

# **INTRAORGANIZATIONAL TECHNOLOGY**

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Technology (from the Greek, *techne*, which means craft, or skill) refers to any manner of systematically applying knowledge or science to a practical application. As such it is one of the central factors motivating the founding, structure, and management of most organizations. Intraorganizational technology can be defined as including all forms of technology that are developed or implemented within the organization. Technology in this context is generally understood to include information technology as well as technology embodied in products, production processes, and design processes.

The management research on intraorganizational technology may be divided into two fairly distinct streams, the research on the development of new technology, and the research on the relationship between technology and the structure and management of the organization<sup>1</sup>. The first stream may be further subdivided into a body of descriptive work that has examined how firm size and industry structure impacts technology development, and a body of prescriptive work that seeks to identify practices firms can employ to improve the development process. The second stream, the impact of intraorganizational technology on the firm, includes such topics as how technology drives structural choice and firm boundaries, and how technology impacts performance. This area has received particularly enthusiastic attention in the last decade, as innovations in both production and information technologies have enabled dramatic transformation of many firms. A summary of some of the key empirical studies covered in this chapter is provided in Table 1.

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<sup>1</sup> One could also consider the research on intraorganizational adoption and diffusion of technology as a third stream (e.g., Cool, Diericks and Szulanski, 1997; Kim and Srivastava, 1998), however this body of research is fairly limited compared to the rich body of research on interorganizational technology adoption and diffusion.

## LITERATURE REVIEW

### **The Development of New Technology**

There is an extensive body of research focusing on the firm as a developer of new technology. This research addresses such questions as what types of firms are more likely to be successful at developing new technologies, and how the technology development process should be managed and its performance measured.

#### *Firm size, R&D investment, and industry structure*

In 1942, Schumpeter challenged the traditional economics antitrust orthodoxy by proposing the following two hypotheses: 1) innovation increases more than proportionately with firm size and 2) innovation increases with market concentration. Schumpeter's arguments for why firm size would increase technological progress included arguments for both rate and effectiveness effects, though he did not explicitly distinguish the two. Arguments for rate effects include 1) capital markets are imperfect, and thus large firms have an advantage in obtaining financing for R&D projects, and 2) firms with a larger sales volume over which to spread the fixed costs of R&D experience higher returns (or lower relative costs) than firms with lower sales volume.

A third argument relating to firm size, that there are scale economies in the technology of R&D, could incorporate both rate and effectiveness effects. On the one hand, scale economies may arise because fixed investments in R&D may be amortized over a larger volume of R&D projects, thus resulting in declining marginal costs for R&D expenses. This would make a given rate of R&D investment less costly for firms with a large R&D base than for those with smaller

R&D bases. However, scale economies may also arise because of experience or learning curve effects. This would imply that the firm becomes better at R&D, and should gain increases in R&D effectiveness. A fourth Schumpeterian argument, that R&D is more productive in large firms with well-developed complementary activities such as marketing and financial planning, supports the proposition that firm size increases R&D effectiveness.

These hypotheses sparked a flurry of empirical investigations, yet results remained inconclusive, encouraging substantial debate on the topic. Competing arguments were offered that suggested a negative relationship between firm size and R&D. For instance, one prominent argument is that as firms grow, efficiency in R&D decreases because of loss of managerial control (Cohen and Levin, 1989). A second, related argument is that as firms grow, it becomes increasingly difficult for the individual scientist or entrepreneur to appropriate the returns of their efforts, therefore their incentives diminish. Cohen and Levin (1989) point out that even "Schumpeter (1942) himself suggested that this feature of the bureaucratization of inventive activity could undermine capitalist development" (pg. 1067). Along this vein, Rotemberg and Saloner (1994) proposed that as firms become more diversified, they are less able to provide efficient incentives for employees that allow them to innovate without suffering from conflicting goals. A fourth argument arises from the capital markets argument posited in favor of firm size; that is, small firms, who are less able to finance a large volume of R&D projects, will choose their projects more carefully, and thus have a higher proportion of successful projects. This implies that there are diminishing returns to R&D. This proposition was somewhat confirmed by Sherer (1983), and by Griliches (1990) who concludes that small firms appear to be more efficient, receiving a larger number of patents per R&D dollar (Griliches provides a well-crafted and often cited

review of the work done on returns to R&D and the use of patents as a measure of innovative output for readers interested in more extensive discussion of these topics).

Contrasting results were found in a more recent study by Blundell, Griffith and Van Reenan (1999). In this study the authors use firm-level accounting data, share price information, a count of innovations, and a count of patents to test the relationship between market power and rates of innovation. Their sample includes 3551 observations from 340 British manufacturing firms. They conclude from their study that "less competitive" industries (industries with lower import penetration and higher concentration levels) innovated less overall. However, within industries, the high market share firms tended to be more effective at commercializing innovations, and tended to benefit most from innovations.

Though undoubtedly many scholars find the arguments or evidence on one side of the issue more compelling than the other, it is probably most accurate to say that the issue remains unresolved.

### *Improving the Effectiveness of the Development Process*

Due to the extreme strategic importance of technological innovation to firm success, researchers have vigorously attempted to identify what makes some firms more successful at development than others. This is an extensive area of research and there are several good books and literature reviews on the topic (e.g., Clark and Wheelwright, 1993; Brown and Eisenhardt, 1995; Schilling and Hill, 1998), therefore I will simply attempt to provide a brief overview of the key themes here. Note that while much of this research has focused on new technology embodied in

products, most of it is equally applicable to new technology embodied in processes, therefore little distinction will be made between the two in the current discussion.

