Hanks, 1994; Haneda and Odagiri, 1998; Leiponen, 2000). A literature review of the area found that two-thirds of the studies showed a positive relationship between innovativeness and performance, but the rest found a negative relationship, or none at all (Capon, Farley, and Hoenig, 1990).

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Yet in retrospect these findings are logical, since individual innovations can vary widely in their performance outcomes. An excessive focus on innovativeness masks the innovation-level contingencies that determine the success or failure of individual innovations. Thus an important question arises, which has been insufficiently addressed in the literature: When does innovation improve firm performance, and (perhaps more importantly) when does it not?

To begin to address this question, we need to redirect our attention from the predominant focus on the *antecedents* of innovation, to the firm-level *outcomes* of innovation. It is important to characterize what we currently know about the outcomes of innovation in order to delineate the gaps in our knowledge, as well as to identify research programs capable of filling in those gaps.

In this paper, we seek to make a contribution by presenting the results of an exhaustive review of extant knowledge on the outcomes of technological innovation. Our synthesis of the literature allows us to relate, in one parsimonious model, the drivers and moderators of the antecedents, technical outcomes and performance outcomes of technological innovation and technological change (Figure 5). We also make sense of the proliferation of terms, and consequent terminological ambiguity, which characterizes a lot of work on technological innovation.

Our review shows that we know where technological innovation comes from, as well as what makes some firms more innovative than others. Thus there is a very well-developed body of knowledge on the antecedents of technological innovation (Figure 2).

In addition we find that we know a lot about how technological innovation leads to industry-level technological change. As such, there is also a well-developed body of knowledge on the technical outcomes of technological innovation (Figure 3).

We find that we know quite a bit about how and when industry-level technological change is likely to improve firm performance, and when it is likely to worsen it. Thus there is also a fairly well-developed body of knowledge on the performance outcomes of technological change (Figure 4).

However, we find that we still know very little about when individual innovations will improve economic performance, and when they won't. Thus the clarification of the determinants of the performance outcome of technological innovation represents the next frontier for research on the outcomes of innovation in general, and technological innovation in particular.

By accumulating the aforementioned streams of research (Figures 1-4), we derive the model in Figure 5, which thus summarizes what we currently know about the determinants of the antecedents, technical outcomes, and performance outcomes of technological innovation.

In the next section, we briefly discuss the conceptualization of technological innovation and our organizing framework for the literature review, as well as some descriptive statistics in the review. We then go on to the characterization of the existing knowledge, followed by a discussion of the findings and then the conclusion.

Technological Innovation and Performance Outcomes

Innovation is the embodiment of new approaches to doing business in products/services and/or their production and delivery systems (Burgelman, Maidique, and Wheelwright, 2001; Grant, 2002). These "new approaches" however, may have different foci. Thus an innovation's novelty may arise from "new approaches" to technology, firm organization, financing, business model etc.; embodied in products or processes (Drucker, 1985; Grant, 2002; Hamel, 2000; Kim and Mauborgne, 1999; Markides, 1997). As Peter Drucker puts it, "innovation goes right through all phases of business. It may be innovation in design, in product, in marketing techniques. It may be innovation in price or in service to the customer. It may be innovation in management organization or in management methods" (Drucker, 1954: 40).

Technological innovation has become more important in recent times, as technical advancement has quickened and grown more pervasive. As a result, firms have increasingly sought to create enhanced value through the embodiment of technical advances or new technologies in products and/or their production and delivery systems. Thus technological innovation is not just the commercialization of new technologies, but *innovation, where the focus of novelty is technological.* For this reason, it is not confined to "high technology" industries but is, in Drucker's words, "as important to a bank, an insurance company or a retail store, as it is to a manufacturing or engineering business" (ibid). The end product of technological innovation may thus not be a technology itself, but it will embody at least some new technology or technical advance.

Nevertheless, like any other innovation, one of the most important criteria for judging technological innovation has to be its impact on performance. The outcome of technological innovation is critical because an important reason why firms innovate is "to create enhanced value in products and services and to gain sustainable advantage in relation to rivals" (Burgelman and Rosenbloom, 1997: 274). Differences in profitability between competing firms are often a disequilibrium phenomenon resulting from internal or external change (Grant, 2002; Rumelt, 1987), where "internal change is generated by innovation" (Grant, 2002: 231). Hence the characterization of existing knowledge about the determinants of the outcomes of technological innovation is an important task.

One Term, Several Uses

Unfortunately, this task is complicated somewhat by the fact that scholars investigating the outcomes of "technological innovation" have not used the term in a univocal way.[1] Three distinct uses emerged from an iterative analysis of the terminology in major English-language journal articles and books on the subject.

Firstly, the term "technological innovation" is sometimes used to refer to an *improvement in the performance of a technology* (or technologies) along some dimension(s) relevant to the technology in question; even before it is, or can be, embodied in products or processes. This phenomenon is primarily technical, and not necessarily commercial or strategic in nature, as experience shows that many technologies never become commercially viable. Henceforth therefore, we will refer to this phenomenon as a *technical advance.*

At other times, "technological innovation" is used to refer to the *substitution of the core technologies* used to develop products that satisfy a particular need, and/or their production and delivery systems. According to Anderson and Tushman, "the core technology of an industry"

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[1] Table 1 gives an idea of the complexity of analysis required to relate existing studies considering the outcomes of "technological innovation."

often "evolves through long periods of incremental change punctuated by technological discontinuities" (1990: 606). This is an industry-level phenomenon that arises from a complex interaction between technical advancement, innovation, and other social, economic, and political processes. Henceforth therefore, we will refer to this phenomenon as *technological change*.

Table 1

Existing Dimensions of Some Concepts in Technological Innovation and Change

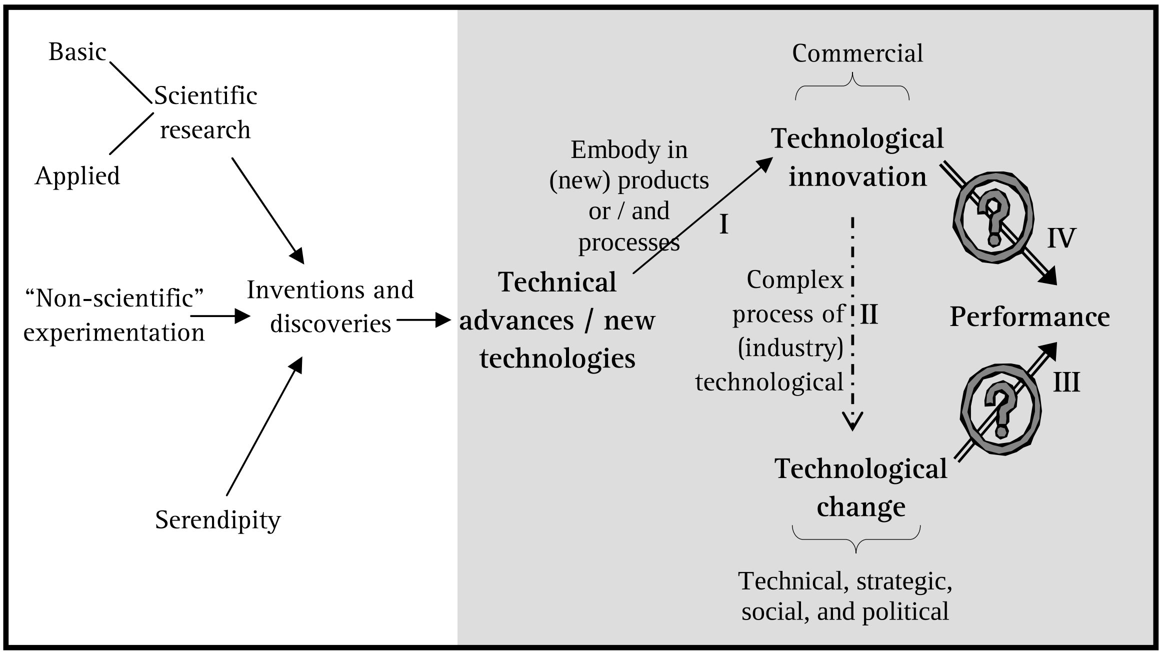
Concept	Classification	Dimension	Source
"Technology"	*Product or process*	Technology application	Wide usage e.g. Butler, 1988
	Sustaining or disruptive	Impact on established trajectory of performance improvement expected by customers	Christensen and Bower, 1996
"Innovation"	*Incremental, modular, architectural, or radical*	Impact on core design concepts embedded in components, and their linkage	Henderson and Clark, 1990
	Incremental or radical	Differential improvement of innovation over previous state	Wide usage e.g. Abernathy and Utterback, 1978.
	Systemic or autonomous	Extent to which value is independent of other innovations	Teece, 1987
	Regular, niche-creating, architectural or revolutionary	Impact on technological and market "transilience"	Abernathy and Clark, 1985
"Technological Innovation"	*Incremental or radical*	Novelty for incumbents, of technological knowledge-base	Wide usage e.g. Hill and Rothaermel, 2003
	Incremental or drastic	Degree to which previous product is still a viable substitute	Arrow, 1962
"Technological Change"	*Incremental or radical*	Degree to which incumbent technological capabilities made obsolete	Wide usage e.g. Afuah, 2000
	Incremental or generational	Degree of improvement within the same technological paradigm	Lawless and Anderson, 1996
	Incremental, complementary, or encompassing	Type of alteration made to "core" or "complementary" activities	Nagarajan and Mitchell, 1998
	Competence-enhancing discontinuity, competence-destroying discontinuity or incremental TC	Degree of technical advance; technological paradigm of the new technology; and impact on incumbent capabilities	Tushman and Anderson, 1986

Finally, as mentioned earlier, "technological innovation" may refer to the *embodiment of technical advances or new technologies* in products/services and/or their production and delivery systems. This usage refers to a firm-level phenomenon with commercial or strategic aims, and is thus perhaps the most conceptually consistent of the three uses of the term. Henceforth therefore, unless used between quotation marks, the term *technological innovation* (TI) will refer to this phenomenon.

Figure 1 gives a visual summary of the definitional associations between these three uses of the term "technological innovation."

Figure 1

Concepts in Technological Innovation and Change



Antecedents and Outcomes of Technological Innovation

Our distinction between three uses of the term "technological innovation" allows us to show that the various "performance" outcomes in the literature can actually be grouped into two types of outcomes: technical outcomes, and firm performance outcomes properly speaking.

