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Preface

The research project on *Systems Analysis of Technological and Economic Dynamics* at IIASA is concerned with modeling technological and organisational change; the broader economic developments that are associated with technological change, both as cause and effect; the processes by which economic agents – first of all, business firms – acquire and develop the capabilities to generate, imitate and adopt technological and organisational innovations; and the aggregate dynamics – at the levels of single industries and whole economies – engendered by the interactions among agents which are heterogeneous in their innovative abilities, behavioural rules and expectations. The central purpose is to develop stronger theory and better modeling techniques. However, the basic philosophy is that such theoretical and modeling work is most fruitful when attention is paid to the known empirical details of the phenomena the work aims to address: therefore, a considerable effort is put into a better understanding of the 'stylized facts' concerning corporate organisation routines and strategy; industrial evolution and the 'demography' of firms; patterns of macroeconomic growth and trade.

From a modeling perspective, over the last decade considerable progress has been made on various techniques of dynamic modeling. Some of this work has employed ordinary differential and difference equations, and some of it stochastic equations. A number of efforts have taken advantage of the growing power of simulation techniques. Others have employed more traditional mathematics. As a result of this theoretical work, the toolkit for modeling technological and economic dynamics is significantly richer than it was a decade ago.

During the same period, there have been major advances in the empirical understanding. There are now many more detailed technological histories available. Much more is known about the similarities and differences of technical advance in different fields and industries and there is some understanding of the key variables that lie behind those differences. A number of studies have provided rich information about how industry structure co-evolves with technology. In addition to empirical work at the technology or sector level, the last decade has also seen a great deal of empirical research on productivity growth and measured technical advance at the level of whole economies. A considerable body of empirical research now exists on the facts that seem associated with different rates of productivity growth across the range of nations, with the dynamics of convergence and divergence in the levels and rates of growth of income, with the diverse national institutional arrangements in which technological change is embedded.

As a result of this recent empirical work, the questions that successful theory and useful modeling techniques ought to address now are much more clearly defined. The theoretical work has often been undertaken in appreciation of certain stylized facts that needed to be explained. The list of these 'facts' is indeed very long, ranging from the microeconomic evidence concerning for example dynamic increasing returns in learning activities or the persistence of particular sets of problem-solving routines within business firms; the industry-level evidence on entry, exit and size-distributions – approximately log-normal – all the way to the evidence regarding the time-series properties of major economic aggregates. However, the connection between the theoretical work and the empirical phenomena has so far not been very close. The philosophy of this project is that the chances of developing powerful new theory and useful new analytical techniques can be greatly enhanced by performing the work in an environment where scholars who understand the empirical phenomena provide questions and challenges for the theorists and their work.

In particular, the project is meant to pursue an 'evolutionary' interpretation of technological and economic dynamics modeling, first, the processes by which individual agents and organisations learn, search, adapt; second, the economic analogues of 'natural selection' by which interactive environments – often markets – winnow out a population whose members have different attributes and behavioural traits; and, third, the collective emergence of statistical patterns, regularities and higher-level structures as the aggregate outcomes of the two former processes.

Together with a group of researchers located permanently at IIASA, the project coordinates multiple research efforts undertaken in several institutions around the world, organises workshops and provides a venue of scientific discussion among scholars working on evolutionary modeling, computer simulation and non-linear dynamical systems.

The research focuses upon the following three major areas:

1. Learning Processes and Organisational Competence.

2. Technological and Industrial Dynamics

3. Innovation, Competition and Macrodynamics

I Introduction

This is a preliminary report on a comparative study of how several major "high tech" industries evolved in the United States, Japan, and in Western Europe. At the most general level, the inquiry is about the ways in which the development of these industries was similar, and different, in the different countries, and the factors explaining the differences. I and my colleagues are especially interested in understanding the factors behind instances where firms in a particular country gained a significant competitive advantage over firms based in other countries.

The study presently includes seven industries: organic chemical products, computers, software, semiconductors, numerical controlled machine tools, pharmaceuticals in the age of biotechnology, and medical devices[1]. The birth of several of these industries was associated with the opening up of a major new technology. In each technological advance has been rapid, and

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[1] The authors of the industry chapters are:

Chemical products: Asish Arora and Nathan Rosenberg
Computers: Timothy Bresnahan and Franco Malerba
Semiconductors: Richard Langlois and Edward Steinmueller
Software: David Mowery
Numerical controlled machine tools: Roberto Mazzoleni
Pharmaceuticals in the age of biotechnology: Rebecca Henderson, Luigi Orsenigo, and Gary Pisano
Medical devices: Annetine Gelijns and Nathan Rosenberg

In addition, a number of other scholars are participating in the project as general discussants and contributors.

competition has involved innovation in a central way. The industry studies presently are far from completed, and thus I can not report on them in any detail. However, I can lay out some of the general analytic perspectives that have guided the studies, and provide some illustrations drawing from the industry cases.

