CHAPTER 1

Introduction

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I. Defining Industrial Leadership

This volume contains studies of the evolution of seven industries, exploring the development of each in the United States, Japan, and Western Europe. The industries are machine tools, organic chemical products, pharmaceutical biotechnology, medical devices, computers, semiconductors, and software. Each industry study compares the development of these industries in the different countries and considers the factors that explain cross-national and cross-industry differences. Together, we hope that these studies will shed light on the sources of industrial leadership, a concept we discuss next.

The choice of these seven industries was motivated by our concern to cover an array of diverse industries in which technological innovation plays an important role. Several of these industries, such as semiconductors and computers, trace their birth to the opening of a major new technology in the postwar period. Technological advance in some of these industries, particularly organic chemical products and semiconductors, has had profound impacts on the products and processes of a wide range of downstream industries. In turn, the technology employed in some of these industries, such as machine tools and computers, has been powerfully influenced by upstream innovation.

At one time or another in the history of virtually all of these industries, firms located in one country or a small number of countries developed superior product or process technologies, ways of organizing production, or marketing strategies that gave them significant advantages over firms based in other countries. The identity of leading firms sometimes changed, occasionally more than once, during the development of several of these industries. In some cases this shift in the locus of firm leadership involved a shift of leadership among different nations, but in others, shifts in firm leadership produced new leading firms of the same nationality as the old leaders. Each industry study attempts to identify the factors that led to the emergence of national leadership, and the reasons behind the shifts that occurred.

We have adopted the term *industrial leadership* to denote our focus on industries in which being ahead of one's competitors in product or process technology, or in production and marketing, gives firms an advantage in world markets. As such, we are concerned with the translation of technological expertise into commercial success, rather than solely with technological innovation per se.

We prefer this term, rather than "comparative advantage," because industrial leadership explicitly denotes performance in industries where technological sophistication and innovative performance are key factors. Other analyses of business history and strategy use the term *competitive advantage* for this purpose, but most of these studies focus on factors internal to the firm. The term *industrial leadership* prevents any presumption as to whether industrial leadership is determined by strengths that firms build for themselves, by their national environment, or by something in between (e.g., regional factors or institutions or other factors that are specific to an industry).

The industry studies in this volume have much in common with some earlier work in which cross-national differences in technology, management, and competitive performance in a particular industry have been the central focus (see, e.g., Beer, 1959, on dyestuffs, or Malerba, 1985, on semiconductors). Such studies often have explored national differences in competitive performance. But most of these previous studies focus on an individual industry or a small number of industries, and thus shed little light on differences in the sources of industrial leadership across industries and historical eras. This issue is the central concern of this volume.

We believe that this volume is unique in (1) considering the evolution of a number of technology-intensive industries in different countries and attempting to explain the factors behind national differences; (2) exploring a number of different explanations of the sources of industrial leadership; and (3) being open to the possibility, indeed the likelihood, that these explanations differ from industry to industry and from era to era.

The approach taken in these studies would seem a useful one for addressing questions of interest to scholars, managers, and policymakers. Examples of such questions include the following:

1 How secure is the U.S. lead in computers or biotechnology?
2 Can Western Europe catch up to the United States and Japan in electronics?
3 Does Japan need to strengthen significantly her university research system in order to keep at the forefront of electronics, or to catch up in pharmaceuticals?

4 What role does competition policy play in the development and maintenance of industrial leadership?

In addition to their intrinsic interest, these kinds of questions are at the heart of debates over strategic trade policy and active industrial policy. We believe that the issues in this debate need clarification and hope that detailed studies of the factors behind the patterns of industrial leadership of the sort we present here can contribute to such a clarification.

II. Summaries of the Industry Studies

Each of the industry histories is a complex story. In this section, we briefly summarize each industry study. Rather than attempting to summarize the detailed analysis of subsequent chapters, we wish here simply to convey an idea of the phenomena addressed in each study.

Firms specializing in the design, production, and sale of machine tools began to emerge in the first decades of the 19th century. Through the middle of the 19th century, British firms were in the forefront of machine tool technology. After that time, the rise of mass production in the United States contributed to the emergence of a significant American machine tool industry. By the early 20th century, U.S. firms had moved into the position of leadership in the design and production of machine tools that they held through World War II. In the late 1950s and early 1960s, numerically controlled machine tools were introduced as a result of R&D programs originally sponsored by the U.S. Department of Defense. By the mid-1970s, numerical control had become standard in a wide range of machine tool types, and Japanese companies had displaced U.S. firms as leaders in many parts of the industry. Our study focuses on the loss by U.S. firms of industrial leadership during the era of numerical control.