First, there has been considerable research into how firms should choose new development projects, resulting in a number of valuation and portfolio balancing models. Development projects are often divided into categories such as radical versus incremental, or platform projects (those which spawn entire families of new products) versus derivative projects. It is typically suggested that firms map their development projects by type, and seek to balance their portfolios according to their objectives and resources (Wind and Mahajan, 1988). Recent research has explored the treatment of development projects as real options, and utilizes options analysis approaches for assessing the cost and gains of undertaking a new project. This topic is discussed further in the new and emerging areas for research section.

A second major area of research has explored the role of teams and team leaders. For example, research has indicated that different types of development projects have different resource needs and management requirements. Major new projects involving breakthrough technologies may require full-time, collocated, cross-functional teams (Clark and Wheelwright, 1993; Johne and Snelson, 1989), sponsored by a senior executive (Zirger and Maidique, 1990; Damanpour, 1991). However, for development projects representing only a minor enhancement of an existing product or process, a full-time collocated team may be unwarranted (Schilling and Hill, 1998).

A third area has focused on the development of tools and metrics for improving and managing the development process, such as Quality Function Deployment (Griffin and Hauser, 1992),

stage-gate processes (Cooper and Kleinschmidt, 1991), and computer-aided design. Such tools can enable better identification of the match between project objectives and outcomes, enable rapid prototyping, and improve the project's likelihood of being completed on time and within budget.

Rather than being driven by a strong theoretical focus, most of the empirical research on the development process has taken an inductive approach in pursuit of identification of best practices. A prime example is Cooper and Kleinschmidt's series of studies on new product development, including studies of how new product development success should be measured (e.g., 1987) and studies that attempt to identify what makes some companies more successful than others at new product development (e.g., 1993, 1995). In their 1993 study, Cooper and Kleinschmidt find that the most important success factor of development projects was the degree of product differentiation, followed by synergies, order of entry, and stage of product life cycle. They found that market attractiveness and market competitiveness had little impact on the likelihood of project success. In their 1995 benchmarking study of how firms managed the development process, they conclude that the most successful firms 1) have a well-structured and rigorous (yet flexible) new product development process that includes extensive up-front research, tough go/kill decision points, precisely defined product requirements, 2) have a well-defined new product strategy with a long term orientation and clearly communicated new product goals, 3) dedicate adequate human and capital resources to their projects, including senior-level management commitment, and 4) have high levels of R&D expenditures as a percent of sales (indicating support for an increasing returns to R&D argument).

Zirger and Maidique (1990) have also conducted a well-cited study that offers both a broad and deep examination of the drivers of development project success. They conducted a field study from 1982 to 1986 of 330 electronics product successes and failures. They conclude that in addition to the overall quality of the research organization and the performance of the product, the likelihood of project success is significantly influenced by its fit with the firm's existing competencies (similar to Cooper and Kleinschmidt's findings regarding synergy), and the degree of managerial support during both the development and introduction stages.

### **The Impact of Technology on Organizational Structure, Management, and Performance**

#### *Production Technologies: From the Woodward Typology to AMT*

Joan Woodward produced one of the first and most influential studies of the impact of technology on organization. Her study of one hundred manufacturing firms indicated a strong relationship between production technology and other organizational dimensions including structure, formalization, centralization, and worker skill levels. She organized the firms on a scale of technical complexity that was eventually consolidated into three technology categories: small-batch and unit production, large-batch and mass production, and continuous process production (Woodward, 1958). Woodward's findings were replicated numerous times, and her typology continues to be influential today.

However, in the late 1980s, dramatic developments in both computers and manufacturing processes enabled the introduction of a series of new technologies known collectively as advanced manufacturing technology (AMT), that were anticipated to make small-batch production as cost and time efficient as mass production. Also called computer integrated

manufacturing (CIM) or flexible manufacturing systems (FMS), AMT systems utilized computerized processes to increase both the speed and flexibility of manufacturing. Computer aided design enabled rapid prototyping, while computer aided manufacturing allowed production lines to shift rapidly from one product to another. Administrative automation made the administrative control functions (such as inventory tracking and billing) more efficient. AMT systems were expected to have dramatic impacts on the structure and management of organizations, including enabling a reduction in the number of hierarchical levels, decentralization of decision making, and greater reliance on teamwork (Adler, 1988; Nemetz and Fry, 1988). Of particular importance was the potential AMT offered for making the firm more flexible (Parthasarthy and Sethi, 1992). By allowing firms to quickly alter production, AMT created strategic options for the firm to enter related markets (Lei, Hitt and Goldhar, 1996).

However, empirical investigations of AMT's impact on a firm's flexibility or financial performance have been mixed (Boyer, Leong, Ward and Krajewski, 1997; Brandyberry, Rai and White, 1999; Dean, Yoon and Susman, 1992). Kotha and Swamidass (2000) provide empirical evidence of superior performance arising from adoption of AMT--particularly when it is well integrated with the firm's strategy. They adopt an information processing perspective, and argue that AMT can enhance a firm's information processing capacity. They classify AMT into four groups: product design technologies, process technologies, logistics/planning technologies, and information exchange technologies, and then hypothesize that matching different firm strategies to appropriate types of technologies will result in superior performance. For example, they argue that the efficiency and standardization objectives of firms pursuing a low-cost leadership strategy will be best met by primarily focusing on AMT process technologies. By contrast, the greater

product or market variety characterizing firms pursuing a differentiation strategy will necessitate the use of several dimensions of AMT. Using a survey of 160 U.S. manufacturing firms, they find that firms do often match their AMT choice to their strategy, and that doing so improves performance.