Obviously one basic premise is that industries can be regarded as evolving in some meaningful sense. But just what does one mean when one says that something evolves? (For a general discussion of this issue see Nelson, 1995). Our interpretation in this study is that industry development involves both random elements that generate and perhaps sustain variety, and systematic shaping forces. But then the issue arises as to what the systematic forces are and, relatedly, what aspects of an industry evolve systematically.

The study also obviously is committed to the presumption that an industry can and does evolve in different ways in different settings, in particular in different countries. But if, in fact, one does observe strong differences, what lies behind them? Are there factors that systematically vary across countries that shape these differences? If so, what are they, and are they the same or different for different industries? Alternatively, might the differences be due to differences in the firm and industry structures that just happened to arise in particular countries, with country differences at a higher level having no particular shaping influence? But if this is the explanation, what explains why a characteristic whose source was to some extent random proved durable?

I explore some of these questions in Section II and III, and give an indication regarding what the industry studies suggest regarding them. Then, in Section IV, I speculate on some of the more general patterns that appear to be emerging in the industry studies.

II Industry Evolution

To say that an industry evolves can carry a number of connotations. At the most basic level, it suggests a dynamic process in which both random and systematic elements matter, with the latter in effect "selecting" on the former. However evolution sometimes also carries the connotation of development, of systematic changes occurring as an entity, in this case an industry, gets older. Some theories about path dependent evolutionary processes propose that, while which particular variant initially is selected involves an element of chance, that initial defining event can influence strongly the whole future path of evolution. There is development, but the particular path of development is shaped by random as well as systematic forces.

If one entertains the developmental connotation, one can ask what aspects of an industry change systematically? And what systematic development patterns do they go through? In our study we are focussing on three different but strongly interdependent aspects: technology, firm and industry structure, and supporting and constraining laws, policies, and institutions. In an earlier article in ICC (Nelson,1994) I discussed some of the recent research by economists and other social scientists on these aspects of industry evolution. Below I concentrate on what our seven industry study seems to suggest about them.

The Evolution of Technology

Twenty years ago, Abernathy and Utterback (1978) put forth a theory of the natural evolution of a broad technology that has attracted many adherents. Under that theory, when young a technology is tried out by different parties in a variety of different versions. Each is relatively clumsy. There is no consensus among technical people, entrepreneurs, or potential users regarding what version is or will be the most successful. Relatedly, the market for the products embodying the technology is at once small, and fragmented.

According to this broad theory, with time and effort one or more of the variants gets improved enough to attract a more sizeable market. A number of authors have argued that a single broad dominant product design tends to emerge, with some product differentiation but a great diminution of the variety that existed earlier (Abernathy and Utterback, 1978, Tushman and Anderson, 1986). Product improving technical advance then becomes much more focussed, and incremental. Under some versions of the theory efforts at improving technology tend to shift towards process R &

D.

There are several different theories about the emergence of a dominant design. Under one, the best variant simply comes to be found. Under another, a chance concentration of R & D efforts on a particular broad design results in improvements that make it dominant, and raise the hurdles for other designs to sufficient heights that efforts at advancing them simply are abandoned. In the parlance of modern economics, this is a "dynamic increasing returns" story.

Other dynamic increasing returns stories stress systems aspects. The focus is on interaction economies that may occur when the number who own and use a particular variant grows, or as skills develop that are particular to a certain variant, or investments are made in complementary products designed to fit with a particular variant. (See, e.g., David, 1985, 1991, Arthur, 1989, and Katz and Shapiro, 1994). While sometimes used more generally, the special term "standard" tends to be used to denote the key mechanism or configuration that defines and delineates the dominant "system" when it emerges. As the authors writing in this field argue convincingly, which particular standard emerges and, in effect, "locks" in the system, may be a matter partly of chance.

When Abernathy and Utterback first spun out the dominant design story, they based it on detailed observation of only one industry - automobile manufacturing. Since that time the basic story line has been tried, and found fitting, in a wide range of industries. (See in particular the work of Tushman and colleagues, 1985, 1986, and by Utterback and Suarez, 1993). Some writers clearly believe it is universal. I confess some skepticism about that. The story seems to fit best industries where the product is a "system", and where customers have similar demands.

In the industries in our study, there is evidence of the emergence of a broad market encompassing dominant design in computers, semiconductors, and, with modifications discussed below, numerical controlled machine tools. However, even in these cases, the life span of a particular dominant design has been limited. The markets for organic chemical products, pharmaceuticals, and medical devices, are extremely variegated and no single design meets all needs. There is no evidence of broad dominant designs in these fields. Software needs to be tailored to particular applications, although there certainly is a systems compatibility constraint that binds different programs together.

The case of numerically controlled machine tools illustrates some of the difficulties and complexities of the dominant design concept. Numerical control originally was conceived as a way to bring precision to complex machining operations. The first generation of numerical controlled tools were designed with that end in mind, and was extensively used in producing aircraft. However another use of numerical control turned out to be in flexible manufacturer. The market became divided between tools specialized to these two very different kinds of demand.

