RESEARCH ON TECHNOLOGICAL INNOVATION, MANAGEMENT AND POLICY

A Research Annual

Editor: RICHARD S. ROSENBLOOM
Graduate School of Business Administration
Harvard University

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INTRODUCTION TO VOLUME ONE

This is the first volume in a series reporting current research and thought on the management of technology. Like any other periodic compilation of research, the essential function of this series is to make accessible new knowledge in its field. As one would expect, the contents of these annual reviews will reflect both the distinctive character of the field and the particular biases of the editor. These brief introductory comments will suggest the editor's view of the field and his intentions for the series.

These volumes will be directed toward two audiences: the diverse group of scholars who aim to generate useful knowledge about technological innovation; and the equally diverse group of practitioners in search of knowledge that can help them cope with the pervasive forces of technological change. Papers to be published will, in broad terms, present new knowledge about the process of technological innovation, its management, and its interactions with policies, public and private.

The editor believes that to serve the intended audiences, the series should report *usable knowledge*, in the sense described by Charles Lindblom and David Cohen. Discussing the character of "usable knowledge" in a thoughtful and provocative recent book by that title, they argue that, to be usable, "scientific knowledge" must blend with "ordinary knowledge," stemming from common sense, casual empiricism, and thoughtful speculation and analysis. In this field, the development of scientific knowledge—usable or otherwise—is limited by a paucity of theory and a profusion of concepts. There is no one widely-shared paradigm or theoretical perspective to unify scholarly work. Instead, empirical studies often employ concepts and propositions developed for other purposes, either in basic disciplines, like economics, sociology, or the history of technology, or in applied fields, like organizational behavior or marketing.

Given these aims and assumptions, it follows that the selection of contributors for these volumes should be eclectic. The academic contributors will necessarily include a diverse group representing the many specialized fields that have already contributed significantly to our understanding of this subject. But the management of technology has begun to emerge as a field in its own right. The work of economists, sociologists, and others is being augmented by the fruits of a new sort of scholarship, centered on technological innovation itself, and tied only loosely to these other fields. That work will be represented in each volume, and should provide an increasing share of future volumes.

Eclecticism in the selection of papers will lead, in subsequent volumes, to the inclusion of writings that would not ordinarily be considered as "scientific" knowledge. Of course, the majority of papers will be the usual matter of academic publications—theoretical analyses, literature surveys, and reports of systematic empirical studies. But we also intend to publish "think-pieces" by academic authors and expository writing by wise and seasoned practitioners reflecting on their own experiences. In the editor's view, informed opinion can be as valuable as the findings and conjectures of "scientific" effort in building a body of usable knowledge about a complex social phenomenon. As Milton observed, "where there is much desire to learn, there of necessity will be much arguing, many opinions, for opinion in good men is but knowledge in the making."

Given the expected diversity of readers, contributors, and subjects for this series, there is, of course, some danger that it might aggravate the task of building a common framework for research in this emergent field. On the other hand, we hope that the series will come to be seen as an attractive vehicle of publication for the small but growing group of scholars who identify their primary field as the management of technology. In the editor's opinion, their current efforts are producing what may prove to be the seeds of a unifying theory of the management of technological change. Thus these volumes might contribute to a process that would lead, in time, to a shared conceptual scheme for the field.

Furthermore, in order to give greater coherence to the series, we intend to focus each volume on a single theme. This should also make it practical within each volume to bring together contributors with some shared perspectives.

The theme of Volume One is the interrelations of technical change and competition in industry. The papers in the volume, quite naturally, reflect an economic perspective on the subject. Volume Two will explore institutional and organizational factors affecting innovation, drawing on contributions from a quite different mix of contributors. Subsequent volumes will explore other themes, reflecting the great variety of perspectives and diversity of issues which characterize the field.

The present volume begins with Michael Porter's overview of the technological dimension of competitive strategy. One of the leading current contributors to thought about competitive strategy, Porter has influenced both academic thinking about competition and the practice of firms in formulating strategies. While technology is only one of several factors in the competitive mix, its role is unique and powerful, as Porter shows. He aims in this paper to "establish a conceptual link between technological change and the choice of competitive strategy by the individual firm."