Firstly, one possible outcome of TI is technical in nature. The technology underlying a TI can be so superior to existing alternatives that it triggers a substitution of the core technologies used to satisfy a focal need (Anderson and Tushman, 1990; Cooper and Schendel, 1976; Suarez and Utterback, 1995). This technological change resulting from successful TI is thus a *technical outcome.*

Secondly however, TI also has direct and indirect firm *performance outcomes*. On the one hand, the greater or lesser success of TI has a direct effect on firm performance (Banbury and Mitchell, 1995; Christensen, Suarez, and Utterback, 1998; Gatignon, Tushman, Smith, and Anderson, 2002). On the other hand, technological change arising from TI has important effects on firm fortunes (Christensen and Bower, 1996; Henderson, 1993; Henderson and Clark, 1990; Tripsas, 1997), which we can thus consider an indirect performance outcome of TI.

In conjunction with the antecedents of innovation, we use these two types of outcomes to organize the studies in this review, arriving at the four groups of studies outlined in the next section.

Literature on the Outcomes of Technological Innovation

The literature on innovation is massive. It remains vast even when narrowed to that portion focusing on the outcomes of technological innovation. This literature shows a remarkable breadth in terms of methodology, empirical settings, theoretical foundations, the variables measured, and the dimensions of technological innovation considered. Thus the choice of a template for organizing this subset of the literature cutting across the categorizations was challenging.

Our review of empirical and theoretical literature on the *outcomes* of technological innovation used three main sources: articles published in major English-language organizations- and economics-oriented North American and European journals; scholarly volumes edited by the most influential authors in the field of technological innovation and change; and the seminal books or manuscripts which have most influenced thinking on the outcomes of technological innovation. Some descriptive statistics of the sources reviewed are shown in Table 2.

As it was impossible to cover all relevant studies in one review article, we selected studies based on the rigor of their empirical and/or theoretical development; their importance in starting off important lines of thought or investigation; and the degree to which they were cited by others (Brown and Eisenhardt, 1995). We allowed the network of studies to grow forward and backward in time with no constraints (ibid.), and thus arrived at the present review encompassing 31 journals, 16 edited scholarly volumes, and over 30 books; with the temporal boundaries being 1934 to the present.

We used the emergent distinction between three uses of the term "technological innovation" to organize the literature into four groups, roughly corresponding to the numbered arrows in Figure 1. Thus we divided the voluminous literature into studies of: *innovation antecedents* (arrow I); *technical outcomes* (arrow II); *performance outcomes of technological change* (arrow III); and *performance outcomes of technological innovation* (arrow IV).

Although other classifications of the innovation literature have been used in the past, our focus on firm-level outcomes invariably cut across or over-extended otherwise useful categorizations. For example, one common distinction is that between literature on innovation development and literature on innovation adoption (Rogers, 2003). However, performance outcomes are most pertinent to a subset of the adoption literature which looks at the *effects* of innovation adoption. Some of the other subsets of this literature stream come with the implicit assumption that successful innovation adoption will improve firm performance.

Table 2

Some Descriptive Statistics of the Literature Review

Source	**Summary Statistic**	**Value**
Journals	Number of journals covered by review	31
	Maximum number of articles from one journal	47 (*Strategic Management Journal*)
	Journals with eight or more articles (in order of number of articles)	*Strategic Management Journal, American Economic Review, Management Science, Journal of Product Innovation Management, Rand Journal of Economics, Economics of Innovation and New Technology, MIT Sloan Management Review, Research Policy, Academy of Management Journal, Administrative Science Quarterly, Academy of Management Review, Harvard Business Review*, and *Organization Science*
Books	Number of edited scholarly books	16
	Temporal boundaries of edited books	1962-2005
	Number of other major and seminal books	32
	Temporal boundaries of major and seminal books	1934-2003
All publications	Earliest publication	1934
	Most recent publication	2006
	Time distribution of publications	2005-1999: 25% 1998-1995: 20% 1994-1987: 30% 1986-1979: 15% 1978-1934: 10%

Another common distinction going back at least as far as Schumpeter (1942) is that between invention and innovation, where the latter is seen as the commercialization of the former. Although the literature on invention commercialization is pertinent to our focus on outcomes, it usually overlooks the possibility of non-technology firms incorporating technical advances in their products/services (an issue covered in some of the adoption literature). In addition, the inventions in question are often considered inherently valuable, while for our purposes the performance effect is indeterminate *ex ante*.

Our organizing scheme is thus theoretically motivated, based on our interest in outcomes. The advantage of such a theoretically inspired organizing framework is that it allows indiscriminate attention to be paid to studies examining common issues from diverse perspectives. One disadvantage, however, is the corresponding difficulty in synthesizing findings across different theoretical backgrounds. Nevertheless this difficulty is not insurmountable, but is unavoidable, given this paper's underlying concern with a specific theoretical issue: the determinants of the performance outcome of technological innovation.

In the rest of the paper we review the existing knowledge of the determinants of the outcomes of TI. In doing so, we characterize and present the major findings of the literature on *innovation antecedents* (i.e. innovation itself as an outcome); *technical outcomes;* and *performance outcomes* of technological change and technological innovation.

While studies of *innovation antecedents* have sought the determinants of the amount of innovation observed and why some innovators are more innovative than others, studies of *technical outcomes* have investigated the dynamics of technological change arising from TI. Studies of the *performance outcomes of technological change* have focused on the determinants of the effect of technological change on incumbents and new entrants, in addition to the impact of differential firm strategies for reacting to technological change. Finally, the relatively fewer studies of the *performance outcomes of TI*, have sought to highlight the determinants of the direct impact of TI on firm performance.

As we will soon see, this last field of study is the least developed of the four, providing, at best, tenuous support for the "pervasive positive bias" (McGrath, Ming-Hone, Venkataraman, and MacMillan, 1996: 392) with respect to the performance impact of TI.

Antecedents of Technological Innovation: Drivers of Innovation and Innovativeness

Studies of innovation antecedents form the largest subset of work with implications for the outcomes of TI. These studies have focused on the determinants of the amount of innovation observed and on why some innovators are more innovative than others. Thus this field can be further split into two streams: studies of the drivers of innovation and studies of the drivers of innovativeness respectively.

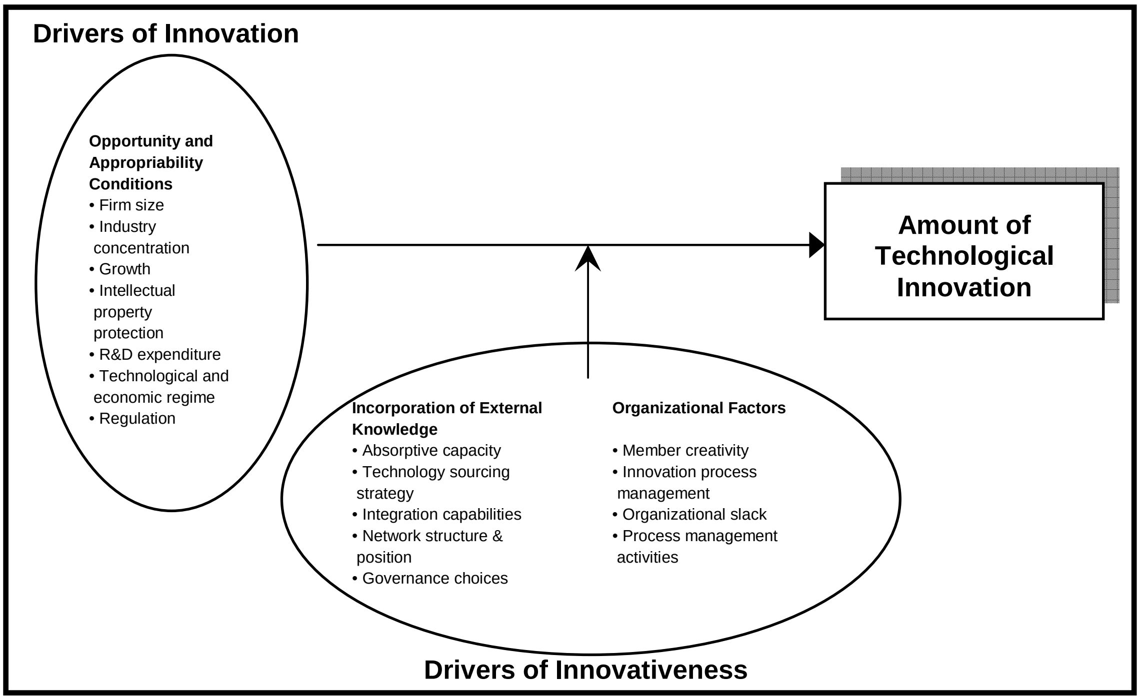
The first (and older) of the two streams grew out of economists' concern with social welfare. At least since Schumpeter (1934) identified innovation as the motor of economic development, economists interested in the socially optimal level and diffusion of innovation, have closely examined the drivers of the *amount of innovation* observed. Early work looked at the impact of market power and concentration on innovation, but later work has considered a variety of variables as affecting underlying opportunity and appropriability conditions, and hence the amount of innovation observed. Most of the empirical work in this stream utilizes econometric methodology, and has an implicit assumption that innovation is inherently valuable.

The second stream of work on the drivers of innovativeness is more recent, and grew out of a conviction in both managerial and academic circles that innovation was the key to firm success. Thus it has focused on explaining *differing levels of innovativeness* across firms in similar situations. One branch of this stream has sought to explain differential levels of innovativeness in terms of differing firm capabilities in incorporating external knowledge. A second branch has focused on organizational variables such as creativity and the management of the innovation process. The studies in both branches encompass a wide variety of methodological approaches, reflecting the theoretical eclecticism typical of the field of strategic management from which many of them are drawn.

Figure 2 summarizes the major drivers of innovation and innovativeness from both streams, while selected studies are summarized in Table 3.

Figure 2

Antecedents of Technological Innovation



Drivers of Innovation

"One of the largest bodies of literature in the field of industrial organization is devoted to the interpretation and testing of several hypotheses advanced by Joseph Schumpeter (1942)" (Levin, Cohen, and Mowery, 1985: 20) concerning the determinants of innovative output. According to Schumpeter (1942), large established firms possessing some degree of monopoly power were likely to be the driving force behind technical progress. He suggested that their superior access to capital and skilled labor, in combination with their ability to effectively appropriate innovation, gave them considerable advantages over small firms and new entrants (Henderson, 1993). Additionally, he emphasized that concentration reduced market uncertainty and provided the cash flow required to engage in costly and risky R&D on an efficient scale (Levin et al., 1985).