British firms also dominated the production of chemicals during the first half of the 19th century, during which the industry relied on craft experience rather than formal science. Dramatic advances in scientific understanding during the last half of the 19th century, however, made it possible to design and produce dyestuffs and, later, synthetic fibers and pharmaceuticals. By the end of the 19th century, German and Swiss firms were the leaders in the organic chemical products industry, leaving British firms far behind. During the period between World Wars I and II, American firms developed significant capabilities in organic chemical products, based on their exploitation of an entirely new feedstock – petroleum. Their development of petroleum-based

processes for the production of organic chemical products enabled American firms to establish a strong position in global production and innovation after World War II, one that was shared with firms in Germany and Great Britain. The 1970s and 1980s saw the erosion of American leadership and the spread of the industry to many corners of the world.

German and Swiss producers of fine chemicals (notably, dyestuffs) moved into pharmaceuticals in the late 19th century and largely dominated this industry until the 1930s. Following World War II, American pharmaceuticals firms, none of whom was based in the chemicals industry, and some British firms (including the leading British chemicals firm) joined the German and Swiss as leading innovators and exporters. The chapter on this industry focuses on the effects of new biotechnology-based techniques for drug discovery, development, and production on both incumbent and new pharmaceuticals firms. These new techniques challenged the drug development practices of established pharmaceuticals firms in the United States, Great Britain, Japan, and other Western European nations.

The medical diagnostic devices industry traces its origins to the early 20th century and the development of X-ray imaging technologies. Our study of this industry deals mainly with the period after World War II and concentrates on electronics-based diagnostic medical devices. The study reveals that American, European, and Japanese firms are strong in different parts of the industry. Companies' reputations for producing high-quality equipment, their mastery of complex marketing and regulatory environments, and their connections with the relevant user communities became more important during this period.

The computer industry, the semiconductor industry, and the software industry all were born after World War II and grew up together. American firms soon came to dominate all three industries. By 1980, however, Japanese firms had become strong competitors in portions of the semiconductor industry (i.e., dynamic random-access memories [DRAMs]). Since the late 1980s, however, Japanese firms have been challenged by South Korean firms in these product areas, and U.S. firms have exploited long-standing strengths in product innovation to reestablish dominance of the overall semiconductor industry. Japanese and Taiwanese computer firms also have developed considerable strength in certain niches, such as laptop computers and computer components. Nevertheless, American firms retain a leading position in most types of computers. And throughout the history of the computer software industry, American firms have dominated global markets in packaged software.

III. Perspectives on the Sources of Industrial Leadership

Explaining these different patterns of industrial leadership was the central challenge taken on by the authors of the industry chapters. Although previous research does not adequately come to grips with many of the issues addressed here, this work does provide some relevant arguments and empirical findings. In particular, this earlier work identifies a set of questions, in the form of alternative propositions, that were prominent in all of the industry studies.

The broad questions that guided our work and discussion can be divided roughly into four groups. One was concerned with the factors behind industrial leadership. A second explored the locus of leadership, be it the nation-state, individual firms, or intermediate structures, such as the region or industry-specific institutions. A third set of questions was concerned with the dynamics of industrial leadership and the evolution of industry structure. Finally there were questions about the roles of public policy in the establishment and maintenance of national industrial strength. In our later discussion of these questions, we note supportive empirical evidence from the following chapters, but more detailed discussion of these issues is found in the individual industry studies and in our concluding chapter.

A. Critical Factors Behind Industrial Leadership

Resources. From the beginnings of modern economic analysis, economists have seen the sources of comparative advantage as residing, at least in part, in differences across countries in the availability of the inputs needed in different lines of economic activity. Economists such as David Ricardo, writing in an era when agriculture dominated economic activity, stressed such matters as climate and land quality. As manufacturing became increasingly important, analysis of the sources of comparative advantage shifted to focus on the quality and price of inputs into manufacturing. Both British and Continental economists understood that the skills of its domestic labor force helped explain British dominance of many areas of manufacturing in the mid-19th century. A number of economic historians have identified the availability of university-trained research chemists as an important factor in German firms' ascendancy in dyestuffs in the late 19th century (see, e.g., Beer, 1959).

The general theoretical propositions put forth by economists about the contributions of differences in broadly defined factor endowments

(such as the prices of "capital" and "labor") to comparative advantage require considerable refinement to explain the development of the industries covered in this volume. Factor endowments do appear to be important in many of these industries, but these endowments typically include factors (e.g., abundant deposits of petroleum, chemical engineers, public expenditures on industry-specific R&D) that are highly specific to individual industries. In particular, industry-specific labor skills play a major role in the shifting locus of industrial leadership in a number of our cases.