The second paper is by Eric von Hippel, whose earlier work on the functional locus of innovation opened an important area for investigation by scholars in management of technology. Here he homes in on the incentives and disincentives for economically-motivated innovators to pursue their nascent innovations. The thrust of von Hippel's paper is conceptual, offering useful taxonomies of mechanisms that help innovators capture the benefits and distribute the costs of innovation. His analysis shows how those mechanisms operate differentially according to the locus of innovation.

The remainder of the volume is devoted to recent empirical research. Separate studies by Francis Spital and Therese Flaherty deal with the same key variables—lead time and market share—in a common setting—the semiconductor industry. Competitive lead in the introduction of new technology is identified by Porter as a fundamental strategic option and by von Hippel as a primary means for capturing benefits of innovation. The studies by Spital and Flaherty look empirically and critically at evidence of its effect on market share—a primary measure of success in the competitive struggle.

The final paper, by Kim Clark, shifts the arena from high technology to a mature and currently troubled industry—automobile manufacture. Using data from a broader study in which he is collaborating with William Abernathy, Clark takes a fresh look at some long-standing ideas about continuity and discontinuity in the development of an industry over time. He begins with an interesting conceptual contribution, offering an economic interpretation of the forces behind evolution in industry. This leads to a question with profound practical implications for the auto industry today: do current developments in the industry represent simply a logical extension of a decades-old evolutionary pattern, or do they signal something very different, a discontinuity marking the start of a new phase in the development of the industry? Clark treats this as an empirical question. His analysis has value not only for the conclusion he reaches, but also as a model for research in other settings.

Richard S. Rosenbloom
Series Editor

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THE TECHNOLOGICAL DIMENSION OF COMPETITIVE STRATEGY

Michael E. Porter

Technological change ranks as one of the principal drivers of competition in industries. Schumpeter (1934) characterized technological change accurately as the source of "creative destruction" by which monopolies were destroyed and new industries created, and examples of the power of technology to change the boundaries or rules of competition are easy to find. Yet the study of technological innovation is too often decoupled from the study of competition and vice versa. Emphasis in the management of technology field is largely given to the internal conditions for success in R&D programs and to insuring the required linkage between innovation and customer needs. Conversely, research in industrial economics has taken a narrow view of technological competition, focusing on the relationship between technological inputs or outputs and firm size, diversification, industry seller concentration, and profitability,[1] and to a limited extent on technological spending as an entry barrier.[2] Missing in

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both fields is a comprehensive view of how technological change can affect the rules of competition, and the ways in which technology can be at the foundation of creating defensible competitive strategies for firms.

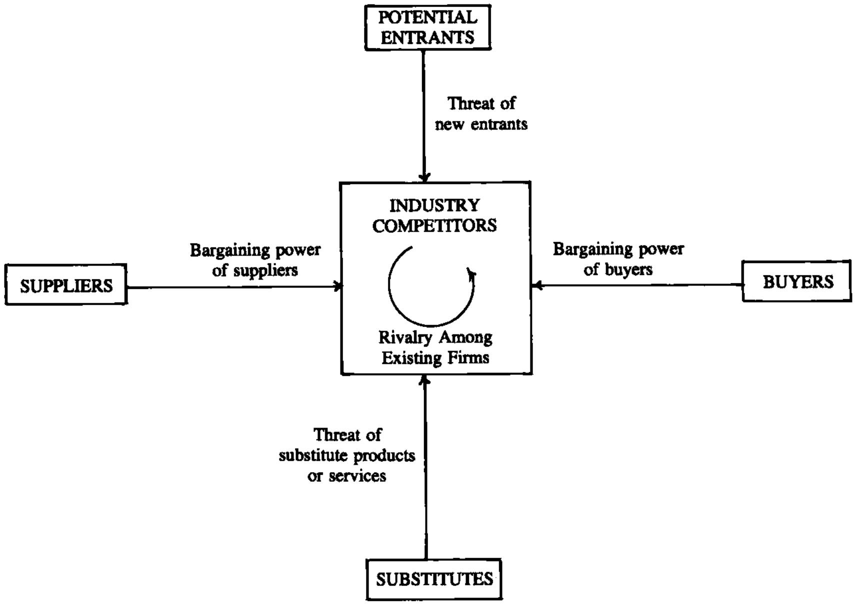
This chapter aims to establish a conceptual link between technological change and the choice of competitive strategy by the individual firm. It will begin by examining the potential impact of technology on industry structure that motivates technological activity. It will then link technological strategy to overall competitive strategy, and show how technological strategy can be a vehicle for pursuing generic competitive strategies aiming at fundamentally different types of competitive advantages. In this context, the structural determinants of the firm's choice of technological leadership or followership will be identified. Finally, I will build on the analysis of individual firm technological choices, in order to model the determinants of the pattern of technological change as industries evolve, and will develop some implications for the choice between pioneering and late entry and the choice of a late entrant's technological strategegly.