In contrast to Schumpeter, other authors argued theoretically that insulation from competitive pressures breeds bureaucratic inertia and discourages innovation (Levin et al., 1985). A seminal article by Arrow (1962) suggested that firms in competitive markets have significantly greater incentives to invest in innovation than do firms in markets characterized by a significant degree of monopoly power. This result, however, was contested by Gilbert and Newberry (1982) who suggested that Arrow's results held only if entry was blockaded. In line with Schumpeter's arguments, they showed that if there was free entry to the industry, incumbent firms with monopoly power would rationally pre-empt potential entrant investment in innovation in order to continue to profit from the extension of existing market power to a new generation of technology (Henderson, 1993).

A subsequent theoretical debate over the issue (Gilbert and Newbery, 1982, 1984a, b; Reinganum, 1983, 1984; Salant, 1984) led to the consensus that whether incumbent monopolists or entrants have greater incentives to invest in innovation is a function of the degree to which innovation destroys existing market power, and of the uncertainty surrounding the innovative process (Henderson, 1993; Lerner, 1997). If the older technology remains viable and the new technology's introduction is not contingent on any single firm's investment, then incumbents have a greater incentive to invest in innovation. On the other hand if the new technology renders the old one obsolete, and its introduction is a function of investments made by each firm, then incumbents with market power will have less incentive to invest in innovation than new entrants (ibid.).

On the empirical front, 40 years of research uncovered no systematic relationship between market power and innovative activity (Cohen and Levin, 1989). Many studies, however, found an "inverted-U" relationship, whereby innovative effort or innovative output first increased with concentration, and then decreased (Levin et al., 1985). Levin, Cohen, and Mowery argued that the ambiguous results were due to the fact that concentration did not have a direct effect on innovation (Levin et al., 1985). They cited studies (Scherer, 1967; Scott, 1984) in which the explanatory power of concentration diminished considerably on controlling for more fundamental technological and institutional conditions, and then went on to replicate the same effect in their paper (ibid).

The emphasis on the importance of underlying technological and institutional conditions was also supported by Winter (1984), who suggested that small- and large-firm innovation responded to distinct technological and economic regimes. He hypothesized that the ability of a firm to innovate was influenced by what he and Richard Nelson (1974; 1982) called the underlying "technological regime." Suggesting two types of technological regimes, he posited that "an entrepreneurial regime is one that is favorable to innovative entry and unfavorable to innovative activity by established firms; a routinized regime is one in which the conditions are the other way around" (Winter, 1984: 297).

Table 3

Determimants of Innovation: Selected Studies

Study	Sample	Context	Outcome (Dependent variables)	Key Results (Independent variables)
Levin et al. (1985)	650 R&D executives	US companies, 130 lines of business	R&D intensity, rate of new product and process introduction	Differences in technological opportunities and appropriability explain innovation output better than "simple" variables like industry concentration
Reinganum (1983)	Conceptual	Economic modeling	Incumbent and new entrant investment in new technology	If innovation is uncertain, incumbent invests less than new entrant when new technology destroys previous market power
Cohen and Levinthal (1990)	1719 business units from 318 firms	US manufacturing firms, 151 lines of business	R&D intensity	Absorptive capacity mediates the impact of opportunity and appropriability conditions on innovation
Zahra and Neilsen (2002)	149 firms	20 US-based industries	Four measures of innovative output	Internal and external, human and technological sourcing strategies differentially impact innovative output. Greater integration increases innovative output
Ahuja (2000)	420 joint ventures and technology sharing arrangements	97 leading chemical firms in US, Japan, and Western Europe	Successful patent applications	Direct and indirect ties increase innovative output while more structural holes reduce innovative output. More direct ties reduce impact of indirect ties
Amabile (1997)	Middle-level managers across four company divisions	Large US electronics products company	Organizational creativity	Eight dimensions of work environment differentially affect creativity
Greve (2003)	357 innovations across 11 firms	Japanese shipbuilding industry	R&D intensity and innovation launches	Innovation development driven by problemistic and slack search; innovation launch driven by higher risk tolerance from unsatisfactory performance

In their 1987 paper, Levin, Klevorick, Nelson and Winter also argued that inter-industry variations in innovative effort were best explained not by concentration, but by the underlying differences in technological *opportunity* and *appropriability* conditions (Levin et al., 1985; Levin, Klevorick, Nelson, and Winter, 1987). Thus variables such as concentration, regulation, intellectual property protection, size and growth, have an indirect effect on the amount of innovation observed, through their impact on technological opportunity and appropriability conditions.

Drivers of Innovativeness: Learning and External Knowledge

Early work examining the impact of external knowledge on differential firm innovativeness had sought to explain the "stylized fact ... that the number of innovations per dollar of R&D decreases with firm size" (Knott, 2003: 697). Indeed the finding that R&D productivity decreased with firm size was a common one (Cohen and Klepper, 1992; Cohen and Levin, 1989). However, in highlighting the different technological regimes facing large and small firms (Acs and Audretsch, 1988; Audretsch, 1991; Winter, 1984), these studies set the stage for a focus on the impact of the incorporation of external knowledge on firm innovation.

In an early study, Gort and Klepper (1982) posited, and found evidence that relative innovative advantage depended on the source of information leading to innovative activity. When information based on non-transferable experience in the market was an important input in generating innovative activity, then older firms would tend to have the advantage over new firms. However, when information outside the industry was a relatively important input in generating innovative activity, then new entrants would tend to have the innovative advantage over the incumbent firms.

Similarly, Knott (2003) highlighted the importance of asymmetric spillovers. She pointed out that if large or leading firms had superior knowledge, then spillovers from other firms would not be helpful to them. Consequently, their innovation would stem exclusively from their own efforts. In contrast, small or follower firms could gain knowledge both from their own investments as well as from spillovers from leading firms. As a result, their apparent innovation per R&D dollar would be higher than that for large or leading firms. This conclusion is consistent with several authors who have suggested that small- and large-firm innovation are not independent. For instance, small firms may owe their innovative activity to former employees of large firms (Anton and Yao, 1995; Cassiman and Ueda, 2002; Klepper and Sleeper, 2002).

Cohen and Levinthal's seminal papers (1989; 1990) introduced the concept of absorptive capacity, defined as "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends" (1990: 128). They argued that absorptive capacity was largely a function of prior related knowledge (1989) and that it was critical to firms' innovative capabilities. Absorptive capacity is cumulative, domain-specific, and path-dependent (Cohen and Levinthal, 1994). Thus firms with greater absorptive capability in a given domain would be more innovative than others in that domain (Cohen and Levinthal, 1990). More recently, Zahra and George (2002) extended the concept of absorptive capacity, reconceptualizing it as a dynamic capability with both a potential and a realized component.

Internal knowledge is also an important input to the innovation process, and its integration with external knowledge is thus a critical determinant of innovativeness. Zahra and Nielsen (2002) found that innovative output developed with internal and external capabilities was affected by the effectiveness of the firm's mechanisms for integrating these knowledge sources. Similarly, Arora and Gambardella (1994) found support for the complementarity of internal and external know-how sourcing, while Cassiman and Veugelers (2002) found support for complementarity between the various innovation activities involved in these sourcing strategies. Thus firms combining different activities in their innovation strategy are expected to attain a higher degree of innovativeness than firms that focus on only one knowledge source.

In addition to this, recent studies suggest that different knowledge sources might be related to different types of innovative output. For example, Nicholls-Nixon and Woo (2003) find from their sample that while internal R&D was positively associated with patent output, acquisition activity was positively related to the number of products based on new technologies, and the use of R&D contracts and licenses was positively related to a reputation for technological expertise.

As a whole, this branch of work on the drivers of innovativeness has gathered momentum in recent times, and a number of insightful studies have shown how innovativeness also depends on variables such as network position (e.g. Ahuja, 2000), technological and market relatedness of merging firms (e.g. Ahuja and Katila, 2001; Cassiman, Colombo, Garrone, and Veugelers, 2003), alignment between governance decisions and the degree of contractual hazards (Leiblein, Reuer, and Dalsace, 2002), and the impact of process management on various types of innovative output (Benner and Tushman, 2002, 2003). A major contribution of this young stream of literature is that it highlights the fact that innovativeness is dependent on a firm's ability to leverage external knowledge, integrating it with its internal knowledge sources.

Drivers of Innovativeness: Organizational Factors

The second branch of innovativeness studies has identified three organizational variables that drive differential firm innovativeness, namely: the creativity of organizational members, the management of the innovation process, and the presence of organizational slack. Individual creativity introduces greater variation into the organization, increasing its innovative output, while competent management of the innovation process removes obstacles that might slow down the flow of innovations, efficiently integrating the innovative efforts of organizational members. Finally, it is has been suggested that spare organizational resources allow experimentation and less strict performance monitoring, leading to increased innovation.

Many authors have considered the improvement of an organization's innovativeness as a question of how to "unlock the ideas and creativity of its employees" (Kim and Mauborgne, 1999: 51). Amabile (1997) for example, stresses that in addition to expertise and creative thinking, employee creativity is also a function of task motivation, and thus motivation is an important driver of organizational innovativeness. Among other things, such motivation requires a concise and compelling articulation of the value of innovation, an orientation away from the status quo, and the activation of an offensive leadership strategy aimed at the future, rather than simply trying to protect an organization's past (Amabile, 1988).

Employee creativity is also related to task organization, management style, and organizational culture. One typical finding in this line is that creativity is fostered by the use of small autonomous units or teams focusing on a common business or product goal (Kim and Mauborgne, 1999). In addition, teams with members with diverse skills, backgrounds, and perspectives are more conducive to higher levels of creativity (Amabile, 1997; Kanter, 1996; Kim and Mauborgne, 1999). Finally, creativity has been found to thrive in the presence of a corporate culture conducive to willing collaboration where managers go beyond a focus on fair outcomes to a focus on fair process (Kim and Mauborgne, 1999).

A second organizational factor driving innovativeness is the competent management of the innovation process. As Christiansen (2000) emphasizes, management structures, systems and practices can cause delays in the innovation process, creating roadblocks for the flow of innovations. Senior managers can improve innovativeness by enhancing systems, structures and practices at three levels, namely: the individual innovation project, the project management system, and business-level strategy (Christiansen, 2000; Duelli and Hültenschmidt, 2002; Kandybin and Kihn, 2004). At the project level, efficiency depends on project setup, supervision, participation, mentoring/consulting, and operational control. At the level of the project management system, attention to idea generation, laboratory management, funding systems, project structure, and project management methods affect innovative output. Finally, the way business systems are managed in terms of strategy, structure, and people has a decisive impact on the level of organizational innovativeness (ibid.).