Institutions. Although the quality and prices of factors of production always have been a part of the economists' theory of industrial leadership, institutions also have played a role. The availability in Germany of university-trained chemists rested on a domestic university system that by the middle of the 19th century was the world's strongest in the training of physical scientists. Recent explanations for the rise of Japanese firms in the production of automobiles and consumer electronics have stressed firm organization, interfirm linkages, and Japanese labor and financial institutions (Aoki, 1990; Womack et al., 1991). The U.S. domestic venture capital industry undoubtedly has contributed to U.S. leadership in semiconductors, computer software, and pharmaceutical biotechnology.

As these examples indicate, the distinctions between analyses of industrial leadership that focus on resource endowments and analyses that focus on national institutional differences are blurry and often reflect different perspectives on the same phenomena. Thus the factors singled out in the "resource-based" analyses, such as an abundant supply of highly skilled labor or risk capital, are identified in the institutional discussions as effective universities or financial systems.

Markets. Much of the institutional analysis is concerned with the characteristics of national or regional markets for inputs and outputs. A considerable body of work argues that suppliers and their customers within a nation, region, or some other form of network tend to work with each other and thereby strengthen their capabilities.

Some of this work (Porter, 1990; Lundvall, 1992) argues that intensive interaction with demanding, knowledgeable customers and users improves the innovative and competitive performance of their suppliers. Another important factor in the development of industries characterized by high fixed costs (e.g., high R&D costs) is the scale of domestic market demand, which may enable producers to achieve lower unit costs and thereby provide an "export platform" (see, e.g., Krugman, 1987). This

phenomenon has been cited in analyses of postwar Japanese protection of domestic markets for semiconductors or computers and forms the basis for criticism of the postwar policies in many Western European nations that favored domestic "national champions" in such areas as defense and telecommunications.

The influence of international differences in the profile of market demand on industry evolution is highlighted by our cross-industry, cross-national framework. Virtually all accounts of the rise to dominance of the American semiconductor and computer industries, for example, emphasize the procurement and R&D policies of the U.S. Department of Defense. As we noted earlier, the particularities of national markets had a profound effect on the development of machine tools in different countries. The inventive efforts of medical device producers in some cases were influenced by the diseases prominent in the producers' countries. Our industry chapters detail these and many other examples.

Technology. Simple Heckscher–Ohlin trade theory assumes that technology is the same in all firms in all countries, but empirically oriented economists long have understood that firms and national complexes of firms differ in their access to and command over technology. Product cycle theory (Vernon, 1966; Posner, 1961) postulates that firms focus their innovative efforts on products that meet the profile of consumer demand in their domestic market. Trade theory also stresses the advantages to "first movers" in the commercialization of technological advances, in part because of the nonconvexities produced by high fixed costs.

Given the nature of the industries in our study, it is hardly surprising that differences in the technological capabilities of firms and national groups of firms figure prominently. But in explaining industrial leadership, differences in technology may be hard to distinguish from differences in resource availabilities (such as highly trained research workers), or institutions (a strong university system), or a domestic market for advanced products that is largely closed to foreign imports.

B. The Locus of Industrial Leadership

As we noted earlier, the industries included in this study display considerable variation in the locus of industrial leadership and differ in the frequency of shifts in such leadership. In this section, we consider alternative explanations for the persistence of industrial leadership at the level of the firm, the nation-state, or some intermediate unit of analysis (e.g., the region).

The Nation-State. Economists traditionally have viewed comparative advantage as defined by features of the nation-state. Thus, Ricardo focused on major differences in soil and climate between England and Portugal. Most theories that focus on institutional differences presume that such differences are international, not intranational or regional in scope. Both product cycle theory, which we will consider shortly, and the new trade theory see the technological possibilities available to firms as essentially defined by their national environment. "Reserved markets," i.e., domestic markets that are protected against foreign competition by tariff or nontariff barriers, are another example of a national, rather than a firm-level, influence.

Most theories of national comparative advantage assume that the discretionary behavior of firms or differences among national firms in their competitive or technological capabilities account for little. Given national factor availabilities and institutions, firms that are in the right industry succeed, and firms that are in the wrong industry do poorly or fail. As we note later, this assumption often but not always is belied by history.

Firms. These presumptions, of course, contrast with the view that the principal determinants of competitive performance are the firm's strategy and structure, to use Alfred Chandler's (1962) terms, which are based on investments in R&D, production, marketing, and management (see Teece, 1993). In the simplest and starkest version of the firm-based explanation, differences in national conditions, be they factor availabilities or institutions, disappear from view. Thus, the Womack et al. study (1991) of the automotive industry emphasizes firm-level differences, and the authors argue that American firms could attain the performance of Japanese firms by emulating their product-development, manufacturing, and labor policies.