I. TECHNOLOGY AND INDUSTRY STRUCTURE

The power of technology as a competitive variable lies in its ability to alter competition through changing industry structure. Viewing competition broadly, there are five fundamental competitive forces (shown in Figure 1) at work in any industry whose collective strength determines the ability of firms to earn rates of return on investment in excess of the opportunity cost of capital: the five forces are the threat of entry, substitution, bargaining power of suppliers, bargaining power of customers, and rivalry among incumbent competitors. Each of these forces has underlying economic, technical, and situational determinants that I have developed elsewhere.[3] These underlying determinants have been termed industry structure, and define the rules of competition in the industry. The same determinants can be examined at the level of the individual firm to assess its fundamental competitive position, using the concept of strategic groups.[4] The same factors that determine entry barriers also determine the mobility barriers that protect firms' strategic positions from attack by rivals, for example.

Industry structure defines the arena and rules of the game in which competitive strategy seeks to best position the firm. The aim of competitive strategy is to create a defensible position for the firm against the competitive forces. One approach to doing this is through finding industry posi-

Figure 1. Forces Driving Industry Competition



tions least vulnerable to the forces, drawing on an understanding of their determinants; for example, one particular market segment might be less exposed to substitution than another. The other approach to competitive strategy formulation is to use strategy to *change* industry structure (the rules of competition) in the firm's favor. When the strategies of highly successful firms are examined, a striking number have succeeded in changing the competitive rules in their industries in ways that are defensible.

What makes technology unique as a strategic variable is its considerable power to change the competitive rules of the game. Technological change can be a great equalizer that nullifies the advantages of incumbents and creates opportunities for newcomers and followers. Technological change is perhaps the single most important source of major market share changes among competitors for this reason, and is probably the most frequent cause of the demise of entrenched dominant firms.

The competitive significance of a technological change depends neither on its scientific merit nor its effect on the ability of the firm to serve market needs per se, but on its impact on industry structure. Technological change can potentially affect a wide spectrum of determinants of industry structure. Where a firm's technological innovations are appropriable, these impacts of technological change on structure are the fundamental motivations underlying the firm's choice of technological strategies.

Technology and Entry Barriers

Technological change can effect industrywide entry barriers and the mobility barriers protecting individual firms' positions in a variety of ways. Technological change can raise or lower economies of scale in nearly every aspect of a firm's operations. While most discussion does not use this terminology, technological change is what underlies the learning curve: the learning curve creates an entry barrier if the learning can be kept proprietary. Proprietary technology can lead to absolute cost advantages in many other ways as well. Technological change can alter the capital requirements for competing in a business, both directly, through requiring firms to make R&D investment, or indirectly, through affecting the capital required for production, logistical, or other facilities. Technological change can enhance or eliminate opportunities for product differentiation, through proprietary product designs (enhancing differentiation), reducing the need for after-sale service (perhaps reducing differentiation), and the like. Technological change can also affect access to distribution through facilitating the circumvention of conventional distribution channels (like the low-cost Timex watch did), or conversely, through increasing industry dependence on distribution channels by requiring greater needs for product demonstration and after-sale service.