A third theme in organizational innovativeness is related to the role played by organizational slack. Cyert and March (1963) proposed that organizational slack, rather than "necessity" bred innovation. According to them, "the difference between the payments required to maintain the organization and the resources obtained from the environment by the coalition ... provides a source of funds for innovations that would not be approved in the face of scarcity" (Cyert and March, 1963: 278-279). Organizations with spare time and spare resources have greater opportunities for experimentation and less strict performance monitoring and so should have the resources and managerial patience needed to innovate.

In one of the few empirical tests of this hypothesis, Greve (2003) distinguishes between absorbed slack, unabsorbed slack, and potential slack. He finds that while absorbed slack is related to increased innovativeness, his sample shows no effect for the other two types of slack. Similarly, O'Brien (2003) argues that financial slack is necessary for innovativeness for three primary reasons. Firstly, cash flow volatility can jeopardize continuous investments in R&D. Secondly, financial slack can help ensure that the firm has the financial resources required to launch new products as soon as they are ready; and finally, sufficient financial slack can assist firms in making the acquisitions they deem necessary to source knowledge for increased innovativeness (ibid: 419-420). Operationalizing financial slack as a low leverage ratio, he finds support for the position that higher innovativeness (intense investment in R&D) is related to higher financial slack.

Innovation Outcomes vs. Performance Outcomes

In summary, we find that the literature provides a relatively clear theoretical account of the antecedents of TI. The amount of innovation observed among a focal group of firms is dependent on underlying technological opportunity and appropriability conditions. These latter in turn depend on factors such as industry concentration, growth, R&D expenditure, firm size, intellectual property protection, regulation, and the current technological and economical regime. At the same time however, innovativeness differs across individual firms facing similar opportunity and appropriability conditions. Such differences are explained by knowledge characteristics like absorptive capacity, technology sourcing strategies, integration capabilities, and network position; as well as by organizational factors such as member creativity, process management, and the presence of organizational slack. As mentioned earlier, these relationships are summarized in Figure 2.

Nevertheless, much of this literature exhibits an underlying assumption that individual innovations are inherently valuable. Theoretically however, individual innovations can be more or less successful, and empirically only a small proportion of innovations are profitable (Andrew and Sirkin, 2003; Rothaermel, 2001). Thus firms following prescriptions for increasing their innovativeness could conceivably find themselves generating a stream of worthless innovations. Therefore, this literature on innovation outcomes does not seem to provide a basis for an *a priori* optimistic view of the impact of TI on performance; nor does it provide much insight into the contingencies that could determine the performance of individual innovations.

Nonetheless, the findings on drivers of innovation form a basis for prescriptions regarding policies to foster industrial innovation and competitiveness. Similarly, the findings on drivers of innovativeness identify levers managers could act on to increase innovative output. However, on the basis of these studies alone, such prescriptions would have to be made with the assumption that the value of a greater number of profitable innovations outweighs the costs of a greater number of failed innovations.

Determinants of Technical Outcomes: Dynamics of Technological Change

Studies relating to the technical outcomes of TI have highlighted determinants of the complex process by which TI leads to technological change. Technical advances on their own do not directly cause technological change; rather, new technologies enter the industry at some time or the other via the TI of one or more firms. If a TI is sufficiently superior to products embodying previous technology, (in the absence of restraining political or social forces) it can trigger a substitution of the core technologies used by industry participants to satisfy customer needs (Cooper and Schendel, 1976; Foster, 1986). This consequent technological change can be considered a technical outcome of TI.

Two broad streams of work have isolated the determinants of the technical outcomes of TI. The first has focused on the *drivers* of the process by which TI leads to technological change. Studies in this stream have looked at the interaction and impact of market opportunities and technological effort on the process of technological change. They have also highlighted how design decisions and customer choices determine the technical outcomes of TI.

A second stream of studies has investigated the *patterns* of technological change. This work suggests that technological change exhibits a cyclical pattern which is repeated over time. As firms introduce technological innovations over time, the consequent technological substitutions display long periods of incremental improvement punctuated by sharp improvements in the industry's price/performance frontier. These latter are then followed by periods of technological ferment which end with the appearance of a "dominant design."

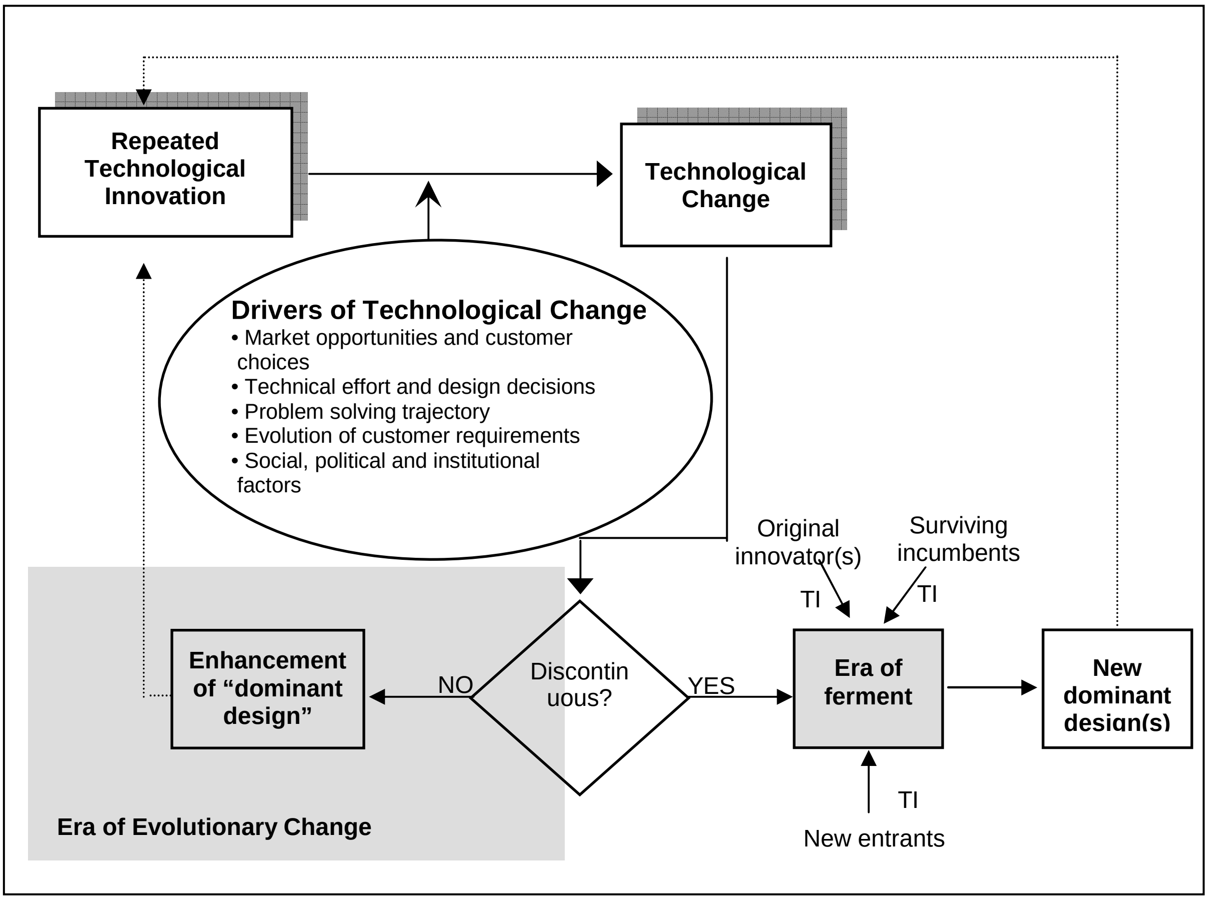
The seminal studies in both streams are based on longitudinal multi-industry data on the dynamics of technological change, although some other influential studies derive their frameworks from an inductive analysis of in-depth case studies. Figure 3 summarizes the findings of both streams on the drivers and patterns of technological change, while selected studies are summarized in Table 4.

Drivers of Technological Change

Early answers to the question of the drivers of technological change (TC) revolved around two basic poles: the so-called "demand-pull" theories on the one hand, and the so-called "technology-push" theories on the other hand. Demand-pull theories pointed to market opportunities as the main determinants of the process through which TI led to TC. In this view, the causal prime mover of TC is the recognition of needs by productive units in the market, followed by attempts to fulfill those needs through technological innovation (Mowery and Rosenberg, 1979). Therefore, market signals direct innovative activity and TC. Proponents of the technology-push theories argued, on the other hand, that TC was autonomous or quasi-autonomous with respect to short-run changes in the economic environment (Pavitt and Soete, 1980). Underlining supply-side factors in TC, they pointed to the increasing role of scientific inputs in the innovative process, the increased complexity of R&D (making it unlikely that it could be a prompt innovative answer to market signals), a significant correlation between R&D and innovative output, and the intrinsically uncertain nature of the innovative process (ibid.).

Figure 3

Technical Outcomes of Technological Innovation



Dosi (1982) was one of the first to point out the flaws inherent in *both* extremes. He pointed out that on the one hand "demand-pull" theories see TC as a passive, "mechanical" reaction to market conditions. They are incapable of "defining the why and when of certain technological developments instead of others and of a certain timing instead of others" (ibid: 150), and they neglect changes over time in inventive capability that do not bear any direct relationship to changing market conditions. On the other hand, "technology-push" theories are flawed as well because they present technical progress as "given by God, scientists, and engineers" (ibid: 151); ignoring the obvious impact of economic factors in shaping the direction of the innovative process.

Dosi sought to harmonize the two extremes by introducing the concepts of "technological paradigms" and "technological trajectories." Technological paradigms are "an 'outlook', a set of procedures, a definition of the 'relevant' problems and of the specific knowledge related to their solution" (ibid: 148). Technological paradigms in technology are analogical to research programs in science, and determine the technological problems to be solved, the scientific principles to be applied, and the material technologies to be used (Dosi, 1984). At the same time though, these *paradigms* also define technological *trajectories*, which are "the direction of advance within a technological paradigm" (Dosi, 1982: 148). In other words, the technological trajectory is the pattern of problem-solving *within* the established technological paradigm, similar to Nelson and Winter's (1982) "natural trajectories" of technological progress.