Brandyberry et al (1999), also using a survey, find mixed results. They examine the impact of different levels of AMT adoption on intermediate performance outcomes (market-oriented flexibility, integration of production processes, and administrative intensity). They conclude that while higher levels of AMT can enhance integration of production processes, some forms of AMT actually lesson market-oriented flexibility. Similarly, Lee (2000) argues that rather than uniformly increasing flexibility, many FMS systems create a set of intrinsic constraints that may hinder the firm's performance. Though there may be conflict about AMT's overall impact on firm flexibility or performance, it did give rise to an unambiguously influential manufacturing trend: mass customization.

### *Mass Customization and Modularity*

Mass customization is the utilization of lean and flexible production technologies to provide high product variety and market responsiveness, while still attaining the low costs of standardized mass production (Kotha, 1995; Pine, 1993). It has been hailed as the new paradigm of production in industries as diverse as apparel manufacturing to telecommunications. One of the key ways that firms accomplish mass customization is to modularize the products or services so that some key components can be standardized and produced on a large scale, yet combined into unique configurations to enable product variety. A prime example is Sony's Walkman, which

utilizes a number of standardized components within a modular architecture that enables a wide range of end configurations (Sanchez, 1999). The proliferation of end configurations based on standardized components enables Sony to closely meet heterogeneous customer requirements while still keeping costs low on the individual units.

Increasing use of modular product designs and production processes spurred a flurry of research into its causal antecedents (e.g., Schilling, 2000) and outcomes (e.g., Baldwin and Clark, 1997; Garud and Kumaraswamy, 1995; Langlois, 1992; Sanchez and Mahoney, 1996). Much of the research on product modularity has tended to examine the advantages of the adoption of modular product designs or production processes. These advantages have included being better able to meet diverse customer needs (e.g., Baldwin and Clark, 1997, 2000; Langlois, 1992; Sanchez, 1995), reap "economies of substitution" (e.g., Garud and Kumaraswamy, 1995), achieve some of the network externality advantages of a standards-based architecture, while still producing unique, proprietary components (Garud and Kumaraswamy, 1995), and creating greater strategic flexibility within the firm (e.g., Garud and Kotha, 1994; Sanchez and Mahoney, 1996). Notably however, the research has been almost entirely theoretical, or based on anecdotal or case-study evidence. Large-sample empirical studies of product modularity have only recently begun to emerge (e.g., Worren, 2001).

The study of modularity at the product level also sparked interest in applying the concept of modularity to the organization level. Did the adoption of modular products or production processes enable the modularization of the firm? Or could the same factors that enabled increasing modularity at the product level be simultaneously enabling greater modularity at the

organization level? These questions initiated a recent trend in the organizational research: explaining and predicting the adoption of modular organizational forms.

## **CURRENT TRENDS**

### **The Adoption of Increasingly Modular Organizational Forms**

In the past two decades, a wave of firm disaggregation surged through many industries. Many large and hierarchical firms were transformed into (or supplanted by) loosely interconnected organizational components, with semi-permeable boundaries (Ghoshal and Bartlett, 1997; Ashkenas, et. al., 1995; Snow, Miles and Coleman, 1992). The locus of production was no longer confined within the boundaries of a single firm, but occurred instead at the nexus of relationships between a variety of parties that contribute to the production function. Achrol (1997) vividly sums up this transformation: “Large-scale downsizing, vertical disaggregation and outsourcing, and elimination of layers of management have gutted the mighty multidivisional organizations of the 20<sup>th</sup> century. Replacing them are leaner, more flexible firms focused on a core technology and process, laced in a network of strategic alliances and partnerships with suppliers, distributors, and competitors” (pp. 56-57, 61). Zenger and Hesterly (1997) provide a good review of evidence that firms are downsizing, vertically disaggregating, and becoming more focused.

The phenomenon received widespread attention, though often by authors employing different terms, including “virtual organizations” (Chesbrough and Teece, 1996; Churbuck and Young, 1992; Davidow and Malone, 1992), “network organizations” (Jones, Hesterly and Borgatti,

1997; Miles and Snow, 1986, 1992), and “modular organizations” (Lei, Hitt and Goldhar, 1996; Sanchez, 1995; Sanchez and Mahoney, 1996). While the terms were sometimes invoked in slightly different ways, they all sought to describe the supplanting of tightly-integrated hierarchical organizations by “loosely coupled” networks of organizational actors (Orton and Weick, 1990).

By drawing on Simon's (1962) work on systems and "near decomposability," and Weick's (1976) ideas of "loose coupling," researchers were able to apply some of the concepts developed in the study of modular product systems to the structure of organizational systems. The terms "loose coupling" and "near decomposability" both describe systems in which components are only weakly connected to one another. In product and organizational systems these terms typically refer to systems in which the components are relatively independent, and may be separated and recombined. Sanchez and Mahoney (1996) pointed out that the adoption of modular product designs enabled the looser coupling of production groups within the firm. The architecture of the modular product design and the standard interfaces specified therein provided a form of "embedded coordination." The standard interfaces ensured that components could be developed and produced relatively autonomously, thus the production groups responsible for them could be similarly compartmentalized. So long as the components conformed to the standard interface, compatibility was assured. This line of reasoning thus posited that much of the modularization (or disaggregation) of the production chain was the outcome of utilizing modular product designs.