Technological change can also raise or lower switching costs, or buyers' fixed costs of changing suppliers. Technological choices by competitors determine the need for retraining users or reinvesting in ancillary equipment when changing from one supplier to another. Technological assistance by suppliers in designing products into a buyer's product can elevate switching costs, while standardizing technological interfaces between products can reduce them.

The R&D function itself also has potential implications for entry and mobility barriers. The essentially fixed costs of product development can lead to economies of scale favoring firms that can amortize these costs over large volumes. Maintaining an effective R&D program may itself be subject to economies of scale, though there is much disagreement about this in the literature.[5] It has also been argued that the need for substantial R&D creates capital barriers to entry (Grabowski and Mueller, 1978).

Whether technological change raises barriers industrywide or raises mobility barriers protecting the strategic position of the innovating firm depends on the defensibility of technological changes from imitation by incumbent competitors. For example, Bausch and Lomb's low cost spin casting production technique for making soft contact lenses has been defensible and a prime mobility barrier, while the automatic drip coffee maker was widely imitated and its effect on industry structure was industrywide. Defensible technological changes that raise mobility barriers usually carry the greatest competitive significance for a particular firm. However, a technological change that triggers industrywide imitation resulting in a favorable impact on industry structure may boost the profit potential of all industry participants (including the initiator) enough to justify the cost to the innovator.

This analysis also suggests that technological change can *reduce* entry (or mobility) barriers and hence reduce the attractiveness of industry structure. Thus it should not be presumed that all technological change is beneficial from a strategic viewpoint, even if the firm can defend its innovation from imitation. A technological change that allows customer needs to be better met, for example, may reduce opportunities for product differentiation or lower the economies of scale in the business.

Another important implication of the discussion is that technology, though potentially creating entry/mobility barriers, can be the vehicle that allows new firms or industry followers to overcome entry/mobility barriers.[6] A technological breakthrough can provide the cost or differentiation advantage to allow the firm to fund the cost of overcoming other entry barriers. For example, its lead in radial tires gave Michelin an edge in product differentiation that allowed it to make significant inroads into the U.S. tire market, where distribution and advertising scale economy barriers are high. Rosenbloom's (1978) example of the penetration of the steam locomotive oligopoly by General Motors' diesel locomotive provides another potent example.

Technology and Buyer Power

Technological change can shift the bargaining relationship between an industry and its buyers. As described above, technological change can change product differentiation or switching costs, which are both instrumental in determining buyer power. Technological change can also affect the ease of backward integration for the buyer, a key buyer bargaining lever. Technological change can also impact the relationship between the industry's product and the buyer's business and hence the basis of buyer choice. For example, technological change that allows the seller's product to favorably affect the performance of the buyer's product (for example, a better electric motor sold to an air conditioner manufacturer) may reduce the price sensitivity of the buyer.

Technology and Supplier Power

Technological change can also shift the bargaining relationship between an industry and its suppliers. Technological change can eliminate the need to purchase from a powerful supplier group or, conversely, can force an industry to purchase from a new, powerful supplier. Technological change can allow substitute inputs to be used in the firm's product, which creates bargaining leverage against suppliers. R&D investments by a firm to assure proprietary control over frontier technology for its raw materials or other inputs can facilitate the use of multiple suppliers, or allow the breakup of purchased systems into components that can be sourced individually, both reducing supplier leverage. These practices have been instrumental in enhancing the bargaining leverage of U.S. auto producers over component suppliers. Technology can also overcome switching costs that suppliers have put in place. Of course, technological change that locks the firm into particular inputs or has the affect of raising switching costs can worsen the bargaining relationship with suppliers.