Also, while technology life cycle theories tend to posit that each industry goes through one cycle - from infancy to maturity as it were - in most of the industries in our study there are episodes where, after the technology appeared to have settled into a groove, there was a revolution. This is particularly striking in computers, whose underlying technologies changed radically with the advent of the integrated circuit, and again with microprocessors. The basic circuitry of numerical controlled machine tools for flexible manufacture has shifted from closed loop to open loop and back again. The technology of many medical devices has been revolutionized by advances in microelectronics, and fiberoptics. Biotechnology is revolutionizing the technology of pharmaceutical R and D.

Put another way, to the extent that there are periods when a technology appears to be moving towards some kind of an equilibrium or along an equilibrium trajectory, that equilibrium is not forever. Perhaps the appropriate concept is that of punctuated equilibrium. And, in our industries at least, the periods of punctuation - when the technology is changing from one pattern to another - often are marked by shifts in the locus of industry leadership.

The Evolution of Firm and Industry Structure

Which brings me to the second aspect of industry evolution we are studying - changes in firm and industry structure over time. Here, as with technology, there is a body of theorizing which posits a standard pattern of evolution. Or, rather, we have two bodies of theory, one in economics, and the other in organization theory.

The line of theorizing in economics basically begins with Mueller and Tilton (1969). After more than a decade of little follow on, in the 1980s Gort and Klepper (1982) and Klepper and Grady (1990) developed the empirical and theoretical argument further. Utterback (1994) has added significantly to the presentation. The basic propositions are these. During the early period of experimentation and flux, before a dominant design emerges, there are no particular advantages to incumbency. Market demand is fragmented across a number of variants. Firms producing particular designs tend to be small. Model change is frequent. There is a considerable amount of exit from and entry into the industry.

However, after a dominant design becomes established, firms that do not produce a variant of it tend to drop out of the industry, or into small niche markets. With product design more stabilized, learning by incumbent firms becomes more cumulative, and potential entrants increasingly are at a disadvantage. With the market less fragmented and more predictable, firms try to exploit latent economies of scale, and advances in process technology both reflect and enforce this. Generally scale intensive technology is capital intensive as well, and so the cost of entry rises for this reason too. There is "shake out" in the industry and structure becomes more concentrated, with the surviving firms tending to be relatively large.

Organizational theorists will recognize, of course, that a theory with the same domain, and with many of same conclusions, has grown up among scholars studying the evolution of populations of organizations. Here, however, the connections with hypothesized patterns of technological evolution tend to be weaker, or at least less well articulated. And the key concepts are quite different (see Hannan and Freeman, 1990, and Carroll and Hannan, 1995). These include the disadvantages, in terms of access to external resources and support, of firms trying to work in new areas, the "legitimation" of such activity with time and as the number of firms engaged in it grows, the gradual institutionalization of ways of doing things in a field, and the crowding of the field which ultimately slows entry.

In my view, rather than being at odds, the economic and sociological theories about the evolution of firm and industry structure are quite complementary. Their story lines combine nicely rather than clashing.

But while the story is coherent, as with the theory about dominant designs, one can question how universal is the proposed pattern of industry evolution. The empirical work by Gort and Klepper (1982) and Klepper (1993) show that the basic story does seem to fit a wide range of industries in the U.S. Utterback and Suarez (1993) and Utterback (1994) similarly claim widespread applicability. However, there certainly are exceptions.

These exceptions include several of the industries in our study. Thus while a few software giants have grown up, the industry continues to include many small firms, and entry and exit continue at a rapid pace. Many small companies coexist with a few large ones in the medical devices industries, and new devices often continue to be introduced to the market by new small companies. As noted, in computers the advent of radically new component technologies has set in train bursts of new entry in an industry that prior to these developments had seemed to be stabilizing. Machine tools continue to be made by a large number of small firms, although a few large ones exist. Only in chemical products and semiconductors does the theory seem to fit tolerably well, but even here entry by companies in countries that previously had no presence in the industry continues to occur.

Also, virtually all of the studies mentioned above have been focussed on the United States. One of the interesting questions being probed in the present study is whether there are significant differences across countries in the pattern of industry evolution. There definitely seems to be. For one thing, the evolution of industry structure in the United States appears to involve the entry of new firms when technology changes radically to a much greater extent than in Japan or Europe. There also are other interesting differences. More on this later.

Theorizing about the evolution of firm and industry structure has not, in general, considered the question of the degree of vertical and horizontal integration of activities within firms, or the extent to which division of labor develops between firms. Probably George Stigler's argument (1971) on this, put forth many years ago, is the most familiar to economists. He proposed that the natural tendency was for an industry to move from an initial situation where firms did a wide variety of things "inside" because, in effect, there were no "outside suppliers", to one where there was more division of labor. On the other hand, it can be argued that, as a technology matures and sales of a product grow large, there may be gains to a firm from specially tailoring a product system, which may lead it to take more of the component design and production inside.

Perhaps the best example of the Stigler story revealed in our case studies is the rise of specialized chemical process plant designers and builders that occurred during the 1930s, and has been specially important since World War II. An important consequence has been the unifying of process technology among chemical product firms, regardless of their nationality.