Other researchers, however, argued that modular organizational forms were not simply the result of the modularization of production processes, but rather that the same forces driving the increased advantages of modularity at the product and production process level (e.g., high speed technological change, heterogeneous technological options, customer heterogeneity, the availability of standard interfaces) also acted to increase the gains from the adoption of modular organizational forms (Garud and Kumaraswamy, 1995; Schilling, 2000; Schilling and Steensma, 2000). This line of research poses that high-speed technological change can cause rapid proliferation of both diverse technological options, and diverse customer demands, thus increasing the advantages to be gained through flexible production configurations.

Furthermore, just as standards among product components reduce the specificity of components to one another, the establishment of formal or informal standards to facilitate coordination of particular organizational components can reduce any performance advantages achievable through tightly integrating those components. Standards such as ISO 9000, uniform employment policies, shared groupware platforms and the like, can enable effective loose coupling at the organizational level. Less need for integration frees firms up to pursue more flexible production configurations. For instance, firms could become more specialized by spinning off activities that could be obtained through more loosely coupled arrangements such as outsourcing. Firms could make increasing use of contingent labor or alliances to access capabilities quickly (and retain the ability to divest them quickly) rather than building such capabilities in house. All of these loosely coupled organizational forms enable more specialized components of production to be fluidly recombined into a large variety of configurations--making the entire production chain an

increasingly modular system, and making the boundaries of the organization somewhat more ambiguous.

There is some empirical evidence emerging that some of the same factors that enable modularity at the product level also enable increasingly modular organizational forms. Argyres' (1999) study of the development of the B-2 "Stealth" bomber provides an in-depth look at one example of a loosely coupled production configuration, and provides rich detail of the processes used by the various firms involved. He found that the four developing companies established a shared "technical grammar." This shared technical grammar resulted in a set of social conventions that acted as a standardized interface facilitating communication and governance between the various autonomous entities involved in the bomber's development.

There is also evidence that industry-level differences in the heterogeneity of inputs and demands, availability of standards, and rate of technological change, can result in differential rates of use of alliances and alternative work arrangements across industries. Schilling and Steensma (2000) used a large sample cross-sectional study of 330 U.S. manufacturing industries to examine whether heterogeneity in production inputs and customer demands influences the degree to which firms utilize modular organizational forms. In the study, modular organizational forms included alliance formation, use of alternative work arrangements and contract manufacturing. They found that heterogeneous inputs and demands were significantly and positively related to the use of modular organizational forms, and that the availability of standards and a high rate of technological change strengthened this relationship. This indicates support for the proposition

that many of the same factors influencing the adoption of modular product forms also influence the adoption of modular organizational forms.

Many of the research arguments and results emerging from the modularity line of research are mirrored in a closely related vein of inquiry: the impact of advances in information technology on the firm.

### **The Impact of Information Technology**

Though information technology has always been relevant to organization design and management, recent explosive growth in information technology, combined with the wave of firm disaggregation described earlier, motivated researchers to look at the relationship between information technology and firm boundaries with renewed vigor. Most of this research has employed either an information processing or transaction cost perspective. Though arising from different origins, both perspectives argue that advances in information technology lower the costs of coordinating activities within and across firm boundaries (Brynjolfsson, 1994; Zenger and Hesterly, 1997). The information processing perspective posits that advances in information technology can both increase a firm's capacity to process information, and lower its costs of processing information. The resulting lower cost of coordination frees the firm to pursue more structural alternatives for production than would otherwise be feasible. Similarly, transaction cost economists note that transaction costs are directly related to the cost of information (Alchian and Woodward, 1987). Advances in information technology can lower a firm's search costs for locating suitable partners, as well as lower the costs of monitoring performance. Thus by reducing transaction costs (which, according to transaction cost economists, are among the

primary reasons for integrating activities within the firm), advances in information technology enable the firm to make greater use of market transactions.

There is a growing body of empirical evidence in support of these arguments. For example, in the Argyres study of the development of the B-2 bomber described previously, he concludes that enhanced information technology limited the need for coordination of activities through hierarchical control. Providing broader evidence, Hitt (1999) studied 549 firms over eight years in a panel study design. Utilizing data on information technology hardware spending, firm specific financial information, and measures of firm structure, he explored the relationship between information technology, internal coordination costs, external coordination costs, vertical integration, and diversification. He found that increased use of information technology at the firm level was significantly related to decreased vertical integration, and that there appeared to be a positive relationship between use of information technology and diversification, though the evidence for this was weaker. He concludes that information technology reduces both internal and external coordination costs.

Brynjolffson et al. (1994 ) point out that if information technology decreases the cost of internal coordination more than external coordination, we would expect firms to grow in size (because the cost of doing more things internally decreases). Similarly, if information technology decreases the cost of external coordination more than internal coordination, we would expect the average size of firms to decrease, as firms would buy more things externally. Malone (1987) argues that information technology should increase both kinds of coordination costs more than it should impact production costs, and that this will lead to more external buying. According to

their argument, in general, buying externally imposes higher coordination costs (because of the need to find suppliers, negotiate contracts, etc.) but lower production costs (because external suppliers can pool the demands of multiple customers, leading to economies of scale and other cost advantages). If information technology reduces both internal and external coordination costs more than it reduces production costs, then it always impacts the balance between coordination costs and production costs the same way: in favor of buying.

Brynjolfsson et al (1994) test the relationship between information technology and firm size using data on average number of employees per firm, sales per firm and value added per firm, and information technology investments and total capital investments for every U.S. manufacturing and service industry, from 1976 to 1989. They found that investments in information technology were significantly related to decreasing firm size as measured by employees per establishment, employees per firm, sales per establishment, and value added per establishment. The most significant declines in size occurred one to two years after investment in information technology. Brynjolfsson et al conclude that information technology does appear to be reducing the costs of coordination, resulting in firms placing increasing reliance on market transactions.

