STRATEGIC MANAGEMENT *of* TECHNOLOGY *and* INNOVATION

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THIRD EDITION

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STEVEN C. WHEELWRIGHT is the Edsel Bryant Ford Professor of Business Administration at Harvard Business School, where he also serves as Senior Associate Dean. Dr. Wheelwright teaches Technology and Operations Management in the MBA program and in several HBS executive education programs. Dr. Wheelwright has been on the faculty at the Stanford University Graduate School of Business and on the faculty at INSEAD (Fontainbleau, France). Dr. Wheelwright examines product and process development and their connection with competitive advantage and operations excellence. He has co-authored several works with Harvard Business School colleague Kim Clark, most recently *Leading Product Development: The Senior Manager's Guide to Creating and Shaping the Enterprise* (Free Press, 1995). This and other related volumes present a set of concepts and tools proven particularly effective in technology-intensive settings where rapid, efficient, on-target product and process development play a central role in competitive advantage. Along with Harvard colleagues Bob Hayes and Kim Clark, Dr. Wheelwright also published the highly regarded book, *Dynamic Manufacturing: Creating the Learning Organization* (Free Press, 1988), which analyzes some of the manufacturing industry's most pressing problems.

Dr. Wheelwright earned a BS degree in Mathematics from the University of Utah and an MBA and PhD from Stanford University Graduate School of Business. He was vice president of sales in a family-owned printing company and has consulted in the areas of business/operations strategy and improving product development capabilities. Dr. Wheelwright serves on the board of directors of Quantum Corp, Heartport, O.C. Tanner Co, Franklin-Covey, and Millennium Pharmaceuticals, Inc.

PREFACE

Technology and innovation must be managed. That much is generally agreed on by thoughtful management scholars and practitioners. But can the management of technology and innovation be taught, and if so, how? What concepts, techniques, tools, and management processes facilitate successful technological innovations? The answers to these and several related questions are of great interest to those academics and practitioners who concern themselves with organizations in which technology and innovation are vitally important.

In the US, these concerns were heightened during the late 1970s and 1980s when it became clear that the US no longer enjoyed supremacy as the world's technological superpower. Japan, Korea, Germany, and other European and Asian countries had made major inroads in industries once considered unassailable US strongholds. At first it seemed that the challenge was mainly in the traditional, capital-intensive, heavy manufacturing industries such as steel and automobiles. But during the 1980s and early 1990s, the challenge broadened to include machine tools; consumer electronics; many aspects of semiconductors, computers, and telecommunications; aerospace; and some aspects of biotechnology.

Hayes' and Abernathy's 1980 *Harvard Business Review* article, "Managing Our Way to Economic Decline," signaled the growing awareness in the US that effective management of technological innovation was becoming a high-priority concern of US business. During the 1980s and early 1990s, the importance of technological innovation for competitive advantage, at the level of both the firm and the country, spurred research and the development of related teaching materials. Literally hundreds of universities, through their schools of engineering or business (or both), introduced or substantially expanded the management of technology and innovation as part of their curriculum and degree programs, as this field became a major topic of broad interest to students, managers, and academics. The first two editions of *Strategic Management of Technology and Innovation* contributed to the development of courses on this subject in many schools.

In the background of these anxiety-provoking industrial developments and calls-to-arms, however, a new revolution was already in the making: the digital revolution. The first step in the digital revolution was the radical impact of microprocessor technology on computing and communications. The enormous growth of the demand for microprocessor-based personal computers created two new technological giants during the mid-1980s—Microsoft and Intel—that spawned entirely new ecosystems comprising thousands of new high-technology companies providing complementary products. The second step was the growing importance during the 1990s of digital networks for enterprise data communications, which created yet another new giant—Cisco—and also spawned a new ecosystem of new high-technology companies. These developments, in turn, enabled the emergence and fast growth of still other major information processing companies such as Oracle, SAP, and Siebel Systems, among many others. The third step in the digital revolution was the enormous growth since the mid-1990s of the Internet, which also created new ecosystems and literally thousands of new companies including new giants such as AOL-Time Warner, Yahoo!, e-Bay, and Amazon.com. Without exaggerating, it could be stated in 2000 that the Internet has affected all industrial and commercial activity and will be a change of the same or greater magnitude than the introduction of the automobile, electricity, and the telephone. The digitization of telecommunications equipment, the adoption of digital broadband technologies, and the growth of wireless data and voice telecommunications are unfolding aspects of the digital revolution.