Langlois and Robertson (1995) develop a more complex theory than Stigler's. Their focus is on the trade off between the advantages of coordinating technical change that a single organization can achieve, and the advantages of being able to choose from a wide menu that is preserved if one does not try to integrate. The history of the computer industry reflects this more complex story. The major producers of main frame computers originally did inside a lot of their component design and production, including their software. In the U.S. IBM came to unbundle software during the 1970s, leading to the rise of an independent software industry in the U.S. Partly this was forced by anti trust pressure. But partly it occurred because specialized software designers turned out to be better than IBM at certain things. In any case, unbundling did not happen to anything like the same extent in Japan or Europe.

The major computer companies originally tended to produce their own integrated circuits. But the development of strong innovative companies producing and selling integrated circuits, and later microprocessors, led in the United States - less so in Japan and Europe - to computer companies that bought these components from others, rather than producing them themselves. This is the hallmark of P.C. production where even IBM buys components from outside. Again, this development has been less sharp in Japan and Europe.

The Evolution of Supporting Institutions

Firms do not stand by themselves, of course, but rather in a context in which they compete with rivals, sell to customers, are served by suppliers, and draw on particular talents and skills. For an industry with special input and skills needs, expansion in size and effectiveness is strongly conditioned by how rapidly and effectively a support structure providing these grows up. Some industries have special financing needs, and expansion requires that mechanisms arise to service these. While many of these ancillary developments proceed through market or market like mechanisms, a society's institutions -- both general and specific to the broad sector that contains the developing industry -- will of course influence the process.

From one point of view, one can regard a nation's broad institutional structures as basically a given and constant, and consider how these helped or hindered the evolution of the industry's support structure. Where one is observing the same industry growing up in different countries, a central question of interest is whether broad national institutional differences made a real difference in how, and how effectively, the industry evolved.

But from another point of view, particularly if one homes in on institutions specific to particular industries, the question is how various features of the institutional environment themselves adapted and changed in response to pushes and pulls exerted by the development of the new industry. Thus the development of an effective system of labor training, the establishment of product standards, and the emergence of customary patterns of interaction between firms, suppliers, and customers, and across firms in the industry, often require the creation of new informal and formal organizations. As these form people become conscious that there is a new industry, and that it has collective interests and needs (See, e.g. Granovetter, 1985). Industry or trade associations form. These give the industry a recognized organization that can lobby on its behalf for regulation to its liking, for protection from competition from outside the group, for public programs to support it, etc. This is another feature of an industry's evolution that can lock in the status quo.

Quite often when a new technology comes into existence, there is little scientific understanding relevant to it. However in many cases the presence of the new technology then induces scientific research to understand it, and lay the basis for its subsequent development. The result may be the creation of a new scientific field related to that technology (See Nelson and Rosenberg, 1993). Thus, to draw some examples from our comparative industry study, the field of chemical engineering came into existence in the United States to meet the demands of the new chemical products industry. Computer science was brought into existence by the advent of the modern computer.

Recognition of the role of new academic disciplines in supporting a new technology points attention to another aspect in which national differences may be significant. The ability of the new industry to grow up strong in a country may depend on the prevailing strength of university research and training in the relevant underlying fields. It also may depend on the speed and effectiveness with which the national universities build up strength in the new relevant fields. Our industry case studies show both kinds of national differences at work.

There almost always are issues regarding the setting of standards. The nexus involving computer hardware design, and software, is a prominent example. There may be intellectual property rights issues that need to be sorted out - biotechnology is a striking contemporary case in point. There almost always ar issues of regulation; again, biotechnology is an important case in point. In many cases new public sector activities and programs are involved. Numerically controlled machine tools were brought into existence by the U.S. Department of Defense to meet its needs. The military was the early major source of research funding for computers, and they provided most of the early market. The spread of computers in the U.S. greatly benefitted from the advent of internet, nudged into place by the Department of Defense.

These examples indicate that the evolution of institutions relevant to a technology or industry may be a very complex process, involving not only the actions of private firms, but also organizations like industry associations, technical societies, universities, courts, government agencies, legislatures, etc. The "new institutional economics" started with a broad theoretical stance that, somehow, institutions changed optimally (if perhaps with a lag) in response to changes in economic circumstances that called for those changes. Recently however scholars are beginning to highlight the interest group conflict over government policies in a field, and the strong sensitivity of outcomes to political structures and processes. (See, e.g., North, 1990, Shepsle and Weingast, 1981, and Cohen and Noll, 1991). Not only is there an abandonment of the assumption of "optimality" of institutional response; there now is recognition that such developments are strongly path dependent, and that one needs a process model to predict and understand what the institutional accommodations will be. It is sure that the way the process works, and institutions evolve, differ from country to country.

III Theories of the Sources of Comparative or Competitive Advantage

The foregoing discussion leads naturally into consideration of the reasons why an industry might evolve differently in different countries. One answer is that, where one observes significant differences, the reason resides in particular characteristics of the different countries. There is a long standing tradition in economies of seeing the sources of comparative advantage in country level variables. On the other hand, another strand of theorizing down plays the relevance of this line of causation, and stresses the importance of the firms that happened to take hold in different countries. From this point of view, countries are strong in certain industries because their firms are strong, rather than because of any broad national features. Still other theories place the emphasis on structures smaller than a country but larger than individual firms.