Overall there has been a growing consensus that advances in information technology should enable a wide range of economic actors--including suppliers, customers, and rivals--to combine their activities in flexible networks of "virtual" organization (Byrne, 1993; Davidow and Malone, 1992; Zenger and Hesterly, 1997). However, this still leaves a number of important questions unanswered. To what degree will firms disaggregate? Will information technology completely

eliminate the need for hierarchical relationships? This seems an unlikely scenario, but the boundary conditions for the evolution towards componentization of the firm have yet to be addressed. What structural forms will these new organizations of the future take, and how will the structure of organizations be related (or unrelated) to firm ownership? How will information technology affect the geographical distribution of organizations? These questions (and others) are discussed further in the next section.

## **OUTSTANDING QUESTIONS FOR FUTURE RESEARCH**

Since the work on modular products and production processes, firm disaggregation and the adoption of loosely coupled organizational forms are relatively new areas of research, there is a wide array of important questions that remain to be addressed.

### **Modular Products and Processes**

Though researchers have cited advantages of modular product designs and production processes that include providing more end configurations for customers and achieving economies of substitution within the firm, there has been little work examining when firms will choose different kinds and degrees of modularity. A firm may use modular product designs within the firm that do not extend to the customer level. Such modularity enables the standardization of core components while still achieving a wide range of configurations, yet from the customer's perspective the product is not modular--it is fixed in a single configuration. The typical Sony Walkman demonstrates this type of modularity. Alternatively, firms may also employ modular designs which explicitly give configuration discretion to the customer, such as Ikea's mix-and-

match shelving units, for which the customer chooses their own range of components and assembles the configuration they desire. There are also intermediate forms of product modularity, such as when the customer has some discretion over configuration, but does not typically assemble the product themselves. The firm may assemble the configuration the customer desires (e.g., when a customer chooses options to be installed on a new vehicle), or there may be a market for third-party intermediaries (e.g., third party assemblers have become common in the market for personal computing equipment). Further, modular product designs may enable the combination of components from multiple vendors (as is common in stereo componentry) or only from a single vendor (as with the Ikea shelving system mentioned earlier). When will different forms of modular product designs emerge? How will these different forms affect both customer value and firm competitiveness?

Several researchers have noted that the modularization of product systems can shift the locus of competition within an industry from the system level to the component level. Rather than producing entire product systems, firms can specialize in particular components in which they have a competitive advantage (Baldwin and Clark, 2000; Sanchez and Mahoney, 1996; Langlois, 2000). On the other hand, specializing in components rather than producing an entire product system can reduce the firm's market power or control over the system architecture (Schilling, 2000). Thus a vitally important area of research that remains to be systematically examined is how an industry-wide shift to greater reliance on modular product systems results in a reallocation of rents and competitive positioning. When will firms resist modular product designs? When will they be successful doing so? There has been some work that has speculated

on these questions (e.g., Chesbrough and Christensen, 2000; Schilling, 2000), but significant empirical work has yet to emerge.

There are also a number of important questions that must be raised regarding the nature of the standard interface that enables modularity. In some modular product systems, the interface is "open" and considered a public good (Garud and Kumaraswamy, 1993; Sanchez, 1995). One could consider the electrical outlet format used in homes to be such a standard. The specifications are freely available to any vendor that wishes to produce a product that interacts with the interface. Other modular product systems are based on interfaces that are proprietary, and have degrees of "openness" (Garud and Kumaraswamy, 1993; 1995). For instance, the Window's operating system could be considered a fairly open standard, yet it is owned and controlled by Microsoft, giving Microsoft both discretion over end configurations, and ensuring that Microsoft receives rents from its use. At the other end of the spectrum, McGraw Hill's Primis modular textbook system is based on proprietary software that has very little "openness." The software enables only McGraw Hill to assemble the modular textbooks, and constrains a customer's choice of text components that may be used (it is possible, however, that publishers will migrate towards a more open interface in the future) (Venkatraman, 1997). Important research questions for the future include how the ownership and control of the interface determines its value to producers and customers, its rate of adoption, who garners the rents from its use, who controls the design of the overall system architecture, and the rate at which the architecture and interface evolve (Henderson and Clark, 1990). This is a particularly fertile area of research that is so far relatively untapped.

## **Firm Disaggregation and the Adoption of Modular Organizational Forms**

The existing research on firm disaggregation and the adoption of modular organizational forms has only begun to scratch the surface of the implications of this phenomenon. Two particularly looming questions that this area raises are 1) what are the limits to disaggregation?, and 2) to what extent does proximity still play an important role in production?

In 1965 Gordon Moore, future co-founder of Intel, estimated that transistor density would double every eighteen months. Moore turned out to be basically right, and the exponential growth rate of semiconductor performance came to be known as "Moore's Law." This rate of increase was not expected to continue indefinitely; at the time of his original estimate Moore posited only that it would last "at least the next ten years" (in Mann, 2000:9). Some analysts have predicted the law will hold until 2017, others predict it will come to an end much sooner, as producers run into design constraints for which there are not yet technological solutions. Regardless, however, of the time frame or rate of deceleration, it raises obvious questions about the relationship between information technology growth and firm size and structure. If information technology advances at a rate consistent with Moore's Law, and if information technology reduces internal and external coordination costs, what implication does Moore's Law have for the rate and extent to which firm structures evolve? What are the limits to firm disaggregation? To what degree will market transactions and fluid network structures displace hierarchical control?