The digital revolution has once again put the United States at the center of technological innovation. It also has increased the importance of technology and innovation as issues of strategic concern for just about every company. Indeed, Intel's Chairman Andy Grove predicted that by 2005 only companies that have adopted the Internet as a mission-critical technology will survive. Hence, *all* companies will have to address technology as a critical element in their strategic management.

In addition to the digital revolution, the realization of the long-anticipated biotechnological revolution also seems imminent. Building on the first gene-splicing techniques developed in 1973, practical applications of cloning technologies have dramatically gained in power during the late 1990s. Such developments and the soon-to-be published documentation of the complete human genome promises to revolutionize the pharmaceutical and healthcare industries during the first half of the 21st century.

This edition reflects and addresses these revolutionary developments. This new edition aims to achieve two important goals. The first is to provide continuity and refinements in terms of conceptual approach. We think this is important because it allows instructors to build further on their intellectual capital investments and deepens their ability to consider new developments and strategy questions in a framework of cumulative knowledge development. The second goal is to provide change in terms of teaching material to reflect the evolving reality of technological innovation in leading companies and industries. We think this is important to help instructors maintain their courses up to date and to stimulate their own interest as well as that of their students. Consequently, the third edition maintains and enhances the conceptual framework developed for the second edition. The power of that framework is demonstrated by its ability to integrate important new theoretical ideas, such as those related to "disruptive technologies." At the same time, the teaching material for the third edition is almost completely new. Many new cases and industry notes that have been developed during 1994-1999 are included in the new edition.

ACKNOWLEDGMENTS

This edition of *Strategic Management of Technology and Innovation* is inspired by the many colleagues whose work has helped shape this dynamic and important field. We continue to be grateful to all our teachers and current colleagues who have contributed to the perspective that informs our conceptual framework and choice of materials. We thank the new scholars who contributed directly to the materials in this third edition by letting us use their work, and our research associates and collaborators on the cases and industry notes. We are grateful for the generous help of the anonymous colleagues who provided insightful and helpful comments on the second edition to improve the third one.

Ultimately, the test of the value of teaching materials lies in their use in the classroom. Many hundreds of Stanford and Harvard MBA students and executive education participants have helped us with that test. We thank them for their feedback and comments.

We express special thanks to Dr. Andrew S. Grove, Chairman of Intel Corp., who continues to be a valued colleague at the Stanford Business School, and provided great research access to one of the most important high-technology companies of our time. Dr. Burgelman especially thanks Dennis Carter of Intel Corporation and Ray Bamford, former research associate, for their help with the extensive research for the new case, Intel in 1999. For Dr. Wheelwright, close colleagues like Kim Clark, Clay Christensen, Kent Bowen, and Bob Hayes have provided invaluable feedback and insight. Senior executives such as Michael Brown at Quantum, Jay Graf at Guidant, and Mark Levin at Millennium Pharmaceuticals have unselfishly contributed to the research and educational processes that lie behind a work like this.

The third edition of *Strategic Management of Technology and Innovation* would not have been possible without the support of the Stanford Business School and the Harvard Business School. For Dr. Burgelman, this support has come through the 1996-1997 GSB Trust Fund Fellowship and through the ongoing support for his research and course development that depends, to a large extent, on the generous contributions of the school's alumni and friends. For Dr. Wheelwright, this support had come through the HBS Division of Research.

As anyone who has completed a book-length manuscript knows, the final product is a team effort. This third edition would not have been completed without the help of Tracy Jensen, our editorial assistant at McGraw-Hill; Philip Meza, Dr. Burgelman's research associate at Stanford Business School; and Kathleen Hoover, Dr. Wheelwright's administrative assistant at Harvard Business School.

Finally, a word of thanks to Rita Burgelman and Margaret Wheelwright for their continued support of our sometimes relentless efforts.

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CONCLUSION: INNOVATION CHALLENGES IN ESTABLISHED FIRMS

INTRODUCTION: INTEGRATING TECHNOLOGY AND STRATEGY

Technology and Strategy: A General Management Perspective

A key purpose of this book is to help the general manager—someone responsible for the overall strategic management of an organization or autonomous business unit—deal with issues of technology and innovation. Established high-technology companies typically spend at least 5 percent of sales on technology and innovation-related activities; start-up companies may spend significantly more. Although most of the companies studied here are considered high-technology, the issues and problems associated with technology and innovation in the environment of the 1990s are part of the general management task in *all* firms.

One key task of the general manager is to acquire, develop, and allocate an organization's resources. Technology is a resource of paramount importance to many organizations; managing this resource for competitive advantage entails integrating it with the firm's strategy. A second key task of the general manager is to develop and exploit the firm's capacity for innovation. This requires that the general manager be able to assess the firm's innovative capabilities and identify how they may be leveraged or improved. This chapter provides a set of tools the general manager can use to accomplish both of these major tasks.