More complex versions of this theory incorporate factors external to the firm, blending national and firm-level influences into their explanation. For example, Chandler (1990) recognizes that the large scale of the American market during the late 19th and early 20th centuries meant that U.S. firms operated in a domestic market that differed fundamentally from that faced by British firms. Scholars like Aoki (1990) stress that broader Japanese institutions – especially those associated with finance and employment – sustain and support the particular managerial and organizational characteristics of Japanese firms. Nevertheless, all of these authors argue that there is considerable room for discretionary behavior of firm managers, whose decisions influence competitive performance and, ultimately, industrial leadership.

Regions, Networks, and Sectoral Support Systems. Still other theories identify the locus of industrial advantage in structures that are larger than the individual firm, but smaller than the nation-state. Alfred Marshall (1948, originally published 1890) identified the complex of institutional structures associated with the "industrial district" as an important factor behind British preeminence in textiles. The industrial district of Marshall, Krugman (1991), Harrison (1992), Piore and Sabel (1984), or Saxenian (1994) includes a collection of firms that compete with each other for customers, but that also cooperate in certain ways, for example, in establishing standards and in collectively supporting institutions that train specialized labor. The district also contains firms that provide specialized or custom inputs and machinery, as well as those providing various financial and brokerage functions.

Most "industrial district" theories argue that a region defines a network, but networks do not always require geographical proximity. For example, the widespread links between 19th-century German chemical companies and German university chemists often connected a professor with his former students – no regional connection necessarily existed. Similarly, important links between university researchers and U.S. biotechnology firms are not always regionally focused (Audretsch and Stephan, 1996). The connections, rather than geographical proximity, are the focus of attention in various studies of the alliances between new biotechnology firms and established pharmaceutical companies that have been involved in R&D and commercialization of several new pharmaceuticals (see Powell et al., 1996). The networks of firm connections that extend from Stanford and MIT include not only firms in Silicon Valley in California, and on Route 128 near Boston, but also firms in Europe and Japan.

We argue that these networks, whether regional or not, influence the emergence of what we call sectoral innovation systems. In addition to the firms in the industry, and their suppliers and customers, such sectoral innovation systems often include the following: specialized labor markets and training institutions; specialized financial intermediaries; professional and industry associations; close links with certain university departments and schools; specialized regulatory structures and other bodies of law tailored to the industry; and government support programs. These sectoral innovation systems differ across industries, but also frequently are very different from country to country for a given sector (see Carlsson, 1989; 1997).

Government policy has influenced the development of many of these industries through its support (intentional or otherwise) for the creation and growth of sectoral innovation systems, structures that include

industry-specific networks of institutions, regulatory policies, and R&D infrastructure. The R&D and procurement programs of the U.S. Defense Department contributed powerfully to the entry of new firms into the semiconductor industry, the growth of university–industry research linkages in the computer and electronics industries, and the creation of the academic discipline of computer science. The extramural research support of the U.S. National Institutes of Health helped create competitive firms and strengthened links between academic and industrial researchers in biotechnology. Japan's Ministry of International Trade and Industry provided support of a rather different sort, which incorporated lower levels of public R&D spending, for Japanese firms in the electronics and computer industries.

In view of the globalization and the significant cross-border flows of technological knowledge that are apparent in several of the industries analyzed in this volume, the continuing importance of national or sectoral innovation systems may surprise some readers. Yet these industry studies strongly support the continuing importance of such systems, without denying the realities of increased international interdependence in virtually all of these industries.

C. Dynamics

Although economists often express their theories of comparative advantage in static terms, many of the key variables in those theories, such as resources, institutions, or technologies, change over time. A number of theories examine changes in the nature of a technology, in firm and industry structure, and in supporting institutions as a technology matures. These theories in turn yield several different views of the dynamics of industrial leadership that are germane to our industry studies.

Technology Life Cycle Theory. One group of theories suggest a systematic pattern of change in a technology, an industry, or both as the technology evolves from novelty to maturity. Abernathy and Utterback (1978) are the names most frequently associated with the theory that states that the early days of a technology are characterized by many competing variants. As technological progress proceeds, however, a dominant design emerges, and the focus of technological effort shifts from product design to production process, and production becomes increasingly capital and scale intensive.

Mueller and Tilton (1969) and more recently Klepper and Grady (1990), Utterback (1994), and Klepper (1996) argue that the maturation