National Level Variables

From at least the time of Adam Smith, economists have tended to see the factors influencing industry performance as residing at the level of the nation. Earlier versions of the theory of comparative advantage (for example David Ricardo's) stressed differences across nations in climate, or the fertility of land, or natural resources. Later, the body of theorizing that got systematized in what came to be called Heckscher-Ohlin theory focused more generally on differences across nations in the relative supplies of basically immobile factors of production, and in the differences in factor prices that were the consequence of different factor endowments. In its simplest standard version, Heckscher-Ohlin repressed, or denied, differences in technological capabilities among firms in different countries. Rather, the focus was on the different choices that firms would make among general available technologies as a function of differences in market conditions across countries.

Of the industries in our study, only Chemical Products is strongly dependent upon natural resource inputs. Here Germany, which took the lead towards the end of the 19th century, was abundantly endowed with coal which was the principal feed stock for the new dyestuffs and related new products, but several of her potential competitors also were well endowed with coal. The U.S. industry clearly was advantaged when, in the 1930s, the feed stock shifted to petroleum. However, with the advent of low cost oil shipping, that advantage dissolved. In none of our industries do large relative factor price differences seem a likely powerful reason for inter country differences. However in several industries particular differential skill availabilities did seem to matter. I will return to this issue shortly.

The "product cycle" and related theories of international trade break from the assumption that technological capabilities and abilities are the same across countries, but stay with the broad assumption that, whatever it is that gives an industry a particular advantage in the development and implementation of new technology, these factors reside at the national level (see Dosi, Pavitt, and Soete, 1990). Thus in some treatments the key factor is a relatively large supply of people with a high level of scientific and engineering education. That factor is complemented, in some theories, by the proposition that particular national markets are willing to pay high prices for new products, or to subsidize their creation. In the case of our industries, several scholars have proposed that the rise to dominance of the German chemical products industry at the end of the 19th century was due to Germany's large supply of chemists (see e.g. Beer, 1959) . The U.S. advantage in the creation of software probably was facilitated by the availability of people trained in programming, plus the large stock of computers, first main frame, and later personal computers, in the U.S. The early U.S. dominance in computers has been ascribed, at least partially, to the market for computers provided by the American military, which called into existence technologies which later proved commercially relevant.

For the purposes of discussion here, I want to highlight a view on the sources of national comparative advantage that is at once new and very old, that focuses on national institutions. Thus the differences in the availability of trained people, mentioned above as an explanatory factor, itself needs to be explained. Landes (1980) and Beer (1959) have proposed that the basic reason why Germany, and not Great Britain, gained early comparative advantage in the then new chemical products industry, was the strength of German university research and training. The availability of trained chemists for German industry was a direct consequence of the strength of the German university system. Recent analyses of the reasons why the U.S. has such strength in software and biotechnology stress the research and training capabilities and responsiveness to industrial demands of the American university system.

Other scholars have proposed that other kinds of national institutions make a big difference. In our study we have considered, among other factors, the effects of different national financial systems, and different broad policies regarding competition. The presence of a venture capital market in the U.S., and the apparent absence of its equivalent in Japan, Germany, and other industrial nations, almost certainly is part of the reason why the beginnings of a new industry in the U.S. often has been marked by the birth of small firms, to a far greater extent than in other countries. The differences between the U.S. and elsewhere (except possibly the U.K.) in biotechnology is striking. Similarly, the advent of new technologies opening up new possibilities for computers has spurred entry of new firms in the U,S., much more than elsewhere.

The effects of the unusually strong U.S. anti trust policy also show up clearly in several of the comparative industry studies. Thus during the interwar period, in Germany and the U.K., firms in the chemical products industry tended to merge, often encouraged by government policies. In the U.S. such mergers were basically ruled out by anti trust. As a result, the U.S. was marked by greater intra market diversity and competition among firms. The unbundling of computer hardware and software in the U.S. was first forced by anti trust action against IBM.

The scholars working on the project have discussed whether differences in corporate law, or intellectual property rights law, seem to have affected the development paths taken by the industries in different countries. While the questions are still quite open, my judgment call is "probably not much".

On the other hand, differences in regulatory regimes may well have made a difference in biotech, and in medical devices. But the evidence here is not yet very solid.

Capabilities Residing within Firms

A striking feature of the theories of national comparative advantage discussed above, whether the focus be on resource endowments and prices, or institutions and laws, is that little room is left for discretionary behavior of firms, or differences in firm competencies. Given national factor availabilities and institutions, firms that are in a "right" industry succeed, while firms that are in the "wrong" industry do poorly or fail.