The chapter consists of three sections. In the first, we define a set of key concepts concerning technological innovation and then outline their interrelations. This step is important because strategic management of technology and innovation is a young field and the domains of different, partly overlapping concepts are still somewhat in flux. Though we do not claim that the definitions and interrelations presented here are definitive, they are generally accepted by scholars and practitioners in the field, and they are useful for organizing the discussion of cases and readings that follows. The second section of the chapter discusses the integration of technology with business and corporate strategy. The third section presents a framework for auditing and assessing the firm's innovative capabilities. A brief conclusion follows the third section.

KEY CONCEPTS AND THEIR RELATIONSHIPS

Inventions/Discoveries/Technologies

At the origin of the technological innovation process are inventions or discoveries. As Webster points out, "We discover what before existed, though to us unknown; we invent what did not before exist." Inventions and discoveries are the result of creative processes which are often serendipitous and very difficult to predict or plan. For instance, Aspartame, a sweetener used in many food and beverage products, was a chance discovery. Researchers in universities, the government, and industrial labs following the canons of modern science—as well as idiosyncratic tinkerers in a garage—play a role in these processes. *Basic* scientific research refers to activities involved in generating new knowledge about physical, biological, and social phenomena. *Applied* scientific research is geared toward solving particular technical problems. The cumulative body of systematic and codified knowledge resulting from scientific research forms the substratum for many, but not all, inventions and discoveries (e.g., the wheel was not the result of scientific research).

The criteria for success regarding inventions and discoveries are technical (Is it true/real?) rather than commercial (Does it provide a basis for economic rents?). Through *patents,* inventions and discoveries sometimes allow their originators to establish a potential for economic rents with subsequent innovations (see below), but there may be a significant time lag (10 years or more) between doing scientific research and using the inventions and discoveries to create successful innovations (superconductivity and genetic engineering are examples).

Technology refers to the theoretical and practical knowledge, skills, and artifacts that can be used to develop products and services as well as their production and delivery systems. Technology can be embodied in people, materials, cognitive and physical processes, plant, equipment, and tools. Key elements of technology may be implicit, existing only in an embedded form (e.g., trade secrets based on know-how). Craftsmanship and experience usually have a large tacit component, so that important parts of technology may not be expressed or codified in manuals, routines and procedures, recipes, rules of thumb, or other explicit articulations. The criteria for success regarding technology are also technical (Can it do the job?) rather than commercial (Can it do the job profitably?). Technologies are usually the outcome of development activities to put inventions and discoveries to practical use. The invention of the transistor (1947), integrated circuit (1959), and microprocessor (1971), for example, gave rise to successive generations of new technologies in the semiconductor industry that were, in turn, applied in areas such as data processing and telecommunications.

Technological Innovations

Some innovations are technology-based (e.g., disposable diapers, oversized tennis racquets, electronic fuel injection, and personal computers). Other innovations, such as new products or services in retailing and financial services, are facilitated by new technology (e.g., electronic data processing). The criteria for success of technological innovation are commercial rather than technical: a successful innovation is one that returns the original investment in its development plus some additional returns. This requires that a sufficiently large market for the innovation can be developed. Innovations are the outcome of the *innovation process,* which can be defined as the combined activities leading to new, marketable products and services and/or new production and delivery systems.

Different types of innovation have been identified in the literature. *Incremental* innovations involve the adaptation, refinement, and enhancement of existing products and services and/or production and delivery systems—for example, the next generation of a microprocessor. *Radical* innovations involve entirely new product and service categories and/or production and delivery systems (e.g., wireless communications). *Architectural* innovations refer to reconfigurations of the system of components that constitute the product—for example, the effects of miniaturization of key radio components.

Technological Entrepreneurship

Entrepreneurship is a fundamental driver of the technological innovation process. Technological entrepreneurship refers to activities that create new resource combinations to make innovation possible, bringing together the technical and commercial worlds in a profitable way. Administrative capabilities must be deployed both effectively and efficiently. Technological entrepreneurship can involve one individual (*individual* entrepreneurship) or the combined activities of multiple participants in an organization (*corporate* entrepreneurship).

Activities and Outcomes

The discussion of key concepts suggests that it is useful to distinguish between activities and outcomes. Inventions, discoveries, and technologies (outcomes) are the result of tinkering and experimenting, as well as of systematic basic and applied R&D (activities). Technological innovations (outcomes) are the result of product, process, and market development (activities). Technological entrepreneurship involves product, process, and market development (activities) as well as the development of administrative capabilities.