Hence both technological and market factors drive the process of TC. Although the established paradigm is most influential on TC in the short run, in the long run new technological paradigms can arise from the interplay between scientific advances, economic factors, customer requirements, institutional variables, and unsolved difficulties in established technological paths (Dosi, 1982). Consequently, while the current technological paradigm greatly influences the technological trajectory, a more complex set of interactions determines the appearance of a new technological paradigm.

In a similar vein, Sahal's (1981; 1985) explanation focuses on "technological guideposts" and "innovation avenues." In this system, similar to Dosi's, a technological *guidepost* is a "pattern of design" that charts the course of innovative activity (Sahal, 1985: 71), while TC occurs along innovation *avenues* "that designate various distinct pathways of evolution" (ibid.).

Clark (1985) deepened the analysis of the interaction between technological design decisions and customer choices in the process through which TI leads to TC. As an industry's technology evolves, "the pattern of innovation, the kinds of design changes introduced and their timing and sequence, not only depend on the technical alternatives but on the interaction between the internal logic of the product and the evolution of customer requirements" (Clark, 1985: 236). In other words, on the one hand, observed patterns of TC depend on a sequence of design decisions related to the technical agenda, problems to be solved, cumulative experience, exploration of alternative technical options, and a continual refinement of current designs (McEvily and Chakravarthy, 2002). However, on the other hand these design decisions are also related to "the formation of concepts that underlie customer choice" (Clark, 1985: 241).

Experience with new technological products, problem solving at the customer end, new uses customers discover for products, and emerging customer needs not only affect technical development (as in market-pull theories), but are also influenced by design choices. For example, early customer automobile purchase decisions were framed in terms of a choice between a "horseless carriage" and a "carriage with a horse." However, experience with the new product, as well as continued evolution of the initial product design led to the evolution of the concept from “horseless carriage” to “automobile,” described by a “new” set of attributes such as speed, mobility, endurance, payload, etc., and a “new” set of variants like “roadster,” “touring car,” and “coupe” (ibid: 245).

Patterns of Technological Change

The work of Abernathy and Utterback (Abernathy and Utterback, 1978; Suarez and Utterback, 1995), along with that of Tushman and Anderson (Anderson and Tushman, 1990; Tushman and Anderson, 1986, 1997) has greatly influenced research on the patterns of technological change.

Extending studies on drivers of TC (David, 1985; Dosi, 1984; Nelson and Winter, 1982; Sahal, 1985; Utterback and Abernathy, 1975), Anderson and Tushman held that technological change in many industries is a cyclical evolutionary process in which “the core technology of an industry evolves through long periods of incremental change punctuated by technological discontinuities” and the “emergence of a dominant design” (1990: 606). Thus each cycle is composed of two “eras” and two “punctuation points,” as described below.

In the first stage, “technological change is a bit-by-bit, cumulative process until it is punctuated by a major advance” (Tushman and Anderson, 1986: 441). In this “era of incremental change” (Anderson and Tushman, 1990: 606) there are continual improvements to technology within the same technological paradigm, “through the interaction of many organizations stimulated by the prospect of economic returns” (ibid.). Variation in this era is driven by elaboration of the established “dominant design” and the competitive focus shifts from higher performance to lower cost (Abernathy and Utterback, 1978).

Table 4

Determinants of Technical Outcomes: Selected Studies

Study	**Sample**	**Context**	**Outcome** (Dependent variables)	**Key Results** (Independent variables)
Dosi (1982)	Conceptual	Theoretical synthesis	Dynamics of technological change	Technology advances gradually along *technological trajectories*. *Technological paradigms* stem from the interplay of scientific, economic, institutional and technological factors
Mowery and Rosenberg (1979)	Ten influential empirical studies	Literature review and critique	Drivers of technological change	Studies do not demonstrate that market demand is more influential than technology supply. Both impact technological change
Clark (1985)	Conceptual	Conceptual framework	Drivers of technological change	The interaction between design decisions and customer choices imposes a hierarchical structure on the evolution of technology
Anderson and Tushman (1990)	16 technological discontinuities in three industries over 94 years	Cement, glass, and minicomputer industries	Rate and pattern of technological change	Technological change cycles through eras of incremental change and eras of ferment, punctuated by the advent of technological discontinuities and dominant designs respectively
Schilling (2002)	89 cases of competing technologies	14 product categories with network externalities	Technology "lock out"	Probability of lock out related to insufficient installed base, lack of complementary assets, failure to invest in learning, and poor timing
Suarez and Utterback (1995)	Dominant design emergence and firm entry/exit in six industries over 100 years	US firms in the automobile, typewriter, transistor, calculator, TV and picture tube industries	Probability of firm survival	Exit is more likely the later the entry after dominant design emerges. Survival is more likely the earlier entry comes before dominant design

Nevertheless, this era is characterized by "advances in the technology frontier that advance the state of the art ... *sometimes considerably*"[2] (Anderson and Tushman, 1990: 609) within *the same* technological paradigm. As such, in Anderson and Tushman's scheme, the "era of incremental change" can refer to either "incremental" or "considerable" improvements. Lawless and Anderson (1996) rectify this ambiguity by proposing the concept of "generational" TC, which is "a major advance within a technological regime" (ibid: 1185). Thus the major characteristic of this era of *evolutionary*[3] change is the cumulative enhancement of the current dominant design (sometimes incremental and sometimes generational) *within the same* technological paradigm.

The era of evolutionary change is ended by the appearance of a "technological discontinuity": a sharp improvement in the industry's price performance frontier associated with the emergence of a new technological paradigm (Anderson and Tushman, 1990; Tushman and Anderson, 1986), which introduces an era of intense technological variation. "A revolutionary innovation is crude and experimental when introduced, but it ushers in an era of experimentation as organizations struggle to absorb (or destroy) the innovative technology" (Anderson and Tushman, 1990: 610-611). This "era of ferment" (ibid.) is characterized by competition between alternative technologies within the new paradigm, as well as by competition with old technologies, which typically experience significant improvement, in reaction to the new technological threat (Cooper and Schendel, 1976).

Competition between rival technologies in the era of ferment is a highly complex process whose result cannot be predicted ahead of time (Tegarden, Hatfield, and Echols, 1999). The technical outcome is a function of several factors, such as user preferences and producer market power (Anderson and Tushman, 1990), complementary assets controlled by competitors, industry regulation or government intervention (Suarez and Utterback, 1995), and the presence of "increased returns to adoption" (Arthur, 2001) among the competing technologies (Katz and Shapiro, 1985, 1986; Schilling, 2002).

The case of competition among technologies exhibiting increasing returns on adoption has been especially studied in the strategic management and economic literature. Increasing returns on adoption could come from many sources, such as learning by using, network externalities, scale economies in production (positive feedback), informational increasing returns, and technological interrelatedness (Arthur, 2001; Katz and Shapiro, 1985, 1986). The selection process in this case is potentially "inefficient" in an economic sense because the "winning" technology might not be the socially optimal one (Arthur, 2001). Although it is difficult to say which technology will win *ex ante*, it is not impossible to predict which technologies will end up losing or being "locked out" (Schilling, 2002). Factors that might lead to "lockout" are a relatively small installed base, relatively poor availability of complementary goods, a failure to invest in learning, and poor entry timing (ibid.).

Finally, in mass markets with relatively homogenous customer tastes, or where industry output is a high volume assembled or manufactured product, the era of ferment may end with convergence on a "dominant design" (Utterback and Abernathy, 1975), which is "a specific path along a design hierarchy, which establishes primacy among competing design paths" (Utterback

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[2] Emphasis added.

[3] We introduce this term to stress the fact that technological change in this era can be incremental or generational, as long as it remains within the same technological paradigm.

and Suarez, 1993: 47).[4] However, in technology markets characterized by increasing returns on adoption, the outcome might be the adoption of one or more of the competing technologies, depending on a host of factors such as whether or not technologies are "sponsored" (backed by strategic investment), their future cost advantage (Katz and Shapiro, 1986), the availability of complementary products, installed base, entry timing (Schilling, 2002), learning effects, production scale effects, and lock-in (Arthur, 2001). With convergence on a dominant design(s), the industry returns to an era of evolutionary progress once again (Christensen et al., 1998; Suarez and Utterback, 1995; Utterback and Suarez, 1993), closing the cycle of TC.

Technical Outcomes vs. Performance Outcomes

In summary then, we can identify a relatively mature and well-developed literature on the technical outcomes of technological innovation. These analyses show the emergence of technological change from TI to be partially determined by the path-dependent technical trajectory followed in problem solving, as well as by the overall technological paradigm in force. Technological evolution is further co-determined by the development of customer understanding and choice, under the influence of social and institutional factors. The overall process, though, has been found to be markedly patterned across several industries, exhibiting eras of evolutionary progress and eras of disruptive change, punctuated by "technological discontinuities" and the emergence of a "dominant design" respectively.

Nevertheless, these studies do not seem to justify an overly optimistic view of the performance outcome of TI. The distinction between technical and performance outcomes stressed in this article is important because a favorable technical outcome will not necessarily lead to improved firm performance. In this line, work by Tegarden et al (1999) has highlighted the importance of other variables, such as entry timing (Mitchell, 1989, 1991), integration (Iansiti, McFarlan, and Westerman, 2003), and flexibility to switch to a different technology, as being to some extent independent of the eventual technology outcomes. Other work (e.g. Shamsie, Phelps, and Kuperman, 2004) suggests late-mover advantages as a reason why a focus on the technical outcome alone could lead to disappointing performance outcomes.

Nonetheless, these studies do provide insights useful for the study of performance outcomes. On the one hand, they underline the fact that technological change, although an industry-level phenomenon, is not exogenously given with respect to the actions of industry participants, but is partially shaped by their innovative efforts. TI in effect, is both a "response to incentives" created by industry conditions and a "shaper" of those conditions (Porter, 1985: 195). On the other hand, they suggest that the performance outcome of a technological innovation may be contingent on the technological situation in an industry at a given point in time. Thus an understanding of the processes by which TI leads to technological change should be important for understanding the determinants of the performance outcomes of TI.

[4] McEvily and Chakravarthy (2002: 286) prefer the term "normal configuration," as the term "dominant design" has sometimes been taken to imply "that the same [product] configuration is adopted by all firms."