The presumptions contained in the above theories stand in sharp contrast to those put forth by Business School scholars, to the effect that the principal determinant of whether a firm succeeds is its own strategy and structure, to use Chandler's (1990) terms, and the investments it makes in R and D, production, marketing, and management. (For a fine review, see Teece, 1993.) In the simplest and starkest version of the theory, differences in national conditions, be they factor availabilities or institutions, disappear from view. Thus in the Womack et al study (1991) of why Japanese automobile firms were doing better than American ones, the emphasis was totally on firm level differences, and the authors argue explicitly that American firms, if they chose, could do just what the Japanese were doing and do it as well.

There are more complex versions of this theory that do recognize factors outside of individual firms. Thus Chandler (1990) recognizes that a very large scale of the American market during the late 19th and early 20th century provided a different environment for American firms to develop in than that faced by British firms. Scholars like Aoki (1990) stress that broader Japanese institutions - in particular those associated with finance and employment - sustain and support the particular managerial and organizational characteristics of Japanese firms. However, all of these authors argue, explicitly and emphatically, that there is considerable room for discretionary behavior on the part of firm managers, and that what firms do within these discretionary bands is a major, perhaps the major, determinant of how they do competitively.

In support of this theory it can be argued that, while the special American military demand for computers gave IBM the R and D and production experience it later used successfully to enter and dominate the non-military market, IBM itself took very great risks and developed a strategy and organization that, for many years, proved unbeatable on civilian markets. While the German chemical products companies at the end of the 19th century certainly were advantaged by the availability of many well trained young chemists, these companies themselves took the risk and made the investment in establishing industrial research and development laboratories. In doing so, they were venturing onto new ground.

As the above examples suggest, it may be hard to separate clearly the effects of national economic environmental factors, from the advantages firms gain through their own initiatives. When IBM involved itself in work on computers for the U.S. D.o.D. during the Korean war, its own judgements were that the commercial market for computers was very limited. But IBM clearly was far ahead of its competitors when, somewhat later, it developed a better sense of that market and how to serve it. In the 1920s firms in the U.S. faced lower cost petroleum supplies than firms in Europe. But U.S. chemical companies, in alliance with researchers at places like MIT, took the risks and made the needed investments for moving from coal to petroleum based production.

On the other hand, our industry histories are full of instances of firms who were very strong working with one basic technology or catering to one market, not having the capability to adjust when the technology or the market changed, or new opportunities opened up. In some of these cases the rigidity of the firms seems to have had a lot to do with the structure of their supporting institutions. Thus U.S. machine tool firms were not able to see clearly much less seize the big market for flexible manufacture, largely because they were focussed on the precision machining market of defense procurement.

In any case, it probably is misguided to think of the lines of causation between firm behavior and the economic environment in which firms reside as flowing strictly from the latter to the former. MIT was brought into existence in the late 19th century with the funding of Massachusetts businessmen who were dissatisfied with the training being offered at Harvard.

Regions, Networks, and Sectoral Support Systems

Still other theories identify the source of competitive advantage in structures smaller than a national economy, but larger than the individual firm. Thus Michael Porter (1990) proposes that where one observes strong competitive advantage of firms of a particular nationality, one tends to find a number of such firms competing aggressively with each other. One also tends to find, according to this theory, strong input suppliers, and demanding customers. While Porter notes that such clusters often are associated with particular geographical regions, he does not stress this. On the other hand, Paul Krugman (1991), developing a theme introduced many years ago by Alfred Marshall, has focused explicitly on geographical concentrations.

The industrial district of Marshall, or Krugman, or Harrison (1992), or Piori and Sabel (1994), includes a collection of firms who compete with each other for customers, but who 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, and those providing various brokerage functions.

Annalee Saxenian's study (1994) of electronic firms, particularly those producing computers, in Silicon Valley locates the source of their competitive advantage in the network contained in Silicon Valley. In her story, it is the people in the valley, and their connections, that provide the strength. Firms at any time are simply collections of these people who happen to be working on a particular project under a particular management. She offers little discussion of the question of whether Silicon Valley needs to be understood as a particularly American phenomenon. In any case, her stress is on Silicon Valley, rather than particular firms, or the United States as a nation-state, as the source of competitive advantage for the firms that reside there at any time.

In such analyses, sometimes the focus is on the geographical region, with an emphasis on proximity, and sometimes on the network, with an emphasis on connections. Saxanian's focus clearly is on the region. On the other hand, in the case of the German chemical companies that grew up in the late 19th century, various authors have emphasized their links with chemists in German universities. In some cases, these links were those of a professor with his ex students. Similarly, in various accounts of the rise of the U.S. biotech firms, ties between university and company researchers are stressed. Geographical proximity facilitates these connections, but it is the network that is the center of analytic attention.

It is the connections, not geographical proximity at all, that are the focus of attention in various studies of the sources of strength in the alliances between new biotechnology firms, and established pharmaceutical companies, that have been involved in R and D and commercialization of several new pharmaceuticals. (See e.g. Powell et al, forthcoming.) The network of firm connections that extend from Stanford, and MIT, include not only those with firms in Silicon valley, and on route 128, but also those with firms in Europe and Japan.