Furthermore, as the boundaries of production become more fluid and permeable, how will this affect the structure of property rights with respect to firm ownership? As production components become more loosely coupled in an amorphous web of relationships, and the role of hierarchical

control is diminished, it becomes increasingly difficult to identify the boundaries of a single firm. In fact, it is conceivable that the whole notion of "firm" will be transformed. How will this impact ownership structure and the appropriation of rents?

Another issue arises from the joint effects of advanced manufacturing systems, the modularization of products and processes, and advances in information technology: the role of proximity. The industrial revolution and the rise of mass production systems drew human and capital production factors together into large urban centers. Economies of scale meant that there were significant increasing returns to consolidating production factors into fewer and larger establishments. Proximity between firms, suppliers, customers, and labor reduced transportation costs (Lusht and Farber, 1996), enabled better information sharing (Jaffe, Trajtenberg and Henderson, 1993) and enabled economies of scale and scope in infrastructure development (Marshall, 1922; Romer, 1987).

From the 1950s on, however, the proliferation of private automobiles, highways, air travel, and telephones began to erode the gravitational pull of the urban center (Lusht and Farber, 1996). Metropolitan areas began to spread as both firms and families began to choose locations further from city centers. There is widespread speculation (and emerging evidence) that the rapid innovation in technology will dramatically accelerate this trend (Borja and Castells, 1997; Miller, 1998). Information technology makes distance almost irrelevant in the cost and speed of information transmission. Furthermore, the adoption of flexible manufacturing systems have significantly reduced the minimum efficient scale of production in many industries, while the modularization of products and production processes has further removed the need for proximity

between factors of production. The net result is a diminishment of many of the sources of economies of integration and agglomeration.

However, there are some important advantages to proximity that technology may not overcome. Both the cost and speed of transportation for components and products will continue to be important for a large number of industries, thus leading to clustering advantages for producers and customers. Some forms of information and service exchange are greatly enhanced by physical proximity due to the complexity, richness, or interactiveness inherent in the exchange (Hansen, 1999). Notably, both the resource-based view (Barney, 1991) and the knowledge-based view (Kogut and Zander, 1992) posit that resources that are tacit in nature are more likely to give rise to a sustainable competitive advantage, and proximity may play a pivotal role in the development of and access to tacit resources. Therefore, important work remains to be done on areas including (but not limited to), 1) identifying which sources of advantage from proximity will be impacted by changes in technology, and which are relatively immune to technology's effects, 2) whether proximity will be differentially important to different industries or different portions of the supply chain, 3) identifying the role of government in shaping the advantages of proximity through such functions as regulation, providing infrastructure or other support services for the populations that surround areas of production, and 4) the web of social ramifications that shifting loci of production will have on the spatial dispersion of populations, and the concomitant economic effects.

## **NEW AND EMERGING DIRECTIONS FOR RESEARCH**

Though much of the research described here is very recent, there are some areas of research that stand out as being particularly promising for extending it, or addressing the unanswered questions posed above. Some of these areas of research are natural extensions of previous research, while others involve analogical transfer of ideas across disciplines.

### **Choosing New Technology Development Projects**

One of the most promising new directions for research on technology development is the use of an options approach in choosing development projects. Traditional methods used to evaluate and choose investment projects range from informal to highly structured, and from entirely qualitative to strictly quantitative. Quantitative methods such as net present value (NPV) techniques, provide concrete financial estimates that facilitate strategic planning and trade-off decisions. However, many authors argue that NPV may fail to capture the strategic importance of the investment decision. Recent research has emphasized the role of development projects in building and leveraging firm capabilities, and creating “options” for the future. Investments in new core technologies are investments in the organization's capabilities and learning, and create opportunities for the firm that would otherwise be unavailable (Kogut and Kulatilaka, 1994), thus standard discounted cash flow analysis has the potential to severely undervalue a development project's contribution to the firm.

Several authors have suggested that these problems might be addressed by treating new product development decisions as real options (e.g., Amram and Kulatilaka, 1999; McGrath, 2000). A

firm that makes an initial investment in basic R&D or in breakthrough technologies, is buying a real call option to implement that technology later should it prove to be valuable (Hurry, Miller and Bowman, 1992). Though there has not yet been much empirical work done in the area, several authors have developed methodologies and applications of options analysis to valuing technology development investments (e.g., Amran and Kulatilaka, 1999; Boer, 2000; McGrath, 2000). There has also been some evidence that an options approach does result in better technology investment decisions than a cash flow analysis approach (e.g., Benaroch and Kauffman, 2000).

Other authors, however, warn against too liberal application of the approach, pointing out that technology investment scenarios often do not conform to the same capital market assumptions upon which the approach is based (Perlitz, Peske and Schrank, 1999). For instance, implicit in the value of options is the assumption that one can acquire or retain the option for a small price, and then wait for a signal to determine if the option should be exercised (Bowman and Hurry, 1993). In the case of a firm undertaking solo new product development, it may not be possible to secure this 'option' at a small price, and in fact, it may require full investment in the technology before a firm can determine if the technology will be successful (Schilling, 1998).