Determinants of Perfomance Outcomes of Technological Change

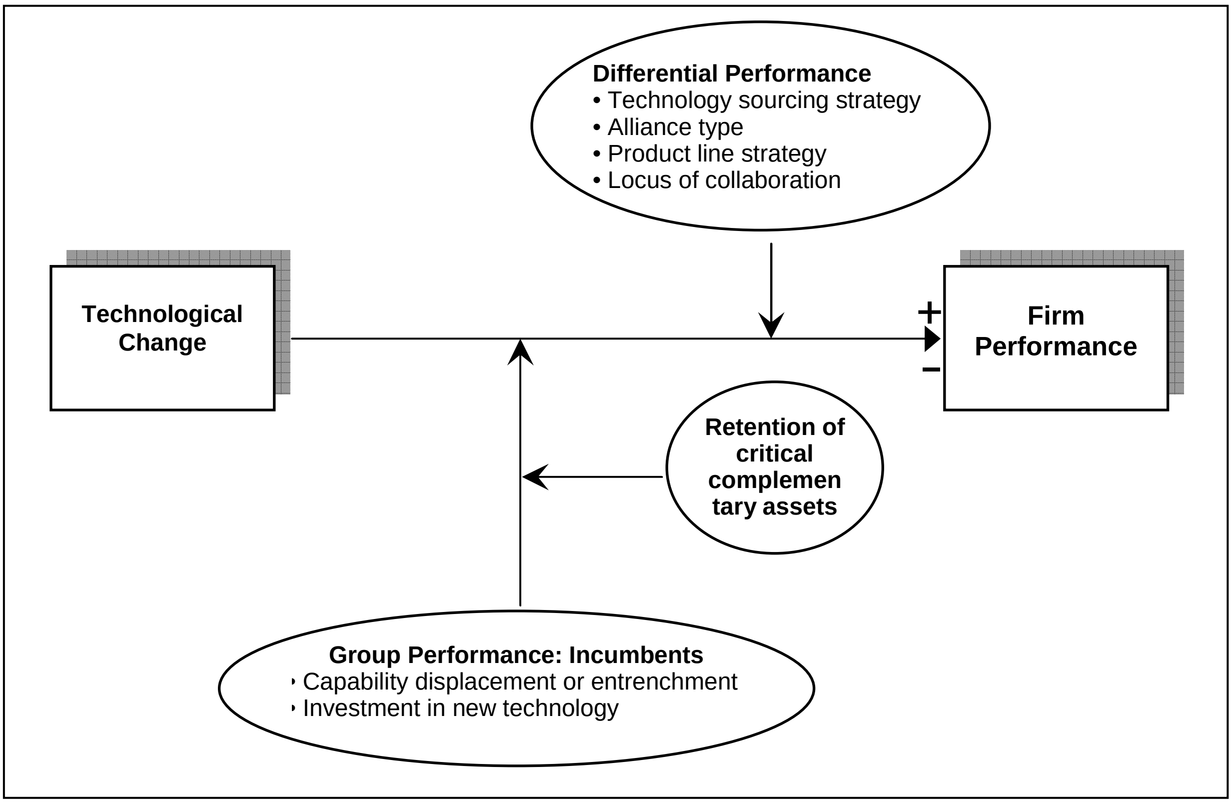
Whereas studies of innovation outcomes and technical outcomes of TI span several decades, studies seeking to explain *firm* performance outcomes of technological change are more recent. Most of the major studies started to appear at the end of the 1980s, promoted by strategic management scholars' interest in firm-level performance outcomes.

A lot of the early work in this area focused on explaining why technological change (TC) often caused the failure of hitherto successful firms. They traced inferior incumbent performance to the impact of TC on firm capabilities, as well as to insufficient investment in new technologies; both mediated by the retention of critical complementary assets. More recent studies, however, have identified and sought to explain differential performance among firms facing the same TC. They have focused on the impact of differential firm approaches to technology sourcing, collaborative alliances, and product line strategies amongst other factors. The major findings of both streams are summarized in Figure 4, while Table 5 summarizes some selected studies.

It is pertinent to note here that many followers of the literature on innovation might inappropriately identify this set of studies as focusing on the performance outcomes of technological *innovation*. As we argued earlier, while technological innovation might be actively pursued by individual firms, technological *change* is more or less passively experienced by all firms in an industry. Thus this set of studies, which focuses on the effects that the substitution of technologies used to satisfy customer needs has on firm fortunes, is classified here as focusing on the performance outcomes of technological *change*.

Figure 4

Performance Outcomes of Technological Change



Technological Change and Inferior Firm Performance

It was observed early on that "radical" technological change often led to the demise of industry incumbents (Abernathy and Utterback, 1978; Cooper and Schendel, 1976; Foster, 1986; Utterback and Abernathy, 1975). Hence much of the initial work in this stream focused on explaining why TC seemed to worsen the performance of "incumbent" firms, sometimes identified in terms of size, and other times in terms of previous market or financial performance (Christensen and Bower, 1996; Henderson and Clark, 1990; Tripsas, 1997). The various explanations that have been given can be grouped into three: the impact of technological change on firm capabilities, the consequences of firm investment decisions, and the moderating effect of critical complementary assets.

Firm capabilities. New technologies resulting from technological change may require capabilities different from those historically possessed by incumbents, or previous capabilities may retain their importance. In the first case, or *capability-displacing* TC, the relevance of historical incumbent capabilities is reduced in favor of a new set of capabilities (Abernathy and Clark, 1985; Clark, 1987). However in the second case, or *capability-entrenching* TC, new technologies continue to require previous capabilities, thus "entrenching" their position (Clark, 1987: 63) within firms.

As could be expected, capability-entrenching TC has been found to favor incumbents (Cooper and Schendel, 1976; Rosenbloom, 2000; Rothaermel, 2001), as the market "rewards" those activities and knowledge bases in which they are already proficient (Hill and Rothaermel, 2003). However, capability-displacing TC has generally been found to prejudice the performance positions of incumbents. In the face of capability-displacing TC, incumbents are either unable to exploit the new technology, or their investments produce poorer results compared to those of new entrants (Christensen et al., 1998; Henderson, 1993; Henderson and Clark, 1990; Tripsas, 1997). Economic, organizational, and strategic factors deny them the flexibility required to react adequately to the change, leading to poorer performance (Hill and Rothaermel, 2003).

Henderson and Clark (1990) for example, showed that the displacement of firms' "architectural knowledge" is especially lethal. Firm knowledge relating to linkages between product components tends to become embedded in structures and information-processing procedures that are difficult to change. Thus when this architectural knowledge gets displaced, firms find it hard to respond adequately (ibid). Nagarajan and Mitchell (1998) also highlight the importance of the dimensions along which incumbent capabilities are entrenched or displaced. They suggest that TC will have different outcomes depending on whether capabilities are displaced in "core" activities ("encompassing technological change") or in "complementary" activities ("complementary technological change").

Finally, Afuah (2000) drew attention to the fact that firm performance could still suffer if TC entrenched incumbent capabilities, but displaced the capabilities of their "co-opetitors" (suppliers, customers, and complementors). He found support for the hypothesis that TC which displaces the capabilities of a firm's suppliers or customers leads to poorer performance for the firm in question. He also suggested that the closer such firms are to their suppliers (operationalized as degree of backward integration), the poorer their performance will be.

Table 5

Performance Outcomes of Technological Change: Selected Studies

Study	Sample	Context	**Outcome** (Dependent variables)	**Key Results** (Independent variables)
Henderson and Clark (1990)	Four waves of architectural technological change	Population-level data on photolithographic industry	Post-technological change firm performance	Incremental technological change that destroys usefulness of architectural knowledge leads to inferior performance
Christensen and Bower (1996)	1400 disk drive models between 1975 and 1990	Complete product and company census of world disk drive industry	Incumbent investment in new technology	Resource allocation and dependence cause firms not to invest in technologies initially unattractive to powerful stakeholders
Henderson (1993)	49 product development projects by 19 firms	Population-level data on photolithographic industry	Investment in new technology and market share	Both investment incentives AND capability displacement explain inferior incumbent performance
Tripsas (1997)	Three generations of radical technological change	Worldwide typesetter industry from inception to 1990	Post-technological change market share	Specialized complementary assets that retain their value buffered inferior post-technological change incumbent performance
Mitchell and Singh (1996)	693 collaborative relationships covering 973 firms over 30 years	U.S. hospital software systems industry	Post-technological change participation in industry	Firms with collaborative relationships in activities central to technological change more likely to shut down. Firms with relationships in activities outside focus of change more likely to survive
Hill and Rothaermel (2003)	Conceptual	Literature synthesis	Incumbent survival after radical technological change	Incumbents perform better to the extent that economic, organizational, and strategic factors reduce inflexibility

Incumbent investment. Another set of studies traces the roots of incumbent demise to a failure to invest in new technology until it is too late. Though apparently a straightforward explanation, varying causal mechanisms have been put forward to explain this phenomenon. One group of studies mentioned earlier suggests that incumbents might not invest in a new technology for fear of destroying current market power and demand for current products (Gilbert and Newbery, 1984b; Henderson, 1993; Reinganum, 1983, 1984). Thus if subsequent TC causes a switch to the new technology, incumbent firms would find themselves in a disadvantaged position.

Arend (1999) presents an alternative explanation focusing on the dynamics of oligopoly. In his model, TC is exogenous and perfectly foreseeable, such that incumbents could implement it and thus block later entrants if they wished to. However, if the new technology implies a short-run cost disadvantage relative to current competitors, in the absence of collusion it is possible that none of the incumbents will invest in the new technology, leaving them open to the adverse impact of new entrants in the future.

A different explanation for failure to invest comes from Christensen and Bower (Christensen, 1997; Christensen and Bower, 1996). Combining resource allocation (Bower, 1970) and resource dependence (Pfeffer and Salancik, 1978) theories, they argue that resources in corporations get allocated to projects targeting the requirements of powerful customers. Incumbents thus will not invest in "inferior" technologies that exhibit a price/performance ratio unattractive to their valuable customers. However, the rate of technological progress can cause incumbents' technology to exceed customer requirements, while simultaneously making previously "inferior" technologies now attractive to their customers (Christensen and Bower, 1996). Thus since they had previously not invested, (because the technology was not initially attractive to their valuable customers), they would find themselves in a disadvantaged position (Christensen, 1997).