In some cases particular government agencies and programs help to define and structure such an extended industry nexus. Thus in the early days of the computer industry, and on several occasions in the history of the U.S. semiconductor industry, the U.S. D.o.D. has provided support, and mechanisms for interaction and coordinated action (see e.g. Kelley, 1995). The National Institutes of Health serves not only to support research relevant to pharmaceuticals and medical devices, but also as a clearing house for various kinds of information. Over the years, MITI has acted to coordinate Japanese firms in electronics.

While stressing somewhat different things, in my view analysts who are highlighting the importance of industrial districts, or complex and possibly geographically disbursed networks, or the role of private or public organizations in helping to coordinate a collection of firms in an industry, are calling attention to basically the same phenomena, which I choose to call here sectoral support systems. The analytic focus is on the institutional structures that tend to evolve to support an industry, which I briefly discussed towards the close of Section II.

These structures clearly are more than the sum of the firms contained within them, although in some cases key firms or groups of firms can have a profound shaping influence. Thus the major U.S. companies in computers and microelectronics played and play a large role in the formation and operation of Sematech and the Semiconductor Industry Association, but these industry wide structures are entities of their own. While almost always contained nationally, and shaped by broad national institutions, these structures are not uniquely molded by them, and to a considerable extent develop on their own track. Thus while the strong research and training support given to the U.S. semiconductor, computer, and software industries by Stanford, MIT, Carnegie Mellon, and several other American universities certainly has been dependent upon the broad research strength the U.S. university system achieved after World War II, U.S. university research strength in computer and materials sciences, and electrical engineering, has been exceptional. So too university research in the biomedical sciences which have supported technical advance in the U.S. pharmaceutical industry, and in medical devices.

Along the same lines, the venture capital institutions that grew up to finance new firms in electronics, and biotechnology, on the one hand can be reorganized as part of the general flexible and variegated U.S. financial system. On the other hand, many of the venture capital firms that grew up to provide support in these two areas are quite specialized.

IV Why Did these Industries Develop Differently in Different Countries?

I noted at the start that the comparative industry evolution project still is in its early stages. However, from what we have done so far, and from a large number of earlier studies describing these industries, it is apparent that each of them developed along somewhat, sometimes significantly, different paths in different countries.

Of course there were and are some very strong intra industry commonalities. Companies producing dyestuffs, synthetic fibers, and plastics, tend to be large, with their own inhouse R & D laboratories, whether they are German, British, American, or Japanese. A semiconductor mass production plant looks pretty much the same, wherever it is. But in the chemical products industry, German companies set up their own R & D laboratories significantly before the British or the American and, for many years, were significantly stronger at product innovation. On the other hand, American chemical products companies shifted to oil from coal as the basic feedstock significantly before the Germans. American companies selling semiconductors tend to specialize on semiconductors. Semiconductor producers in Japan and Europe tend to be part of integrated electrical equipment manufacturing companies.

Let me throw caution to the winds, and give my personal impressions about what is emerging from the study. First, the national differences one observes in industry development tend to be smallest regarding the broad technologies employed by firms in the industry, greater regarding the firm and industry structure that evolved, and often greater still in the character and effectiveness of supporting institutions. This is not to propose that there were not sometimes considerable differences across nations in the technologies national firms commanded. For many years German chemical firms clearly could produce chemical products that other firms could not. American semiconductor firms held significant technological leads over European and Japanese firms in the design and production of integrated circuits up until 1980 or so, and continue to have a significant edge in microprocessors. Japanese companies designing numerical controlled machine tools for general use clearly were way ahead of American firms in terms of how they understood user needs. However, for the most part these advantages seem to reside in the skills and organization of firms, and in their supporting institutional structures, rather than in better command of scientific and technological understanding per se.

Second, as discussed earlier, differences in national factor endowments and factor prices seldom made a big difference, although differences in skill availabilities did on a number of occasions. The major national level variables that made a difference were institutional. But third, in those cases where the national institutional environment, or legal structures, or specific policies, seem to have made a big difference, one also sees firms effectively taking advantage of the potential. As noted earlier, it probably is a mistake to ask whether it is national factors or strong firms that created comparative advantage in a field. Both were important and interacted strongly. The case of the German advantages in dyestuffs at the turn of the century, and that of the American advantage in computers in the 1960s and 1970s are splendid exemplars, as we shall elaborate shortly.

Fourth, it seems important to distinguish at least three stages in an industry's life history: the time when the technology has reached a stage where a sizeable market can be tapped, the period when technology and industry structure have settled down somewhat, and times when new technologies or other changes challenge the prevailing industry.

Differences across countries in inventive and entrepreneurial activity in the period before a significant market begins to be tapped sometimes makes a difference in the ability of the country's firms to compete in that emerging market, but sometimes not. The very early days of the automobile industry saw much more inventing going on in France than in the U.S., but U.S. firms seized the market with Mr. Ford's model T. The early breakthroughs on synthetic dyes occurred in the U.K., but German firms seized the market after firms began to learn how to do research and development effectively in the new field. American firms did the pioneering work in numerical control, but Japanese firms too the mass market. On the other hand, American firms both pioneered in transistor development, and quickly became dominant when transistor technology had advanced to a stage where there was a significant market. What seems to matter is the prowess and orientation of firms when satisfactory designs and production processes begin to emerge, and prior experience in the experimental stage of industry development may or may not be a help.