Technology and Rivalry

Technology can alter the nature and basis of rivalry among existing competitors in an industry. Technological change can raise or lower fixed costs and hence the pressure for price cutting. For example, the shift to continuous process technology in the corn wet milling industry has raised fixed cost and contributed to elevated warfare, as has the increasing size of oil tankers. Technology can affect product differentiation and switching costs, and hence the responsiveness of buyers to price cuts or other competitive moves and thereby the incentives for competitive warfare. Technology affects substitution which can enhance or reduce industry growth and hence rivalry. Technology can also raise or lower exit barriers that enhance rivalry by locking unsuccessful competitors into an industry. Finally, technological change can alter capacity utilization by raising or lowering effective capacity, or the ability to adjust capacity to demand. This affects the likelihood of repeated outbreaks of rivalry.

Technology and Substitution

Perhaps the most commonly discussed effect of technology on industry structure is its impact on product substitution. Substitution is a function of the relative price/performance of competing products and the switching costs of changing between them. Technological change creates entirely new products or product uses that substitute for others, such as fiberglass, personal computers, and microwave ovens. Technological change also can impact both relative price/performance and switching costs among existing products, as manifested in the two-decade-old struggle for supremacy between steel and aluminum beverage cans. The technological battle to improve relative price/performance between industries producing close substitutes is at the heart of the substitution process.

A technological change is potentially significant for competitive strategy if it significantly changes structure through one or more of the mechanisms described above. The impact of technological change on industry structure can be either positive or negative, as has been illustrated. Technological change is not always good for firms' and industries' profitability, as is sometimes supposed; it can raise supplier power, increase rivalry, or otherwise change structure in ways that lower long-run profit potential.

As was noted earlier, a technological change that improves industry structure is generally most significant for a firm's strategy position if it can be defended from imitation. Even a technological change that threatens industrywide structure can improve the strategic position of an individual firm if it is not imitatable. A technological change that is not imitatable can sometimes differentiate the firm's product or improve its cost position, whereas the same technological change would destroy industry structure if it were widely imitated. For example, a reduction in downtime or spare parts utilization can significantly improve a firm's strategic position if the firm can protect its advantage from imitation or stay ahead of imitation. However, if the improvement becomes widespread, the resulting decrease in the need for manufacturer service organizations and the reduction in the proportion of sales to the price-insensitive aftermarket may reduce differentiation possibilities, enhance buyer power, and destroy industry profitability. Thus the analysis of the consequences of a technological change for industry structure both with and without imitation is central to the choice among technological alternatives.

Technology and Industry Boundaries

One of the ways in which technological change affects industry structure, foreshadowed by my discussion of substitutes, is through its impact on industry boundaries. The boundary of an industry is often an imprecise concept, because of the often arbitrary distinctions that exist between the industry's product and substitutes, between incumbents and potential entrants, and between incumbents and suppliers or buyers who may be (or have the potential to be) partly vertically integrated. The industry analysis framework described above mitigates the importance of drawing precise industry boundaries for strategic analysis, because it focuses on competitive forces beyond just rivalry among existing competitors. Nevertheless, it is important to recognize that wherever one chooses to draw industry boundaries, technological change can widen or shrink them.

Technology can widen industry boundaries in a variety of ways. It can reduce transportation or other logistical costs and thereby enlarge the geographic scope of the market. Technological change that reduces the cost of responding to national market differences can make global industries out of domestic ones. Technology can also enhance the functions the product performs, thereby bringing new customers (and competitors) into the market. In industries such as bank cash dispensers, watches, and telecommunications, technological change is blurring industry boundaries and folding whole industries together.

Technology can narrow industry boundaries as well. Technological change may allow the tuning of product characteristics to a particular business segment or specializing the system for producing and delivering a product to a particular business segment. Thus segments can, in effect, become industries with their own product differentiation and distinct production processes.

Finally, it must be stressed that technological change that creates entirely new products establishes new industry boundaries where there were none previously. Recent developments in areas such as bioengineering, consumer electronics, and ceramic materials provide examples of entirely new industries triggered by technological change.

II. GENERIC TECHNOLOGICAL STRATEGIES

Having cataloged the potential impacts of technological change on industry structure and competitive position, the question becomes: How can