Finally, another set of studies underlines the fact that firms are "embedded within a value network of suppliers, customers, investors, complementary product providers, communities, and so on, to which the firm has made strategic commitments" (Hill and Rothaermel, 2003: 261). As Ghemawat (1991) emphasizes, "strategic" decisions, which "commit" a firm to a particular course of action or bundle of resources over the medium to long term, bring along with them a certain degree of inflexibility. In addition, a web of implicit and explicit social commitments to employees, customers, and communities can also impede adaptation (Rosenbloom, 2000; Sull, Tedlow, and Rosenbloom, 1997). Hence incumbents may find themselves *unable* to make the investments necessary to participate effectively in the new technological regime, as a result of prior commitments.

Complementary assets. A third factor, the continued importance of critical complementary assets controlled by incumbents, has been shown to moderate the effect of the previous two on performance. Tripsas (1997) found that when specialized complementary assets (Teece, 1987) unavailable to new entrants retained their value after capability-displacing TC, incumbents maintained their market positions even though the technical performance of their products proved to be significantly inferior to that of the new entrants. Similarly, Rothaermel (2001) found that incumbents whose downstream complementary assets retained their value after TC, entered into alliances with new entrants to access the new upstream technology, in exchange for access to their downstream assets. In other words, these findings suggest that even if incumbents do not have the required capabilities to participate effectively in the new technology, any important complementary assets that "luckily" retain their value after the TC will temper the negative effects of capability-displacing TC.

Technological Change and Differential Firm Performance

Recent work on the determinants of performance outcomes of TC has increasingly focused on differential firm effects. Tripsas suggests that the most serious limitation of the earlier work we have been considering is "its treatment of incumbents as a class of firms without distinguishing between individual firms within that class. There is great variation in the performance of incumbent firms, and understanding that variation is crucial" (Tripsas, 1997: 140). This is further underlined by Hill and Rothaermel's (2003: 257) assertion that the counterexamples to the generalized predictions (e.g. Ahuja and Lampert, 2001; Leifer et al., 2000; Methe, Swaminathan, Mitchell, and Toyama, 1997; Rothaermel, 2001) are too many to be ignored.

An additional reason for the growing focus on differential firm effects is the existence of conflicting group-level findings in the literature. For example while Tripsas (1997) finds that incumbents produced technically inferior products on investing in a capability-displacing technology, Christensen and Bower (1996) find that incumbents led the way, *even in capability-displacing technologies*, as long as their important customers valued them highly. A number of recent studies have begun the attempt to tease apart such interacting effects, extending research on the performance outcomes of TC in two important directions.

Differential incumbent reactions. Firstly, researchers have begun to focus on differential incumbent reactions to TC. Thus Nagarajan and Mitchell (1998) studied incumbents' technology sourcing strategies in the face of TC. They predicted the technology acquisition strategy of incumbents (equity/non-equity alliances or internal R&D) in terms of how capability-displacing TC affects "core" and "complementary" firm activities in manufactured products.

Building on Nagarajan and Mitchell's work, Nicholls-Nixon and Woo (2003) suggest that such differential approaches to technology sourcing, are related to differing levels of innovative output across firms facing the same capability-displacing TC. A related study by Rothaermel (2001) showed that incumbents might react by forming alliances with new entrants when critical downstream complementary assets that they control retain their value after TC. Distinguishing between exploration alliances (aimed at learning the new upstream technology) and exploitation alliances (aimed at leveraging the downstream complementary assets), he found that incumbents that focused on exploiting complementary assets outperformed those that focused on exploring the new technology (in terms of new products introduced). Thus these studies suggest that differential incumbent performance after TC might be related to the "fitness" of the different capability sourcing strategies they use.

Differential firm strategy. Beyond a focus on incumbent reactions, Jones (2003) finds that product line strategy and product platform strategy explain additional variation in performance after capability-displacing TC, controlling for incumbent/entrant-related factors. Specifically he shows that variation in overall product introduction rates and longevity, as well as rates of platform and derivative introduction and longevity, significantly increase his model's explanatory power. His work thus suggests that a focus on new variables could help to identify other drivers of differential post-TC performance.

Mitchell and Singh (1996) take a different approach, analyzing the impact of *pre-TC* collaborative relationships on *post-TC performance*. They find that firms using collaborative relationships in activities affected by discontinuous TC perform worse after the TC, while firms with collaborative relationships in activities not central to the TC have improved post-TC performance. They thus suggest that while collaborative relationships hinder the flexibility of the former, for the latter they provide useful help for navigating the TC.

A final perspective on TC and differential firm performance comes from Lawless and Anderson (1996) who study the indirect impact of *generational* TC[5] on firm performance. They suggest that successive generational TC leads to increased environmental complexity as previous technologies remain in the market, and firms have a broad range of opportunities to be generalists or to specialize in a subset of the available technologies. This is accompanied by an evolution of niches or "firm positions in the marketplace" (ibid: 1186). They find that performance depends on firm strategies that differentiate them within their own niches, and not across niches. They also find that changing niches confers a short-term penalty, and that strong performers adopted new technology quickly without changing niches.

Performance Outcomes of Technological Change

To sum up, the literature reviewed here gives a clear account of some of the determinants of the performance outcomes of technological change. It demonstrates that TC often has a negative impact on the performance of previously successful firms, either because of new technology that requires capabilities different from those they have historically possessed, or because they do not invest in technology that later becomes dominant. This effect is tempered if they control other complementary assets required to exploit new technology successfully.

However, recent work has shown that the same TC can have differential impacts on the post-TC performance of incumbents, as a result of factors such as technology sourcing and collaborative strategies. Other scholars also suggest that variables cutting across both incumbents and entrants can help explain post-TC firm performance. Thus both pre-TC strategic choices, such as inter-firm collaboration, and post-TC variables such as product line and product platform strategies, can influence the impact of TC on firm performance.

Future research in this stream will need to provide more robust explanations of differential post-TC firm performance. On the one hand this might require the identification of other firm- and/or network-level strategies that better explain post-TC performance. On the other hand, there is a need for empirical work that can help to determine the relative efficacy of competing strategies put forward by different scholars.[6]

Nevertheless, the findings of this important stream of work do not provide an account of the determinants of the performance outcomes of firm-level technological innovation. The underlying concern of these studies has been more about firm strategies for coping with the inexorable march of technological change, and less about the possible outcomes of individual technological innovations. Thus these studies do not seem to provide a basis for an assumption that technological innovation will improve firm performance.

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[5] A substantial technological advance within the same technological paradigm.

[6] For example, while Christensen (1997) advocates spinning off an independent firm to cope with technological change, Iansiti et al. (2003) advise as much integration as possible to leverage existing firm assets.

Having said that, it is important to remember, as we pointed out in the previous section, that technological innovation is intimately related to technological change. Indeed Cooper and Schendel (1976) indicate that TI is a common firm reaction in the face of TC. Thus the increased attention to the determinants of the performance outcome of TI advocated in this paper could shed more light on performance outcomes of TC as well.

Determinants of Performance Outcomes of Technological Innovation

Surprisingly few studies have focused on the *determinants* of the performance outcome of technological innovation. While a lot of work has looked at determinants of *innovativeness*, much less light has been shone on the innovation-level contingencies that determine the success or failure of individual innovations (Li and Atuahene-Gima, 2001). Similarly, while a good number of studies have investigated technical outcomes, few have considered how and when technical aspects affect performance. Nevertheless, some important contributions to knowledge on determinants of the performance outcome of TI have staked out the territory, and indicate directions for future work.

In the next section, we review some of these studies and characterize their findings on factors that affect the impact of technological innovation on firm performance. We then synthesize these with findings from previous sections, to give a comprehensive picture of what we know about the outcomes of technological innovation. Finally we conclude, reiterating the need for an increased focus on the determinants of the performance outcome of technological innovation, and offering possible avenues for building on the existing knowledge in this regard.

When Does Technological Innovation Improve Performance?

An important early contribution comes from Teece's seminal 1986 paper that sought to explain why customers, imitators, and other industry participants often benefited from TI, whereas the firm that introduced it did not (Teece, 1987). He showed that under a "weak appropriability regime," most profits go to the owners of specialized complementary assets required for commercializing an innovation. The strength of the appropriability regime is a function of the legal mechanisms available to protect innovations, such as patents, trade secrets, trademarks, and copyrights (Teece, 1987); as well as the knowledge characteristics of the innovation: whether the knowledge is tacit or codified, observable or non-observable in use, and whether it requires tangible assets or not (Teece, 2003). In weak appropriability regimes therefore, innovating firms need to have recourse to strategic action (by carefully choosing firm boundaries) to protect their returns on TI.

A different set of variables was highlighted by Banbury and Mitchell's study, which considered how the timing of TI influenced its impact on performance. In focusing on innovations that "succeed in the market as a class of goods," they sought to "differentiate between the success of an innovation as a class of goods and the success of specific firms that introduce products that incorporate the innovation" (Banbury and Mitchell, 1995: 161, 163). They found that the more often a firm was among the first to introduce TI, the greater its market share. In addition, the greater the number of competitors that introduced a similar TI, the greater the market share of firms that were first to introduce it. Finally, they found that while greater market share reduced the likelihood of business dissolution, TI provided little or no reduction in the likelihood of business dissolution net of the effects of the firm's market share.

Another point of view is offered by Christensen, Suárez, and Utterback (1998) who suggested that the performance impact of TI is dependent on the interaction between its technical and market characteristics. In the technical dimension, they differentiated between new technologies that result from an improvement in product component technology and those that are "architectural": innovative ways of linking proven components. In the market dimension, they distinguished between strategies addressing new market segments and those addressing established markets. They found that firms introducing TI that is architectural *and* targeted at new market segments (emerging segments in which a dominant design had not yet been established) had significantly higher probabilities of survival than firms introducing TI into established market segments, based on improvements in component technology. Also focusing on technical and market characteristics, Nerkar and Roberts (2004) found that while experience gained in markets "distal" to a focal innovation led to higher initial product sales, "proximal" technological experience explained new product success.

A final set of variables are provided by Gatignon et al. (2002) who develop and test constructs for differentiating "innovation" "locus," "type" and "characteristics." With respect to locus, they distinguish between innovations that affect "core subsystems" and those that affect "peripheral subsystems." Innovation types include "architectural" and "generational" innovation, while innovation characteristics differentiate between radical/incremental and competence-enhancing/competence-destroying innovations. To test the nomological validity of their constructs, they apply models of their impact on performance. Their results suggest that the greater the complexity of TI, the greater its perceived success, yet the longer it takes to introduce. TI affecting core subsystems, which was associated with "both new competence acquisition and with building on existing competencies" (ibid: 1118) is associated with the greatest commercial success. In line with Henderson and Clark (1990), they also find that "architectural" innovations are associated with increased time to introduction, but surprisingly, innovations in peripheral subsystems are associated with increased time to market as well.