As indicated above, our cases suggest that, in turn, the prowess and orientation of firms depends both on what the firms have done themselves, and the institutional support structure stimulating and molding their actions. The German university system provided a strongly advantageous environment for the German firms venturing into dyestuffs, but it was the German firms themselves that, in effect, invented the industrial R & D laboratory. The R and D support of the American military clearly is a key reason why American companies like IBM, and American universities like MIT, got experience in computer design and production before companies in other countries. But IBM was, after initially devaluing the idea, farsighted in seeing civilian markets and in putting its money behind these ideas.

All of these examples suggest strongly that how an industry starts out when large markets began to be tapped can have long run consequences. The path dependencies, and particularly the dynamic increasing returns, built into various of the industry evolution theories, seem to show up strongly in our industry histories. Thus the early advantages of the German dye stuff companies, of IBM in computers, and the American semiconductor companies who got their start selling to the military and later to the computer industry, provided the basis for world market dominance that lasted a long time.

Yet from another point of view, the durability of competitive advantage seized early in an industry's growth stage is somewhat surprising. The theories of technology and industry evolution discussed earlier suggest that firm and industry structure tends to change considerably between the time technology has just reached a stage where a sizeable market can be reached, and later in the industry's history when product and process technology have become more mature. One might expect, therefore, that the bases of competitive advantage would change as well. For example, a financial system that well serves the needs of new or small firms might not be good at servicing the financial needs of larger firms. Indeed Ergas(1987), and Florida and Kenney (1990), have made just such an argument, proposing in particular that the economic institutions of the United States are strong at spawning new industries, but weak in sustaining them when they become more mature. The "product cycle" theory of comparative advantage in international trade makes a related argument, that comparative advantage shifts from countries amply supplied with scientists and engineers to lower wage countries as a technology matures.

However, most of the industries in our study do not fit this pattern. Countries with firms who were strong when an industry started rapid development continued to be the home of strong firms as the technology matured somewhat and industry structure stabilized.

An interesting exception is the case of numerically controlled machine tools. Here, as noted earlier, U.S. firms pioneered in the industry, specializing in precision machining. However, Japanese firms seized the much larger market for flexible manufacturers.

Other exceptions are the loss by American firms of the integrated circuit RAM market first to Japan, and now to companies in the Asian nics, and the taking over of organic chemical products by, on the one hand, petroleum firms, and on the other hand by firms in the nics. In my view what is happening here is pretty well explained by the "product cycle" theory I mentioned above. As the technologies in these areas developed a quite predictable track, the advantages of very sophisticated R & D faded, and comparative advantage shifted to other countries where the other factors of production were available and cheaper.

Most of the instances revealed by our study of significant shifts in the locus of comparative advantage came about because a radically new technology came in and obsoleted the competence of companies who previously had been dominant. That is, the story of changing competitive advantage is a Tushman and Anderson(1986), Henderson and Clark(1990), Christensen and Rosenbloom (1993, 1994) story, played out across national boundaries, and in some cases with some interesting particularities. From another point of view, while there is clear evidence of dynamic increasing returns for both a broad technology and the firms employing it, in many of our industries the turn of events broke any presumed "lockin".

Thus the development of process technology using petroleum as the feedstock for organic chemical products was an American endeavor, involving a number of firms and universities, that greatly advantaged American companies. The availability of low cost petroleum was made a real "lockin" breaking opportunity through investments in R and D and new equipment. German companies who had dominated the industry in an earlier era had troubles shifting over.

The computer case is especially interesting. Here the appearance of integrated circuits in the 1970s and microprocessors in the 1980s in effect enabled companies designing and producing computers to purchase a lot of what earlier had to be designed and put together internally. These were competence destroying innovations, par excellence. And on each occasion there was a wave of new entry into the industry, and it was new firms, not the established ones, that seized the new market opportunities. IBM, the dominant firm prior to these revolutions, let the new markets be seized by upstarts and, recently, has seen other firms using new technologies significantly undercut its principal main frame market. But the new firms, successfully seizing the new opportunities were, in both cases, largely American.

This latter case is illustrative of the fact that the U.S. economic environment, at least in the era since World War II, seems to have supported the entry of new firms, both when a new industry is emerging, and when the technology underlying an industry has changed significantly, to a much greater extent than is the case in Europe and Japan. In several of the industries in our study, this capability to spawn new firms has been the basis of the establishment, or in the case of computers the maintenance, of U.S. comparative advantage.

The study I am describing is far from complete. Even if it were further along, space constraints would force my description to be highly selective, and there still would be major questions about just how to interpret some of the findings. However, I believe the conception of the study is sufficiently interesting, and some of the findings that already have been written up in draft chapters sufficiently provocative, to warrant this preliminary report.

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