### **Standard Interfaces and System Architecture**

Though the organizational theory and strategy research on standard interfaces and architectures is relatively thin, there is considerable research on the topic being done by information systems researchers. Much of this research centers on the uses (and advantages) of object oriented programming (OOP). OOP is a way of encapsulating data and functions within a unit of

software (an "object") in such a way that individual objects can be modified (or new objects combined) without requiring changes in the other objects. OOP makes software modular, and consequently makes expanding or upgrading software much simpler and more efficient. The development and implementation of OOP has spawned extensive research on the nature of interfaces and the implications for the architecture of software. This research may prove useful for providing direction for future studies of the modularization of other kinds of products and processes, and perhaps even firm disaggregation. The direct analog between OOP and modular manufacturing processes is already being explored, with OOP being used to simulate the componentization of manufacturing processes (e.g., Narayanan et al., 1998; Zeigler, 1990). Further integration across the information systems, operations management, organizational theory and strategic management disciplines is likely to enable quantum leaps forward in our understanding of standard interfaces, system architectures, and modularity.

### **The Role of Proximity**

Research on social networks and geographical clustering may help to provide answers to some of the questions about proximity posed above. For instance, Hansen's (1999) study of new product development projects indicated that strong ties (i.e., frequent and close contact) were necessary to transfer complex knowledge across organizational subunits. This provides evidence that the importance of proximity is to some degree a function of the nature of the information to be shared across organizational actors and other relevant stakeholders. Similarly, Nahapiet and Ghoshal (1998) posit that the density of social connections within an organization, and shared language, norms, trust, and mutual obligations, can give an organization an advantage in creating and sharing intellectual capital. Other studies have examined the importance of proximity

between firms in the establishment of local relationships and their impact on resource allocation (e.g., Sorenson and Stuart, 2001). The network perspective and interorganizational technology chapters in this volume provide further discussions of this topic.

The preceding raises an interesting paradox. Many authors have speculated that it is the information-based firms that are likely to be most impacted by advances in information technology. As the mechanisms for transferring information enable wider reach, richer content, and faster and cheaper transmission, firms whose primary business is to develop and share information should be most able to exploit any advantages achievable through disaggregation. However the area of research just described argues that information--particularly when it is complex or tacit, is precisely the kind of resource that is not easily developed or transferred through arms-length relationships. Part of the task of resolving this paradox will be disentangling some of the compound constructs we currently use. For instance, though often used interchangeably, the terms information, knowledge, and intellectual capital may represent distinct resources. Terms such as "closeness" will require parsing into different types, such as emotional, intellectual, and geographical closeness. More precision in our research may reveal, for example, that it is altogether possible to have strong ties in absence of proximity. This area of research has developed a strong following, and doubtless will progress rapidly over the next few years.

## CONNECTIONS ACROSS LEVELS

Comparison across the three technology chapters reveals some interesting points of convergence and divergence. For example, the Tushman and Smith chapter on organizational-level technology raises an argument about organizational form and technological innovation that indicates that firm-level research on the impact of firm size or market power on rates of innovation (as discussed in the beginning of this chapter) may be futile: the firm-level of analysis obscures too much variance in the organization of innovative activity. Comparison between this chapter and Stuart's chapter on interorganizational technology also raises some interesting questions about the direction and complexity of the causal path between technology and spatial proximity.

### **Tushman and Smith's Organization-Level Technology**

Both this chapter and Tushman and Smith's chapter on organization-level technology discuss factors influencing the efficacy of the new technology development process. While this chapter focuses on the existing economic research that has examined the relationship between technology development and firm size, R&D intensity, market power and market concentration, the chapter on organization-level technology proposes that particular organizational forms will influence the likelihood of a firm's success at technological innovation. Specifically, it is argued that ambidextrous organizations (those that have "complex organizational forms composed of multiple internally inconsistent architectures that are collectively capable of operating simultaneously for short term efficiency as well as long term innovation") are better able to avoid

becoming trapped by their past competencies, and are able to simultaneously innovate incrementally and explore competence destroying innovation.

If big firms can have internal structures with the incentives and behavior of small firms, then much of the logic of the impact of firm size, R&D expenditures, or market concentration influencing technological innovation rates becomes moot. A single organization may have multiple cultures, structures, and processes within it; large firms may have entrepreneurial divisions that can both tap the greater resources of the larger corporation, yet have the incentive structures of small firms that foster the more careful choice of projects or enhance the motivation of R&D scientists. Such entrepreneurial units may be capable of developing discontinuous innovations within the large, efficiency driven organizations that tend to foster incremental innovations. This perspective provides strong justification for using multiple-level research designs that are able to capture industry-level, firm-level, division-level, and perhaps even project-level effects when exploring the drivers of new technology development success.

### **Stuart's Interorganizational Technology**

Both this chapter and the chapter on inter-organizational technology discuss the relationship between technology and the spatial proximity of firms, though with an interesting difference on causal direction: whereas this chapter discusses the potential impact of technology on the spatial distribution of firms, positing that technological advance may be rendering proximity less important over time, Stuart's chapter has an extensive discussion of how the spatial distribution of firms impacts the rate of technological innovation.

Stuart provides evidence of the importance of proximity, particularly in high technology industries, noting that "relations between people and organizations are bound to relatively stable spatial coordinates" and that "frequent and intensive interactions are often required in the development of technology and technology-based organizations." He points to evidence that geographical clustering has had a significant impact on the transmission of knowledge across firm boundaries, leading to agglomeration advantages in technological innovation. Both positions may ultimately be true; spatial proximity may have had a significant impact on the rate of technological spillovers and the acceleration of technological innovation through cross-fertilization, but those technological advances that enhance the richness and reach of information technology may, over time, lessen the importance of physical proximity in such spillovers or cross fertilization. This is not to say that spillovers or crossfertilization will become less important, or that relationships between firms will become less important; rather it implies that the correlation between geography, and the density or intensity of relationships may diminish over time.