In summary, these and a handful of other studies indicate the existence of several variables mediating the relationship between TI and performance. On the one hand, studies focusing on technical and market characteristics of TI illustrate how these affect the amount of *value created* by TI, and hence its impact on performance. They show that different dimensions in the knowledge and capabilities underlying these characteristics affect performance (Christensen et al., 1998; Gatignon et al., 2002; Nerkar and Roberts, 2004; Sheremata, 2004). On the other hand, studies emphasizing timing, appropriability, and complementary assets illustrate how these affect the *value appropriated* by an innovating firm (e.g. Banbury and Mitchell, 1995; Teece, 1987). Their focus on "valuable" innovations shows that market success is not sufficient to guarantee that TI will improve firm performance.

Nevertheless, there remains a pressing need for further delineation of the determinants of the performance outcomes of TI. Studies which broach this issue are still very few, and do not yet add up to a "solid" knowledge base. There is a need for further empirical testing and replication of the results of these pioneer studies in other contexts. For example, Gatignon et al. (2002) focus on modifications of existing products, which are only one subset of possible TI modes. Similarly, very few studies (Christensen et al. (1998) and Nerkar and Roberts (2004) are two notable exceptions) simultaneously consider technical and market determinants of the impact of TI on performance. There is therefore a very clear need for further work on highlighting determinants of the performance outcome of TI. In closing, Figure 5 summarizes the existing knowledge on the outcomes of technological innovation.

In Search of a Theory on the Performance Impact of Technological Innovation

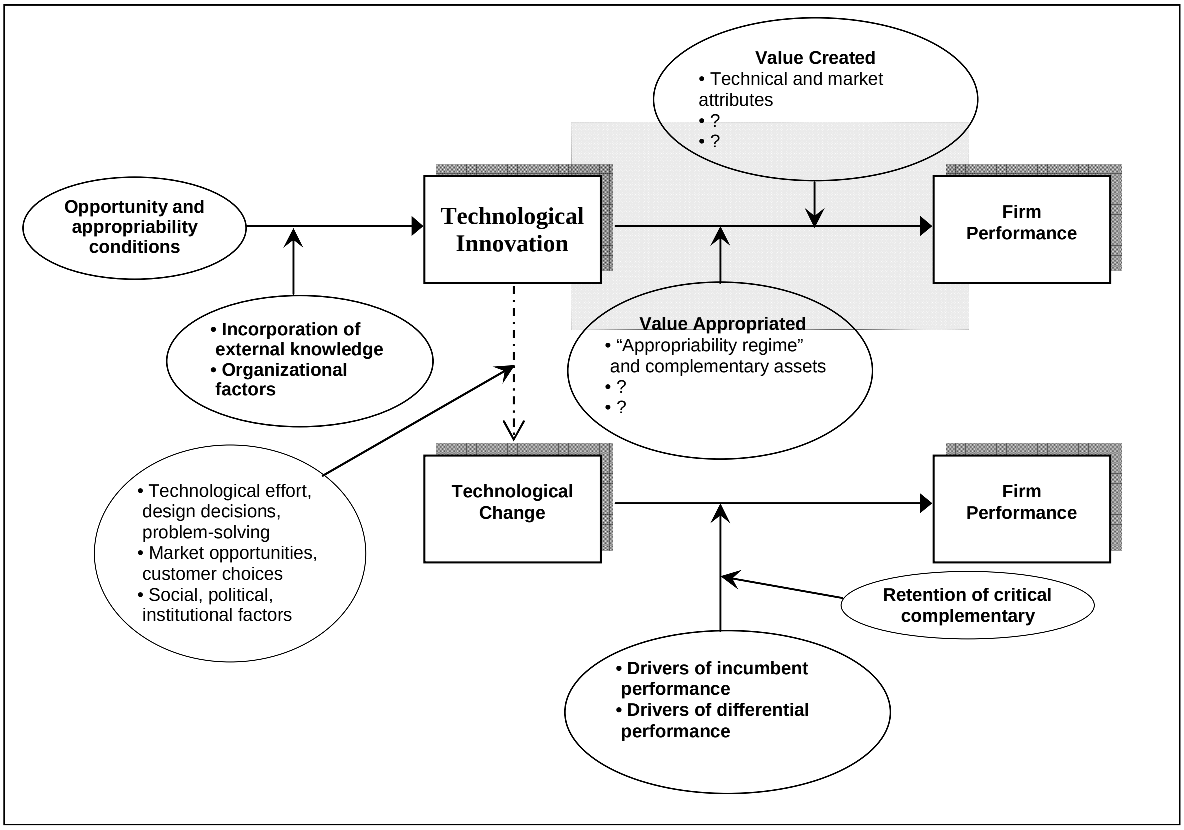
"We stress that being new is not the same as being desirable. ... Recall Kimberly's (1981) comment that the study of innovation suffers from a pervasive positive bias" (McGrath et al., 1996: 392).

Managerial and academic effort in the recent past has focused intensely on issues related to innovation, with the implicit assumption that increased innovation would lead to improved firm performance. Nevertheless, the empirical facts are beginning to indicate that although innovativeness has increased, economic performance has not improved correspondingly (Kandybin and Kihn, 2004; Linder et al., 2003). The success rate of major innovations remains below 20% (Rothaermel, 2001), and tests of the relationship between innovativeness and firm performance consistently exhibit mixed results (Capon et al., 1990; Li and Atuahene-Gima, 2001).

These findings indicate *missing explanatory variables* in the technological innovation-performance relationship. Since individual innovations can have more or less successful outcomes, it is not surprising to find an ambiguous overall impact of innovativeness on performance. What we require is a delineation of the factors – the innovation-level contingencies – which mediate or moderate the relationship between technological innovation and firm performance. We need a "circumstance-based" theory (Carlile and Christensen, 2005) that can explain how, when, and why technological innovation leads to improved firm performance. In other words, what are the determinants of the performance outcome of technological innovation?

Figure 5

Drivers and Moderators of the Outcomes of Technological Innovation



Our review encompassing 31 journals, 16 edited scholarly volumes, and over 30 books, with temporal boundaries from 1934 to the present, shows that the existing literature gives coherent explanations of the determinants of *innovation outcomes* and *technical outcomes* of technological innovation, as well as the determinants of *performance outcomes* of technological *change*. However, we have seen that relatively little light has been shed on the determinants of the *performance outcomes of technological innovation*. This area thus represents the next frontier for "innovation-performance" studies, as highlighted by the shaded portion of Figure 5. We need more studies that map out the contents of the "black box" mediating technological innovation and firm performance. While it is true that institutional and legitimacy factors often drive innovation (Abrahamson, 1991; Ferlie, Fitzgerald, Wood, and Hawkins, 2005; Young, Charns, and Shortell, 2001), it is also true that one of the most important reasons why firms innovate is in order to improve their performance (Burgelman and Rosenbloom, 1997; Zahra, 1996; Zahra and Covin, 1993).

Current work indicates that studies seeking to shed further light on the determinants of the performance outcome of technological innovation could fruitfully focus on two sub-constructs of performance: the amount of value created by TI and the amount of value appropriated by innovating firms. Firstly, the amount of value created by TI relative to competing firm offerings derives from the interaction between its technical and market characteristics and the focal firm's technological and customer knowledge and capabilities (Christensen et al., 1998; Clark, 1987; Danneels, 2002; Nerkar and Roberts, 2004). In addition, since value is created for consumers, aspects of the demand environment, such as the way in which they evaluate TI, and the way in which this evaluation changes as TI performance improves (Adner, 2002), are critical for explaining the impact of TI on firm performance. Thus studies able to: (1) characterize differential firm attributes (e.g. different aspects of technical and market knowledge and capabilities); (2) characterize different technical and market attributes of TI; and (3) characterize aspects of the demand environment, relating all or some of these to firm performance; will advance the search for determinants of the performance outcome of TI.

Secondly, since Teece's (1987) path-breaking paper, most work on value appropriation from TI has focused on factors affecting the imitability of innovations. Innovators are advised to center attention on avoiding imitation, failing which they should achieve a superior position in asset complementary to the innovation at a cost inferior to the anticipated amount of value up for grabs (Grant, 2002; Teece, 1987; Winter, 2000). Yet it is not clear that inimitability guarantees superior appropriation. For instance, in the case of innovation based on externally sourced technology, there remains the possibility of upstream holdup (Ghemawat, 1991) by technology suppliers. On the downstream end, Brandenburger and Stuart (2003) point out that the assumption that a monopoly can extract all the value created from consumers is not unassailable.

There is thus a need for further development in the theoretical understanding of the circumstances under which innovating firms can appropriate superior amounts of the value created by TI under competition. Recent developments in cooperative game theory (Brandenburger and Stuart, 2004; MacDonald and Ryall, 2004) integrated into the "micro-foundations" of the resource-based view of the firm (Lippman and Rumelt, 2003) provide an opportunity for deepening this area of knowledge. This line of work offers an opportunity to highlight the determinants of the distribution of value created by TI among innovating firms, buyers, and suppliers. For instance, studies able to relate idiosyncratic firm endowments to superior "added-value" (Brandenburger and Stuart, 1996) or superior complementarity to a given technology, and hence to the amount of value appropriated, would further advance the search for the determinants of the performance outcome of TI.

Conclusion

"Just because innovation is important, that does not necessarily mean that pursuing innovation will be profitable for the firm" (Grant, 2002: 334). In this paper, we have argued that both empirical evidence and theoretical reflection challenge the positive bias inherent in most approaches to technological innovation. Anomalous results call for deeper theoretical development, and more refined empirical exploration of the determinants of the performance outcome of technological innovation. As a first step in this direction, we presented the results of an exhaustive review of the existing knowledge of the determinants of the outcomes of technological innovation. We characterized three distinct classes of outcomes and presented a model relating the different determinants uncovered in the literature to the various outcomes. We thus showed that while a lot of work has apparently focused on innovation "performance," studies actually explaining the performance impact of technological innovation are few and not well developed. Finally, in the light of the knowledge uncovered and recent developments in work on firm capabilities, we indicated possible avenues for further development of this critical area of research.

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