## **CONCLUSION**

This chapter has examined the existing research on technology development, including work on when firms are likely to be successful at developing technology and how they can improve their development processes. It has also examined the existing and emerging work on the impact of technology on organization structure, management and performance, including the impact of advanced manufacturing technologies, modularity, and advances in information technology. This process has revealed that despite the breadth and diversity of the research that has been

done in this area, we have only begun to scratch the surface. There are vast areas of unexplored research potential waiting to be tapped, and rapid technological innovation is causing those areas to expand. Furthermore, the relevance of such work to managers is irrefutable; the strategic importance of firms' ability to develop, implement and respond to technology has never been greater. It is an exciting time to be pursuing technology research.

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**Table 1: Selected studies in Intraorganizational Technology**

Reference	Key Concepts	Key Variables	Key Findings	Key Contribution	Method and Sample
<b>Development of New Technology</b>					
Blundell, Griffith and Van Reenen (1999)	1) The relationship between market share, market concentration, competitiveness, and innovation	1) innovation (patent counts and innovation counts) 2) market share 3) market value 4) competitive intensity (imports, concentration, union density)	Finds that higher market share firms innovate more, and reap more gains from their innovations (consistent with Schumpeterian hypotheses). However, finds that more competitive industries innovate more on average.	Reassesses the relationship between firm size and innovativeness using new estimation methods that control for unobserved firm specific heterogeneity.	Dynamic count data model estimation using 3551 observations of 340 manufacturing firms listed on the London International Stock Exchange.
Cooper and Kleinschmidt (1993)	1) Identifying the key success factors in new product development	1) project success 2) product differentiation 3) synergy 4) order of entry 5) product life cycle 6) market attractiveness 7) market competitiveness	1) most important determinant of development project success is product differentiation 2) market attractiveness and market competitiveness had little impact	Examines project level, firm level, and industry level determinants of new development project success.	In-depth study of 103 projects undertaken by large chemical firms in four countries.
Zirger and Maidique (1990)	1) Identifying the new product development strategy, process, and context attributes that determine project success.	1) Product technical performance 2) Product value to customer 3) Firm's existing competencies 4) Managerial support	1) In addition to product's performance and value, the integration of project with firm's existing competencies and the degree of managerial support significantly influence likelihood of success.	Uses rich case study data across a large sample of projects to test often postulated drivers of development project success.	Four year field study of 330 new product development projects in the electronics industry
<b>AMT and Mass Customization</b>					
Brandyberry, Rai and White (1999)	1) The impact of advanced manufacturing technology on intermediate performance outcomes	1) Adoption of AMT 2) Market-oriented flexibility 3) Organizational integration of	Higher levels of AMT can enhance integration of production processes. However functionally-oriented AMT can	Empirically assesses the impact of AMT on organizational integration and flexibility. Identifies	Regression and MANOVA of survey data on 132 large U.S. manufacturing firms.

		production processes 4) Administrative intensity	lesson market-oriented flexibility.	constraints of particular forms of AMT.	
Kotha and Swamidass (2000)	1) Implementation of AMT can enhance profitability if type of AMT is matched to firm strategy	1) AMT: product design technologies, process technologies, logistics/planning technologies, and information enhancement technologies 2) Cost leadership strategy 3) Differentiation strategy 4) Profitability 5) Growth	1) Firms implemented different types of AMT depending on their strategy 2) The relationship between strategy and AMT types was strongest for superior performers	Demonstrates support for a contingent model of AMT adoption	Regression using survey data on 160 manufacturing firms
<b>Firm Dissaggregation</b>					
Brynjolfsson, Malone, Gurbaxani and Kambil (1994)	1) Information technology reduces internal and external coordination costs, thereby leading to smaller firms	1) Investment in information technology 2) Firm size as measured by employees, sales, and value-added per firm	1) Investment in information technology is significantly associated with decreases in firm size 2) Decreases are largest one to two years after investment	Demonstrates that advances in information technology may lead to smaller firms on average.	Regression using data on every U.S. manufacturing and service industry, from 1976 to 1989.
Hitt (1999)	1) Information technology's impact on internal and external coordination costs 2) Internal and external coordination costs as drivers of vertical integration and diversification	1) Information technology capital stock 2) Vertical integration 3) Diversification	1) Increased use of information technology is significantly associated with substantial decreases in vertical integration 2) Increased use of information technology is associated with weak increases in diversification	1) Demonstrates the impact of information technology on internal and external coordination costs, and the consequent impact on the boundaries of the firm.	8-year panel study of 549 large firms.
Schilling and Steensma (2000)	1) General modular systems model may be applied to the	1) Heterogeneous inputs and demands 2) Alliance formation	1) Heterogeneity of inputs and demands encourages the adoption	1) Demonstrates applicability of general systems model	Hierarchical moderated regression analysis of data from 330 U.S.

	<p>disaggregation of organizations into more modular forms</p> <p>2) Industry forces influence the likelihood of adoption of modular organizational forms</p>	<p>3) Alternative work arrangements</p> <p>5) Contract manufacturing</p> <p>6) Availability of standards</p> <p>7) Rate of technological change</p> <p>8) Competitive intensity</p>	<p>of modular organizational forms</p> <p>2) Relationship above moderated by the availability of standards, rate of technological change, and competitive intensity.</p>	<p>2) Tests a predictive model about the adoption of modular organizational forms</p>	<p>manufacturing industries.</p>
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